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Master's Thesis of Public Administration

A study on the strengthening of port competitiveness through the establishment of smart port

- Focusing on the case analysis of advanced smart ports -

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February 2023

Graduate School of Public Administration
Seoul National University
Global Master of Public Administration

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– Focusing on the case analysis of advanced smart ports –

Lee, Soo–young

Submitting a master's thesis of Public Administration

September 2022

Graduate School of Public Administration
Seoul National University
Global Master of Public Administration

Park, Youn–Bum

Confirming the master's thesis written by
Park, Youn–Bum
November 2022

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Abstract

This study examines the relationship between the concept of smart ports and port competitiveness, which have recently been in the spotlight, and attempts to derive implications for Korea's smart port development direction through various analysis of advanced smart ports. To this end, this research attempted to analyze the policies of Rotterdam Port in the Netherlands and Hamburg Port in Germany, which are most advanced in smart port development and development, using the analysis framework of four smart port evaluation measures established in A. Molavi et al.

In terms of operation, advanced smart ports achieved complete automation of the entire loading and unloading process in the port, and not only this, but all processes in the port were pursued for unmanned and efficient use of the advanced technologies of the 4th Industrial Revolution. In terms of the environment, interest in eco-friendly ports is increasing. There is a consensus that ports should no longer be independent areas that exist separately from cities, but should establish reciprocal relationships that interact and develop with residents of neighboring cities. In terms of energy, smart ports are expected to become a key supply base for the future hydrogen society. Taking advantage of the functional advantages of combining marine logistics and land logistics, the core infrastructure of the hydrogen economy, such as hydrogen production, storage, and distribution, is built in ports and attempted to combine them with port functions. In terms of safety and security, ports are becoming a competition for the use of advanced technology. Using high-tech equipment such as aviation, sea, and underwater drones, a system that allows real-time management and supervision by artificial intelligence is being established by transplanting a wide port into a virtual reality twin tower.

In the case of Korea, the reality is that it is lagging behind not only European ports that started the development of automated ports early but also automated ports in neighboring China and Singapore. To make up for this, the central government has established a "smart maritime logistics system construction strategy" and plans to operate smart ports in earnest in 2030. However, this plan recognizes smart ports as a sub-factor of the overall logistics function, which only looks at smart ports in the narrow aspect of automated ports, which is very different from advanced ports' perceptions of the future potential of ports. In addition, unlike advanced ports in which private companies and port stakeholders actively participate and cooperate in the development of smart ports, Korea still adheres to the government-led development method, and the role of port authorities to play the most leading role is insignificant. In addition, at a time when environmental problems such as the obligation to transition to a carbon-neutral society in the future and the transition to eco-friendly energy are becoming important, this comparative study was able to derive the lack of concern about the fundamental transition plan or the new role of ports. Unlike ports in Europe, the absence of a key role in the transition to a hydrogen economy seems to stem from a lack of awareness of smart ports, and policy improvements are needed.

Words: Smart Port, Unmanned Technology, Automation,
Logistics Portal, Hydrogen Economy
Number: 2020-23854

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Chapter 1. Introduction

1.1. Study Background

Today's ports are diversifying their roles and functions as a cooperative space for creating value-added, away from the passage for imports and exports, and their importance as a hub for global logistics chains is strengthening (Kim, 2015). At the same time, competition between ports is intensifying to attract volume at low cost and operational efficiency. Busan Port, which was ranked fifth in the world in terms of processed volume in 2018, fell two notches to the world's seventh (Busan Port Authority, 2021) as of 2021, showing inferiority in competition with Chinese ports, which are rapidly growing based on the vast domestic market.

As one of the ways to strengthen competitiveness accordingly, experts are discussing the rapid establishment of smart ports. It is argued that new technologies derived from the Fourth Industrial Revolution can be combined to enhance competitiveness and solve the problems at hand through more efficient and waste-free port operations. In the case of Hamburg, Germany, a smart port logistics system linking shipping, port, and inland logistics information is introduced based on Internet of Things (IoT), reducing port operating costs by 75% and port traffic congestion by 15% and being evaluated as a leading port in the smart port field (Lee, Kang, Lee, Kang, & Jeon, 2017). However, just as there is no single agreed concept for smart ports, there is no clear blueprint for building smart ports. China's ports, which can be called competitive ports, are rushing to digitize them based on fully unmanned automated ports, and advanced ports in Europe are leading in building smart ports by linking shipping, ports, and inland information using IoT technology. On the other hand, the reality is that Korean ports have a low level of automation and lack of information linkage with the outside world such as shipping companies and cities behind them, so they cannot play a role as a central point. In addition, the government-level automation and smart port construction direction and road map establishment are still in the preparation stage. In addition, the level of automation and smartization of Korean ports compared to advanced ports in the world is not actively being measured, or analysis of the cause of slow smart port promotion is not actively conducted (LEE & LEE, 2019).

On the other hand, there are voices opposing the blind establishment of smart ports. According to research on unmanned automation terminals such as the Netherlands and China, investment costs such as infrastructure construction costs, equipment costs, and information technology costs were twice to five times higher than traditional semi-automated terminals, and operating costs were not as expected (Maritime press, 2018). Adding to this, concerns that 90% of existing port jobs could disappear demand macro-level discussions that require social consensus, not just the introduction of technology.

Therefore, in this study, starting with the concept definition of a smart port and looking at various factors that make up a smart port, I tried to compare and analyze the impact of smart port construction on the port's competitiveness and logistics environment. In addition, after diagnosing the level of development of smart ports in Korea, it is intended to provide implications for the future direction of smart port development in Korea.

1.2. Scope and Method of Study

This study reviews the theory and prior research on the relationship between the concept of smart ports and port competitiveness, and attempts to closely analyze the two most leading container ports by borrowing a comprehensive analysis framework for smart ports from previous studies. According to the Container Port Performance Index (CPPI) produced annually by the World Bank Group, roughly 351 major ports handle containers worldwide (World Bank Group & IHS Markit, 2021). However, only the top 20 container ports in the world's container volume account for 44% of the total volume, indicating high congestion in major ports by region (Busan Port Authority, 2021). In terms of the cost and effectiveness of smart port construction, it is highly likely that the competition for smart port will be concentrated on these high-throughput ports. Reflecting this, in the A Framework for Building a Smart Port and Smart Port Index (Molavi, Lim, & Race, 2019) study published in 2019, only 14 major ports with high congestion and regional representation were selected to attempt a quantitative analysis of the degree of smartization. In this study, the difference in index scores between the two leading ports (Port of Hamburg, Port of Rotterdam) and the two ports (Port of Jeddah, Port of Hong Kong) selected at the bottom was more than three times, indicating that the gap in the degree of smartization is very large. Considering this reality, it can be said that it is advantageous as a latecomer to derive implications such as the background, trend, advantages, and disadvantages of smart ports through a close analysis of a large number of ports. Therefore, this study attempted to analyze the aforementioned two ports and Busan ports.

In terms of methodology, by first attempting a theoretical review of existing theories and prior studies on smart port competitiveness, this research captured four main aspects of smart port (Operation, Environment, Energy, Security & Safety) and attempted to review details based on these. In the previous study of Smart Port Index (SPI) adopted as an analytical model in this study, four components of smart ports that are mentioned the most through meta-study, and 88 detailed indicators that can measure them were selected to devise index indicators (Molavi, Lim, & Race, 2019). However, except for some of the existing widely used standardization indicators such as port volume and ship entry and departure, the reliability of the results remains questionable as there are many restrictions on analysis targets and missing information on individual ports. In order to supplement previous studies on smart ports and derive implications for our situation, the analysis model used in quantification studies was borrowed, but qualitative analysis was introduced to each item to view various aspects of advanced smart ports and to derive practical implications. To this end, data such as reports from existing research documents and international organizations and information on the official website were collected and analyzed, and the deficiencies were supplemented through expert advice working in the field.

Chapter 2. Theoretical Discussions and Prior Study Reviews

2.1. Theoretical discussion of smart ports

2.1.1. Significance of Ports

A port in the dictionary sense is defined as "a facility built naturally or artificially, which forms a constant temperature zone by preventing waves acting as external forces, and connects the quantity, unloading, and land of cargo loaded by ships safely anchored and moored." (Ministry of oceans and fisheries of Korea, 2020). However, the port is recognized as a key facility that has played a pivotal role in the formation and prosperity of the city, including creating an industrial complex behind it and creating added value related to ship entry and departure and cargo transportation.

Today, more than 80% of international logistics depend on port trade (World Bank Group & IHS Markit, 2021), especially ports play an important role in enhancing the international competitiveness of domestic industries by providing comprehensive services ranging from unloading, storage, transportation, and processing. As such, ports are one of the most important social overhead capitals to promote trade activities and support economic activities. In the 21st century, the function of the port is qualitatively developed by combining the 4th industrial revolution technology such as unmanned, artificial intelligence, and high-speed network, and expanding quantitatively beyond the existing port's unique berth and loading facilities. The discussion of smart ports, which has been attempted to conceptualize since 2010, is also a concept designed to comprehensively explain the all-round changes in these ports. Therefore, in the following, this article will examine the development process of the port and try to define the concept of a smart port through this.

2.1.2. Development of Ports

Ports have constantly changed and developed to adapt to changes and demands in the environment, and ports in the modern sense of what they are today can be classified as five generations from ports before 1960 to the present. (Molavi, Lim, & Race, 2019) First of all, the first-generation ports before the 1960s did not have any commercial activities emphasized in modern ports, collaboration with nearby local governments, and links between transportation and trade activities. The first-generation port was an isolated port that served only as an intersection of inland and maritime transport.

Since then, the second-generation port, which appeared in the 1960s, began to serve as a service center to support the transportation, industry, and commercial sectors. In addition, cooperation between ports and local governments began to be promoted little by little, and it has grown into an expanded port.

In the 1980s, as the era of container ports, a third-generation port, arrived in earnest, the port industry faced a major change. Accordingly, a complex transportation system linking heterogeneous transportation methods such as ships, railroads, and trucks began to be used in earnest. This has become the driving force behind the establishment of a global production system and supply network. Therefore, the container port, the third-generation port, has become a base for complex transportation and a center for global logistics.

In the 1990s, the globalization of the market accelerated further as information and communication technologies were applied across all industries. In addition, as the alliance between shipping companies and the government-led port development began in earnest, the physical connection between port stakeholders was emphasized. This trend of change has led to the emergence of an integrated port, a fourth-generation port.

In the 2010s, the establishment of a smart port based on an intelligent system is being promoted. Smart ports are known as ports with complex goals such as operational optimization, information sharing, safety and security enhancement, and sustainable development, focusing on unmanned and automated operating systems, skilled and well-educated workers, and intelligent and automated infrastructure. However, since the concept and model of internationally unified smart ports do not exist yet, development is being promoted based on slightly different visions for institutions, scholars, and countries.

Table 1: Ports Development throughout the history

1st Generation	**2nd Generation**	**3rd Generation**	**4th Generation**	**5th Generation**
Isolated Ports (Pre-1960s)	Expanded Ports (1960s)	Container Ports (1980s)	Integrated Ports (1990s)	Smart Ports (2010s)
▪ An Interface between land and sea transport ▪ Mechanical Operation ▪ No commercial activity ▪ No co-operation with surrounding ▪ No connection with transport and trade activities	▪ A transport industrial, and commercial service center ▪ Commercial activities ▪ Closer relationship Between ports and municipalities	▪ Global containerization and intermodalism ▪ Dynamic nodes in international production/distribution network ▪ Integrated transport centers and logistic platforms ▪ Electronic Data Interchange services	▪ Worldwide alliances of containership owners ▪ Centralized administrative offices ▪ Facing the international market ▪ Information and Communication Technology	▪ Skilled and well-educated workforce ▪ Intelligent infrastructure and automation ▪ Knowledge development and sharing ▪ Optimized operations ▪ Enhanced resiliency ▪ Sustainable development ▪ Safe and Secure activities

Source: Molavi, Lim, & Race, 2019

2.1.3. Prior Study of Smart Ports

Smart port is a relatively recent term, but the etymology of "smart" has already been introduced as a new problem-solving method that combines information and communication technology in various fields. From a technical point of view, "smart" means automated computational principles such as autonomous configuration, autonomous protection, autonomous healing, and autonomous optimization (Spangler et al., 2010). In the field of urban planning, "smart growth" was a concept that emerged in the 1990s, and began as a social-led response to the increasing cost of maintaining public facilities, traffic congestion, air pollution, and the decrease in public space. It has been recognized as a sustainable approach to reducing congestion and preventing environmental degradation while driving socioeconomic growth in formulating urban development strategies (Nam & Pardo, 2011). In this extension, "smart city" means urban administration that maximizes services to citizens, optimizes available resources, integrates core facilities to reduce waste, establishes preemptive management measures, and supplement control and monitoring methods for facilities to operate efficiently (hall, R. E et al., 2000). Governments and public institutions are also actively utilizing the concept of smartization as a term for policy orientation to pursue sustainable development, sound growth, and a better quality of life for citizens (Center on Governance, 2003). These examples have become widely used in various fields, such as smart homes, buildings, airports, hospitals, and ports, which are integrated with information and communication technologies such as mobile terminals and built-in sensors and are connected to networks and controlled autonomously.

As discussed earlier, attempts have been made to explain new problem-solving methods that are distinct from existing people-centered methods using the term smart in various fields. However, the ambiguity caused by the term "smart port" is due to the fact that smart ports cover several subconcepts as complex concepts. First of all, there is no disagreement over the concept of smart ports that maximize operational efficiency such as automated ports and robotics ports that automate loading and unloading facilities in ports and automate transportation equipment by combining technologies such as IoT, A.I., and big data representing the 4th industrial revolution. Jeon Hyung-mo (2020) said that smart ports can be divided into automation of port equipment systems and smartization of ports that optimize operations by collecting information between ports and logistics bases in ports and ports in real time. In particular, Japan's mid- to long-term port policy, "PORT 2030," uses technologies such as artificial intelligence (AI) and the Internet of Things (IoT) to see the overall smart port operation as the future of smart ports. This is because smartization contains predictable advantages such as reducing working hours, increasing work efficiency, reducing labor costs, and preventing safety accidents. This is spatially a change within the traditional port boundary and is a perspective that focuses on the essential function of the port. However, the boundaries of smart ports become blurred from the perspective of applying and expanding the technology of the 4th Industrial Revolution. This perspective recognizes ports as hubs of logistics flow and resource utilization beyond existing port automation and intelligence, and aims to be a physical portal that connects information and information and connects countries using advanced technologies derived from the Fourth Industrial Revolution technology. The Korea Maritime Institute (2018) stated that smart ports are aimed at improving efficiency with new technologies and innovation, and that they are basically pursuing information technology-based port automation such as IoT and AI, and collecting, analyzing, sharing, and integrating various information generated from ports. However, it was pointed out that smart ports and automated ports are actually recognized as the same concept in Korea, and the concept of smart ports should be expanded to include social and environmental perspectives including port cities, energy, people, and management. Lee Eon-kyung (2019) defined the highest-level smart port as a port where all stakeholders in the entire supply chain, including shipping and port cities, are linked through digital technology beyond the port. In addition, it was explained that through trust-based collaboration, operational efficiency and profits are maximized in terms of logistics, and that it means a sustainable port that guarantees safety and eco-friendliness in terms of port workers and citizens near the port. In other words, one of the reasons why smart ports are in the spotlight today is that ports are expected to play a key role in the relationship between neighboring cities and countries and create new business and added value due to the development of logistics and information processing technology. Apart from the prosperity of the port, the expectation that sustainability issues related to negative external effects such as pollutants and energy waste emitted by the port, safety accidents in the port, and explosion accidents of dangerous substances will be significantly lowered through tracking management using artificial intelligence, smart grids, and IoT technologies has also amplified interest in smart ports. In the end, the ambiguity related to the definition of smart ports can be seen as an expression of various expectations for the role of future ports, and the ambiguity of the boundary range resulting from the process of expanding the area of one-dimensional port management to multiple dimensions.

Table 2: Definition of Smart Port

Range	Researcher	Definition
Narrow Range of Smart Ports	Spangler et al. (2010)	▪ Meaning of autonomous and active computer processing in the entire port activities
	Ministry of Oceans and fisheries of Korea (2017)	▪ Ports that utilize resources most efficiently by automatically and autonomously collecting, disseminating, analyzing, and executing information by incorporating the technology of the Fourth Industrial Revolution
	Sanghei Choi (2018)	▪ Robotic Port: Port for unmanned and automatic handling of inner wall cranes, yard cranes, transport vehicles, operating

		systems, etc., which are equivalent to loading and unloading operations in the port
	Peter, JLT Mobile Computer (2016)	▪ Integration of physical infrastructure and IT technology into automated ports with all port devices linked by IoT
	Tan (2016)	▪ Reducing operating costs and minimizing environmental impacts by actively utilizing ICT such as sensors and smart devices ▪ Predictability, connectivity and sustainability are key factors
Broad Range of Smart Ports	KMI (2019)	▪ Beyond information sharing in ports, various information such as ports, cargoes, transportation networks, transportation means, etc. is collected, analyzed, shared, and made decisions through information exchange between systems ▪ Efficient use of energy, eco-friendly, sustainability, and connection with behind-the-scenes cities
	Cho Yongchul (2019)	▪ Using IoT and AI-based automated equipment and technologies to handle cargo, optimize logistics, improve eco-friendly and energy efficiency, strengthen connectivity in background cities, collect, process, analyze, and share data across logistics networks
	Sanghei Choi (2018)	▪ Intelligent port: a port that collects, analyzes, delivers predictions, and executes information based on super connections between resources
	Deloitte (2017)	▪ Fully integrated ports with insight based on IoT technology, with efficient port operations, expanded port activities (external markets), and new business model opportunities
	Molavi et al. (2019)	▪ Ports consisting of highly educated participants, skilled labor, intelligent infrastructure, and automation to achieve objectives such as knowledge development and sharing, operational optimization, port resilience, sustainable development initiative, and safety and security

2.1.4. Smart Port Index (SPI)

An index is defined as "a relative value of a value at a reference point in time to see differences in levels for a phenomenon or to compare trends for a few phenomena with each other". As can be seen from this definition, the index summarizes complex and multidimensional social phenomena and concepts on a single scale, and has the advantage of being able to compare countries and regions (Cha, 2021). In particular, its effectiveness stands out in certain policy areas because it can be used to identify strengths and weaknesses and to prioritize future policies by comparing them with other targets. Efforts have also been made to develop these indices and compare them between ports in the smart port field, and in the study of Cha Jae-Ung (2021), the theoretical framework of smart ports was divided into four areas: technology, society, operation, and information. Using exploratory factor analysis, the core items of smart ports were converted into 16 individual indicators and included in each area to develop an index that can measure and compare the degree of smart port development.

Earlier, the establishment of the concept and components of smart ports began with the Smart Port Project (2014) promoted under the funding of the European Union. This project considered operations, energy consumption, and environmental sectors to set the criteria for becoming a smart port (Won & Cho, 2020). By sector, detailed standards were prepared, consisting of nine indicators in the operating sector, eight in the energy sector, and six in the environmental sector.

Table 3: EU Smart Port Project Components

Port Operation	Energy Consumption	Environment
▫ Quarry Productivit ▫ Infrastructure ▫ Ship Accommodation ▫ Maximum Processing capacity ▫ ITS Technology Level ▫ Automation	▫ Total Energy Consumption ▫ Container Energy Consumption ▫ Port Authority Consumption ▫ Lighting Consumption ▫ Equipment Energy Consumption ▫ Renewable Energy Usage ▫ Energy Management	▫ Environmental Management System ▫ Garbage Management ▫ Water Management ▫ Air Pollution ▫ Noise Pollution ▫ Sea Pollution

Resource: Won & Cho, 2020

Meanwhile, in a study by A. Molavi et al. (2019), four major components of smart ports, including the EU's Smart Project, were derived, that is, operational, energy, environmental, safety and security, and the bottom 88 indicators that can be actually measured were selected to measure the degree of smartization using existing literature, media data, and public information on the port authority website. Through this, it was intended to create an index that can be used by port authorities aiming for smart ports to help them understand their weaknesses and strengths at this point and establish policies. In addition, a numerical index was presented to measure the degree of development of smart ports by taking a step further from developing smart indices and conducting measurements on only 14 actually leading ports. Through this, it was found that ports located in Europe generally have a high level of smartization of ports and lag behind those of Asian ports (Molavi, Lim, & Race, 2019).

In this study, I will review the theoretical aspects of the construction of smart ports that have been accepted so far, and explore the relationship between the development of smart ports and the competitiveness of ports through comparative analysis of advanced smart ports. To this end, A. Molavi's SPI, which presented comparable data by comprehensively measuring the degree of development of smart ports, was used as an analysis frame to analyze the degree of smartization of individual ports in detail. In particular, the SPI index assumes a comprehensive port operation system that considers environmental aspects, efficient energy use, port safety, and security, including in-port automation, which has been important, as an ideal model and compares its development. Therefore, it is not only the most comprehensive smartization evaluation index, but also provides an analysis method that can derive implications for detailed development directions. In addition, it is expected that it will be able to help set the direction of policies that require selection and concentration among the elements of smart ports as a latecomer by incorporating them into our reality. However, as A. Molavi's study revealed, it is impossible to collect standardized and published open data for all container ports except for representative data such as handling volume and ship entry and exit due to security issues such as port operating characteristics and ports operated by country or terminal operator. Accordingly, prior SPI studies are also focusing on efforts to develop the index.

2.2. Theoretical discussion of port competitiveness

2.2.1 The Concept of Port Competitiveness

Olaf Merk of the OECD ITF (International Transport Forum) emphasized the importance of building smart ports in competition with other ports, referring to smart ports as "the only port that can survive in the future, and no waste of time, space and resources." (Lee, 2020). In other words, in order to survive in competitive relations with neighboring ports, the establishment of smart ports is essential, reflecting expectations that competitive advantages and sustainable prosperity can be pursued.

The competitiveness of the port is directly related to the continuous attraction of shippers and the creation of high added value. There are estimated to be about 350 major container ports involved in international logistics around the world, and research on the competitiveness of ports has continued to find answers to why some ports constantly attract shippers, expand port routes, and prosper.

Lee Chung-Bae (2014) defined port competitiveness as "a variety of abilities to secure competitive advantage over competitive ports," and cited the geographical location of ports, port service and rates, port facilities and productivity as determinants of competitiveness. In other words, port competitiveness can be said to be "a state in which the overall combination of all factors and factors has a comparative advantage compared to other competing ports." The fact that a specific port is competitive means that one of the ports of various other countries that can be used for cargo transportation is preferred as a port of call because it is advantageous under various conditions. In other words, the goal of port competition is to minimize the transfer of existing supplies to competitive ports and to maximize profits by processing large volumes at the same time. Therefore, port competitiveness refers to the strategic capacity to secure new shipments while maintaining the volume of domestic ports in competition with other ports within the same area. In general, it relies on hardware factors such as the number of births, cranes, site area, and processable volume, and software factors such as the system to operate and support it and the cost required. Among them, the expansion of hardware facilities to efficiently handle large volumes of traffic occupies the largest proportion (Yeo, 2011). Jeon Il-Soo et al. (1993) analyzed the competitiveness of the world's 20 largest container ports using the multi-attribute utility function, and derived port location, port facilities, port cost, service level, dock operation type, and port management entity as competitive factors. Lee Seok-Tae (1998) presented the port's volume, facility and operation type, port location, and service as major factors of port competitiveness. On the other hand, there is a study pointing out that existing studies on port competitiveness focus only on the deployment of human and material resources for logistics activities in ports, such as port facilities, transportation time, and port efficiency, which is making it difficult to accommodate increasingly complex external environmental changes and reflect new demands to secure growth engines (Kim, 2015). To this end, the concept of competitiveness was expanded to derive the concept of sustainable competitiveness that sensitively responds to and accepts the needs and changes of the external environment. To build sustainable competitiveness, ports must not only meet user expectations and needs, but also accommodate the diverse needs of related industries and communities, and shift their focus to laying a sustainable growth foundation for today's global climate change. The expansion of discussions on this port role is becoming the basic premise of smart port construction.

2.2.2. A Prior Study on Port Competitiveness

The factors that make up port competitiveness have changed according to the stage of port development. Since the 1980s, when container ports appeared and developed in earnest, studies on port competitiveness have been actively conducted, and studies on early port selection and its determinants have suggested physical factors, i.e., geographical excellence, transportation cost, and inland transport networks, as major factors to determine port competitiveness (Bird and Bland, 1988).

Since the 1990s, factors that determine port competitiveness have diversified due to the incorporation of IT technology, and the relative importance of the determinants has also expanded from geographical and physical factors to various activities in ports. For example, port efficiency and productivity were found to be important indicators of port performance in the 1990s and factors that determined competitiveness (Tongzon, 1994). In the 2000s, the increase in international trade and the liberalization of the transportation market expanded the scope and function of ports, prompting various strategic approaches to meet new demands. Mangan et al. (2008) emphasized the importance of complex transportation systems for port-oriented logistics systems, Notteboom and Rodriguez (2005) emphasized the importance of developing non-physical resources such as software as a strategic space for logistics activities, and Yeo et al. (2008) revealed that the relative importance of factors that determine port competitiveness is shifting from physical to non-physical.

To evaluate the competitiveness of ports as a logistics hub, Tongzon (2009) presented eight important determinants: port efficiency, cargo handling cost, reliability of services, preference as a carrier's port of call, route depth to accommodate large ships, response to changes in business environment, inland accessibility, and service differentiation. In addition, Yeo (2008) presented seven factors for the evaluation of the competitiveness of Northeast Asian ports, including port service, development status of the rear site, availability, convenience, logistics cost, accessibility, and connectivity.

Table 4: Studies on Port Competitive Factors

Category	Researcher	Determinants
Research in the 1990s	Lee & Lee (1993)	▪ Port location, port facilities, port volume, port cost, port service, port operation type
	Jeon, Kim & Kim (1993)	▪ Port facilities and equipment possession status, port productivity, price competitiveness, and port service quality (container device, acceptance period, EDI system, customs clearance system)
	Kim, H (1993)	▪ Annual volume of goods, port facilities, port logistics costs, service level, and logistics service environment
	Peters (1990)	▪ Port services, capabilities and conditions of available facilities, port operation strategies, changes in the international political and social environment, and changes in transportation and unloading functions
	UNCTAD (1992)	▪ Geopolitical location, port backwater transport, port service availability and efficiency, port service price, socioeconomic stability, information system
	McCalla (1994)	▪ Changes in port facilities, inland transportation networks, shipping company's choice of port, and container transportation routes in demand for container shipping
Research in the 2000s	Yeo (2002)	▪ Location conditions, dock facilities, volume of goods, cost, information service
	Kim, G (2007)	▪ Port cost, port network establishment, size of background complex, port labor stability
	Tongzon (2001)	▪ Strategic location, operational efficiency, high port connectivity, adequate infrastructure, adequate information systems, and extensive port services
	Peter and Casaca (2003)	▪ Port operation flexibility, manpower, information technology, port facilities and equipment
	Yeo (2008)	▪ Port service, development status of background site, availability, convenience, logistics cost, accessibility, connectivity

As discussed above, the factors that make up the competitiveness of ports have changed according to the expansion and role of ports. This trend has been synthesized with the rise of the concept of 5th generation ports, that is, smart ports, since the 2010s. In the future, ports require the role of sustainable ports that meet internal and external environmental changes and expectations. In terms of operation, it is necessary to link countries and countries with efficiency, automation, and intelligent infrastructure to act as a physical portal between various industries as a starting point and end point for logistics. In terms of the environment, international environmental regulations and climate change should be prepared by minimizing pollutant emissions, and waste should be minimized and contributed to the community through eco-friendly energy production and use. At the same time, the intelligent role of creating industrial conditions for zero safety accidents and detecting and blocking explosion accidents or smuggling when handling dangerous goods is also considered as a factor that constitutes the competitiveness of ports.

2.2.3. Port Competitiveness and Performance Evaluation

Looking at previous studies on the competitiveness of container ports, the competitiveness of ports has been evaluated in the following three ways. (Park, Oh & Park, 2005) First, there are studies that measure the production efficiency of container ports, second, studies that introduce and analyze the international competitiveness of container ports, and third, studies on the selection behavior of shipping companies and shippers who choose specific ports. First of all, looking at the studies that evaluated competitiveness in terms of production efficiency, K.Cullinane et al. (2002) evaluated the competitiveness between adjacent ports by using terminal wall length, terminal area, and number of cranes as input factors for only 15 ports in Asia and comparing container throughput as output factors. In the study of Park (2004), the competitiveness of the target ports was ranked by substituting berthing capacity and cargo handling capacity for 11 trade ports in Korea, and comparing cargo throughput, number of ships entering and leaving ports, port income, and customer satisfaction.

Table 5: Port Competitiveness Analysis Models

Researcher	Target Port	Analytical Model
J.Tongzon (2001)	16 ports around the world	▪ Input elements: Number of cranes, Berth, Tug, Terminal, Delay time, Labor ▪ Output elements: volume of goods, ship entry and exit
Y. Roll et al	20 ports of	▪ Input elements: Annual average annual labor force figures, total investment capital and facilities per

(1993)	Israel	port, etc. ▪ Output elements: Cargo handling capability, service level, user satisfaction, and number of times of ship use
Park, Oh & Park (2005)	28 ports in Northeast Asia	▪ Input elements: Inner wall length, number of G/C, CY area, CFS area ▪ Output elements: Total volume, port usage
V.F. Valentine 외 (2002)	12 ports in Europe and East Asia	▪ Input elements: Number of containers, total length of berth, total length of container berth ▪ Output elements: Total tonnage of cargo handling
K. Cullinane et al (2002)	15 ports in Asia	▪ Input elements: Terminal wall length, terminal area, number of cargo handling equipment ▪ Output elements: Container throughput
Park (2004)	15 ports in Asia	▪ Input elements: berth capability ▪ Output elements: Cargo throughput, number of incoming and outgoing vessels, port income, and customer satisfaction

Next, as a study examining competitive factors, Koo, Hwang, & Dong (2010) analyzed the major port competitiveness determinants by combining a wide range of domestic and foreign port competitiveness and analyzed the correlation by using port location, port facility, port background, port cost, and port service. Through this, port comprehensive services that can work 24 hours a day were found to have a significant positive effect on port competitiveness, while water depth, number of routes, and port logistics costs did not have a significant effect on competitiveness, that is, increased processing volume.

As discussed in previous studies, various factors that improve the competitiveness of ports were constructed, and as a result, port volume, ship entry and exit, and customer satisfaction were used as dependent variables to measure port competitiveness. This is because as port competitiveness increases, owners of goods and shippers naturally choose the port and port volume increases, and as port competitiveness implies, increasing port volume and creating value-added are the final goals of competitiveness.

2.3. The relationship between smart ports and port competitiveness

2.3.1. Smart Port Components and Port Competitiveness

Until recently, studies have been conducted to capture various aspects of smart ports to form sub-elements and measure the degree of smartization of ports based on them. As previously discussed, Molavi, Lim, & Race (2019) devised four elements constituting smart ports to measure the degree of smartization development of ports and developed 88 measurement indicators to develop Smart Port Index to compare the degree of smartization of each port. In this study, the key components of smart ports are comprehensively covered by the key elements of smart ports discussed recently, including the operational, environmental, energy use, safety and security of ports. However, the discussion on whether these components of smart ports have a significant impact on the competitiveness of actual ports is focused on the automation aspect of ports, that is, cost reduction and operational efficiency. This is based on the practical problem that factors such as energy, environment, and safety are difficult to quantify the performance. Therefore, in the following, theoretical discussions on the relationship with port competitiveness according to the four smart port sub-components of the SPI index to be used as an analysis frame will be reviewed in terms of environmental needs and expected effects.

A. Operation

In terms of efficient operation and cost reduction, the port space is expected to be a venue for information and communication convergence technology called the 4th Industrial Revolution. Advanced technologies such as artificial intelligence-based robotics, automation, autonomous vehicles, the Internet of Things and big data, virtual reality and augmented reality, and blockchain are being combined to increase operational efficiency and productivity (Hong, 2018). IBM, which plans to develop a container tracking management service using blockchain technology, is expected to improve visibility by supporting all participants related to container transportation, including shipper manufacturers, international logistics agents, sea carriers, dock operators, consignee, customs office and port authorities (Korea Marine Institute, 2017). It is expected that real-time risk management such as smooth supply of raw materials in the global supply chain will be possible as the location and status of goods can be tracked using blockchain technology and IoT technology (Choi, 2017). In order to reduce logistics costs, completely unmanned automation without workers in container yards is also being promoted. Currently, in Korea, container cone removal, sea work of the inner wall crane, and land work of the yard crane are still being carried out as manpower work. Remote adjustment is considered automation in the case of the inner wall, which is difficult to completely unmanned due to the movement of ships on the sea. Currently, Rotterdam Port in Europe, Long Beach Port in the U.S., and Qingdao Port in China operate terminals in a representative unmanned automation method (Choi, 2017). Research and development of new concept unmanned automated container terminals using Overhead Shuttle, Stacker Crane, and Overhead Rail are also underway by developing from existing automated guided vehicles and shuttle carrier-based unmanned automation terminals. Since the ultimate purpose of the unmanned automated container terminal is to process many cargos in a limited time, research and development for terminal operation system and equipment development to process more cargo safely and quickly than the current system continues.

Technology development that can systematize and support tasks performed in ports such as artificial intelligence and big data utilization is also being carried out at the same time. It is pursuing intelligent and unmanned port operations based on the Internet of Things, artificial intelligence, and big data, which are representative new technologies leading the era of the 4th industrial revolution. It can provide a digital twin platform that integrates and visualizes various signals of terminal equipment by developing a container terminal automation solution. Restrictive work control using existing CCTVs was not smooth, but real-time work control has recently become possible through technology, and real-time location tracking has been possible by grasping the movement of yard cranes in the yard. An intelligent service is being implemented to manage the movement speed of the equipment, whether the work is performed, and the scheduled completion time to notify in advance when the goal is difficult to reach or work delays are expected.

As reviewed above, technical applications in the operational aspect are the areas where high-tech technologies are most actively applied and visible results such as operating cost reduction are shown. This automation and efficiency can contribute to the smooth flow of international logistics, as well as the reduction of port handling costs and the establishment of optimal plans for each stakeholder as cargo transport becomes visible. Choi (2008) conducted a survey of domestic shippers and suggested that they prefer ports with excellent port cost, location, and service. Ports that handle cargo at the most efficient, intelligent, and low cost based on technology will have a comparative advantage over other ports in terms of competitiveness.

B. Environment

The 21st United Nations Framework Convention on Climate Change adopted the Paris Agreement. Unlike the Kyoto Protocol system, which gave only developed countries the obligation to reduce greenhouse gas emissions, 175 countries strengthened their obligations to respond to climate change. In the Paris Agreement, Korea should reduce its emissions by 37% by 2030 (Hong, 2018).

Regulations on the emission of ozone layer destructive substances, nitrogen oxides, sulfur oxides, and volatile organic compounds that cause air pollution are being strengthened. In order to prevent air pollution by international commercial ships, fuel sulfur content will be regulated to less than 0.5% from 2020, and the US coast, Caribbean region, North Sea and Baltic Sea, which are selected as emission control areas, will be regulated to less than 0.1%. In the case of nitrogen oxides, ships built since 2011 will be subject to stricter regulations of less than 14.4kg/kwh, and the Caribbean Sea and North Sea, which are emission-regulated waters, will be subject to stricter regulations of less than 3.4 kg/kwh. Greenhouse gases emitted from ships should also be reduced to 30% compared to 2014. Shipping companies should make efforts to reduce air pollution using low sulfur oil or alternative fuels (IMO, 2017).

On November 4, 2016, the Paris Convention, which imposes greenhouse gas reduction obligations on all countries, came into effect, and the International

Maritime Organization is promoting the establishment of a roadmap for greenhouse gas reduction. The development and application of energy-saving technologies to meet ship energy efficiency design indicators (EEDI) is required (Korea Maritime Institute, 2017). The Korean government is also seriously dealing with the fine dust problem. It plans to use environmental satellites to investigate the cause of fine dust and improve the accuracy of the forecast by conducting joint research with neighboring countries. It plans to strengthen regulations on workplace emissions and close old thermal power plants to reduce the proportion of coal power generation, and ultimately stop new thermal power plant construction. Since there is a limit to solving the fine dust problem in one country, the government is making efforts to reduce fine dust through the agenda of the Korea-China summit and the promotion of multilateral agreements in Northeast Asia (National Planning Advisory Committee, 2017).

Looking at the competition conditions for smart ports of world-class advanced ports, eco-friendly as well as automation and intelligence are considered important. The power source of the container moving device in the port is electrified using a replaceable battery, and the battery station is operated as a space to charge and replace the replaceable electric battery. LNG use of ship fuel is being promoted as one of the representative eco-friendly port strategies.

This change is appropriate to be seen as reflected in future port technologies as efforts are made to reduce greenhouse gas emissions and air pollution rather than eco-friendly development due to the introduction of smart ports (Hong, 2018). However, the increase in interest in various environmental regulations and sustainable development is expected to increase interest in eco-friendly ships and ports, as seen in the competition for sales of eco-friendly vehicles, and will be an important factor in determining the social acceptability and competitiveness of ports in the future.

C. Energy

Port and port logistics require a lot of energy. With the development of ports, the demand for energy use has increased as the demand for maritime transport increases, and as industrial activities in ports increase. However, considering today's rising energy prices and limited supply conditions, smart ports should also consider efficiency in energy use. To this end, smart ports not only require efficient energy use solutions such as smart grids, but also pay attention to the production of eco-friendly energy that utilizes large sites and resources in ports.

Energy use in ports can be considered in two main aspects. First of all, direct and constant energy use in the port is the use of lighting systems, offices, gates, and storage warehouses in the yard, crane work according to the amount of processed goods, power consumed by ships at anchor, and indirect energy required by various unloading equipment. In existing fossil fuel-dependent systems, it is difficult to cover rising fuel costs and faces limitations in solving environmental problems such as carbon dioxide emissions. Developed countries are scrambling to introduce carbon dioxide neutral policies and set specific deadlines. Typically, in the case of the European Union, a deadline for carbon neutrality policies is set by 2050 and energy use strategies in each field are being fully adjusted. Therefore, energy production or the use of renewable energy, which is mentioned as an essential element of smart ports in the future, is expected to be a key factor enabling sustainable development of smart ports. To this end, various methods such as wind power, solar power, and tidal power generation that can be produced in the port are being attempted, and the use of eco-friendly alternative energy such as biomass (methane/hydrogen) and biodiesel is also actively considered. (MedMaritime SMART PORT, 2016)

Energy management systems can provide continuous advantages in the use of energy in ports. Ports can monitor and adjust the energy consumed by various activities by visualizing the entire process of energy use. Integrated information processing systems and visualization systems related to energy use can help a lot with such efficient energy use and can expect substantial cost savings (Molavi, Lim, & Race, 2019).

D. Safety and Security

It is also necessary to respond to the occurrence of safety accidents in ports. In Korea, an average of 9.7 people per ye are suffering from safety accidents in ports. Safety accidents in ports are caused by various causes such as accidents during unloading operations, traffic accidents in ports, and fires (Korea Port Logistics Association, 2021).

Port loading and unloading refers to the work of performing shipment, transportation, appropriation, classification, and arrangement of ships from a port. Mechanization is being carried out according to the trend of privatization of the pier, but cargo unloading, which requires manpower, must be accompanied by manual labor. The unloading operation must be completed in a short time because speed is vital. The working environment of the port may be poor because of poor natural conditions such as hot weather and cold weather (Korea Maritime Institute, 2012). As a result of the 2020 disaster analysis of domestic port loading and unloading, 43 out of 116 victims (37%) were workers for more than 10 years, 56 (48.3%) worked from 7 a.m. to 12 a.m. and 30 (25.9%) from 12 p.m. to 17 p.m. As a result of the review of the accident rate by cargo, 20 steel (17.2%), 9 containers (7.8%), and 7 miscellaneous goods (6.0%) were found in order. The accident rate by operation stage was found to have a high accident rate during unloading operations, including 63 on-board operations (54.3%) (Korea Port Logistics Association, 2021). It is expected that the automation of ports and the minimization of manpower will drastically reduce the ratio of safety accidents in ports. In particular, in the event of a safety accident, work can be delayed and port operation efficiency can be seriously hindered due to on-site inspections by port authorities. By preventing safety accidents, it is possible to increase competitiveness by enhancing the reliability of the port.

In addition, as can be seen from the case of the Tianjin Port explosion (2015), safety accidents in ports are likely to spread to large accidents because dangerous cargo is stored at the same time in ports. The main causes of the Tianjin Port explosion are a decrease in the level of awareness of safety management in the port, a lack of accident response system, and a lack of sharing of dangerous cargo information. In Korea, safety management is becoming important in all fields, and the importance of port safety management is being highlighted as port safety accidents have occurred frequently in the past (Kim, Kim & Kim, 2015). In addition, since there is a possibility that force majeure safety issues such as natural disasters and port union strikes will be highlighted, each port is paying attention to the possibility of smart ports in response.

Ports are also spaces that require thorough security management. However, there is a limit to managing and controlling the vast amount of land. Advanced service technologies for port security and safety management are also provided, enabling efficient security and safety management. To this end, IoT-based technology is being actively introduced to understand the location and current situation of equipment and manpower in the port in real time. WhereNet in the U.S. introduces IoT technology to provide services to understand real-time equipment and manpower work conditions in ports.

The relationship with port competitiveness at the sub-component level of smart ports is summarized as follows. Automation and intelligence of ports, which are key elements of smart ports, contribute to overall cost reduction by reducing operating costs and the possibility of errors. In other words, it is possible to provide a higher quality service at a lower cost, which plays a key role in the comparative advantage of ports. In addition, data generation and sharing technologies such as blockchain and IoT technologies provide port transparency and predictability to various participants, which allows the port to serve as a portal for projects such as various logistics and background links. Just as portal sites on the Internet attract loyal customers due to the locking effect, physical ports can also serve as portals for the logistics industry by providing the core values that participants need. In addition, ports are also bound to be affected by environmental issues such as global warming and increased natural disasters. Efforts to reduce carbon dioxide emissions and early establishment of an eco-friendly port image will provide a place to operate freely under environmental regulations and pressures in the future and will ensure the sustainable development of ports. Port safety accidents and security accidents can directly affect port reliability and cause short-term port closure or permanent damage to port facilities. Beyond simply being inexpensive to use, it can be said to be a reliable port without defects in the processing process. Therefore, we are looking for countermeasures in smart ports.

2.3.2. Trends in Smart Port Development

Currently, there is no smart port that perfectly implements technologies to respond to the 4th industrial revolution such as the Internet of Things and big data.

In the fields of unmanned automation, eco-friendly ports, and the use of renewable energy, which make up smart ports, development of smart port is being carried out individually to meet the conditions of each port. Starting with unmanned automation, eco-friendly development has recently been incorporated. The port operation efficiency is pursued, focusing on the establishment of intelligent and automated terminals, and at the same time, efforts to make it eco-friendly are being made. Traditionally, European ports are leading, followed by the United States and China.

It is analyzed that fully automated terminals such as Rotterdam APM Terminal in 2015, Long Beach Port in 2016, and Qingdao Port QQ CTN in 2017 have an effect of improving productivity by about 40% and reducing operating costs by about 37% (Korea Maritime Institute, 2017). The European container terminal (ECT) DDN terminal in Rotterdam, the Netherlands, began operating the world's first unmanned automated terminal in 1993. By attempting to change the container device length from horizontal to vertical, the current standard for container terminal device length around the world has been changed. Container transport vehicles and yard unloading equipment in the port were unmanned to implement a completely unmanned automated terminal. Rotterdam Port operates DDN Terminal in 1993, DDE Terminal in 1996, DDW Terminal in 2002, and Euromax Terminal in 2010 as fully unmanned automated terminals.

The CTA terminal in Hamburg Germany, began operating the world's second unmanned automated container terminal in 2003. Although the Dutch ECT was benchmarked, there is a difference in the unloading system. A dual hoist second controlled container crane was used and ARMGC of five stages and ten rows was introduced. All tasks such as safety wall equipment, linkage of transportation equipment in ports, container transport, and yard loading are being automated without permission. Landing work through cranes on ships is operated in a manned form, and since 2009, the "Smart Port Logistics Project" has been implemented to maximize port efficiency by enabling integrated management of logistics, environment, and administration through the Internet of Things.

LA Port and Long Beach Port in the U.S. are operated manually for inner wall work and automation for land areas. The container crane is operated manually, and the main line work is carried out with a rail-type automatic crane. In the case of the long beach container terminal (LBCT), there were also port-related technology problems, but it was difficult to automate completely unmanned due to opposition from the port transportation trade union, which was concerned about a decrease in port unloading jobs. After the complete unmanned automation of one berth in 2016, a total of three berths are being fully automated.

Eco-friendly port operations are strongly conducted under the leadership of California, the United States. In the case of California, the use of alternative maritime power (AMP) is mandatory from 50% in 2014 to 70% in 2017 and 80% in 2018. Therefore, all ships entering the U.S. state of California must gradually promote ship unloading facilities suitable for AMP facilities and the use of eco-friendly ship fuel. As global cooperation on climate change becomes important, eco-friendly port operation has been included as a factor that cannot be overlooked in building and operating smart ports, and ports that want to become global logistics hubs need to meet environmental standards.

China is pushing for a smart port pilot project in 11 ports nationwide. In order to realize smart logistics and safely manage port cargo, a plan was established to designate 11 smart pilot ports and promote smart port policies from 2017. According to the plan, smart port policies are expected to be implemented from four perspectives: automation, safety management, linked logistics efficiency improvement, and port logistics information sharing (Hong, 2018).

Qingdao Port QQ CT (Qingdao Qianwan container terminal) and Xiamen Oeacn Gate Container terminal (XOCT) are operated as fully unmanned automated terminals. Qingdao Port has been implemented with complete unmanned automation that performs container unloading and transportation work with artificial intelligence. It operates an unmanned system until the operation of automatically removing and detaching the lower container fixing device. Xiamen Port is piloting 16 double trolley container cranes, 16 automated stacking cranes, and 18 battery Automated guided vehicles (AGVs). The fourth stage of Yangsan Port in Shanghai was completed in 2018 with 26 remote control container cranes and 120 battery AGVs. China has also been actively willing to operate eco-friendly ports by designating emission-regulated waters for major ports and mandating the installation of land-based power equipment in ports from 2020 (Cha, 2021).

Singapore's TUAS terminal plans to fully unmanned all 65 berths by 2040, and

15 berths of Pasir Panjang were completed in 2018. According to the TUAS terminal development plan, it is intended to implement all functions of smart ports such as eco-friendly ports and artificial intelligence. The first phase of the TUAS project is being constructed with a terminal length of 8.6km and a total of 20 seats, and the first phase of the terminal operation began in 2021. Currently, a 10-kilometer-long two-stage terminal construction plan is underway.

In the case of Japan, in the era of the 4th Industrial Revolution, the overall industry goal of 'Connected Industries' was set. Based on these top goals, the mid- to long-term policy "PORT 2030" in the port field was established, and "PORT 2030" established three goals and eight detailed strategies: Connected Port, Premium Port, and Smart Port. It plans to actively utilize technologies such as artificial intelligence (AI) and the Internet of Things (IoT) in port operations to platform ports that incorporate the 4th industrial revolution technology. In particular, it plans to focus on port construction and maintenance, disaster prevention, and safety management, and we will take the lead in responding to the shortage of manpower in the super-aged society. Accordingly, the Ministry of Land, Infrastructure, and Transport of Japan set detailed goals such as building and operating intelligent ports and creating new values through the connection of all objects, manpower, companies, information, and space (Cha, 2021).

Table 6: Global Smart Port Development Trends

Ports	Start of Operation	Focus of Smart Port	Characteristic
Rotterdam	1993	Automation, Environment, Energy, Safety	Smart Port Roadmap - Smart Energy/Industry - Smart Logistics - Port Infrastructures - Innovative Ecosystem
Hamberg	2003	Automation, Environment, Energy Safety	Smart Port Project - Smart Port Energy - Smart Logistics
LA/LB	2015/16	Automation, Environment	Zero-Emission 2030 Port Optimizer software
QQCTN	2017	Automation, Environment, Energy	85% reduction in manpower required, Hydrogen Energy Source
Shanghai	2017	Automation, Environment	Smart/Eco-Friendly/Efficiency Oriented, Largest Automation Terminal in the World,
TUAS	2021	Automation, Environment	Smart Nation Project, Smart Nation Program Office,

Japan	Undetermined	Automation	Maintenance/disaster management, Responding to staff shortages

Resource: Cha, 2021

2.4. Results of previous study review

As seen in the case of smart port construction, each port is striving to build smart ports in various aspects according to their conditions and needs. Rotterdam Port, which has already implemented a development strategy with automated ports in mind since the 2000s, is promoting projects to play a pivotal role in various fields using the 4th industrial revolution technology. In particular, leading port operators from various countries around the world are gathering to form a Smart Port consortium and use it as a channel to share their experiences and knowledge about smart ports.

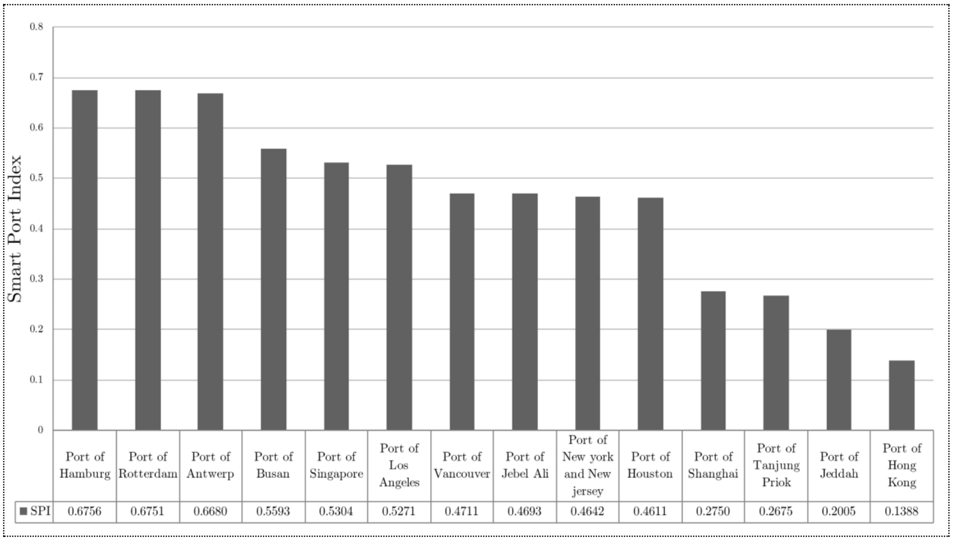
Many studies on existing smart ports were exploratory studies for unfamiliar concept definitions or developed evaluation indexes to evaluate and compare the degree of development of smart ports. However, there were insufficient studies that explained and analyzed various aspects of ports that are leading the technological development in the field of smart ports, and in particular, there were insufficient reviews that provided important implications for the establishment of smart ports in Korea.

In terms of port competitiveness, there were many attempts to extract policy suggestions to strengthen port competitiveness by studying the relationship between port location, operation efficiency, port cost, service level, and etc., which were studied in depth, but there was no research on the relationship between smart ports and port competitiveness. While the existing competitiveness study is a study on the efficiency of port operation and the optimal response of the operator, the discussion of smart ports differs greatly in scope and goal due to the response to changes in the external environment and the sustainability of the port. Therefore, I would like to analyze how the energy use, environmental interest, and safety and security aspects of port operations, which have been neglected due to the efficient operation of ports, affect port competitiveness along with operational efficiency.

3.1. Analysis Targets and Data

Europe is at the forefront of smart ports. In particular, Rotterdam Port in the Netherlands and Hamburg Port in Germany are considered to be the gateway ports to compete for the top container handling in Europe and are leading the development of smart ports in the world. Chung (2018) introduced policies and technologies of Rotterdam and Hamburg ports to examine the trend of smart ports, and Lee (2020) also analyzed only two ports in Singapore and Europe for case analysis of smart ports. A. Molavi's study also confirmed that the two ports were ranked first and second side by side in the SPI index, measured by quantifying the degree of development of smart ports, and that they were leading in the field of smartization of ports.

Figure 1: Comparison of Smart Port Index for 14 Ports



Source: Molavi, Lim, & Race, 2019

The two ports in Europe are not only leading the market by collaborating with global companies in policy and practice tasks in the smart port field, but also trying to standardize smart port technology by establishing networks with nearby ports. Therefore, I intend to derive policy implications by using the two ports as the subject of analysis. For this analysis, previous research data were mainly referred to, and information was collected through analysis data of research institutes, port policy promotion data, official website, and publications.

In this study, the main subject of comparative analysis with the two advanced ports is Busan Port. Busan Port is the world's seventh-largest port in terms of container throughput, the world's second-largest port in terms of transshipment cargo throughput, and Asia's representative hub port with 12,000 container ships entering and leaving per year (Busan Port Authority, 2021). UNCTAD ranked busan ports fourth in the world in the Port Liner Shipping Connectivity Index (PLSCI), which is calculated by considering six criteria each year, including the number of regular routes and the capacity to accommodate ships in ports (UNCTAD, 2021). Since it is the most congested, it is necessary to smartize the port, and it can be said that it is a port that can expect a high competitiveness strengthening effect from the establishment of a smart port. Therefore, I will examine the current status and strategy of smart port development in the two ports of Europe and review the current status of Busan Port and related policies to review implications.

3.2. Analytical Model

In previous studies on smart port and port competitiveness, it is expected that the establishment of smart ports will enhance port operational efficiency and solve environmental problems such as air pollution, workplace safety accidents, traffic congestion, and excessive energy use. Therefore, I would like to set a research question on how the establishment of smart ports will affect the competitiveness of ports, first look at the background and conditions of introducing smart ports, and analyze the degree of smart ports and Busan ports using the four main areas used in A. Molavi's research.

Table 7: Research Analysis Model

Domains	Environmental conditions
Operations	▫ Productivity ▫ Automation ▫ Intelligent Infrastructure

Environment	▫ Environmental Management Systems ▫ Emissions and Pollutions Control ▫ Waste management ▫ Water management
Energy	▫ Efficient energy consumption ▫ Producing and use of renewables ▫ Energy Management
Safety and Security	▫ Safety management systems ▫ Security management systems ▫ Integrated monitoring and optimization systems

Resource: Molavi, Lim, & Race, 2019

The detailed indicators constituting the four areas of smart ports are as follows. In terms of operation, it is an intelligent foundation that intelligently manages comprehensive port operations by combining measurable productivity with cargo handling time and cost, automation degree to minimize human intervention using advanced technology, and I.A. This includes the management of traffic congestion inside the port, the optimal schedule of ship operation, and the efficient operation of linked transportation. In terms of the environment, the existence of a management system that can manage environmental problems in ports, the use of advanced technologies to measure and monitor them, and the provision of a system to monitor water quality, air quality and pollutant emissions in ports are subject to evaluation. In terms of energy, efforts to increase the efficiency of overall energy use in ports and the transition to eco-friendly energy are important. In addition, the presence or absence of an energy management system that can manage it collectively is also an evaluation index. Finally, in terms of safety and security, it is important to evaluate the presence and utilization of agile management systems that comprehensively monitor safety issues and can immediately respond to problems when they arise. In the same context, security is also an important factor in the establishment of a port security monitoring system using advanced technology. The operation of an integrated system that can monitor this in an integrated manner and utilize the produced information to provide quick feedback and make policy decisions can be a useful indicator for evaluating the degree of port smartization. A. Molavi's research focused on developing and evaluating numerical indicators, so there is a limit to capturing a wider variety of smart ports.

To compensate for this, in addition to the core evaluation indicators related to the four areas, this study will analyze various efforts that have been widely developed, such as efforts to build an innovative ecosystem in ports, use of external resources, and lead smart port standardization.

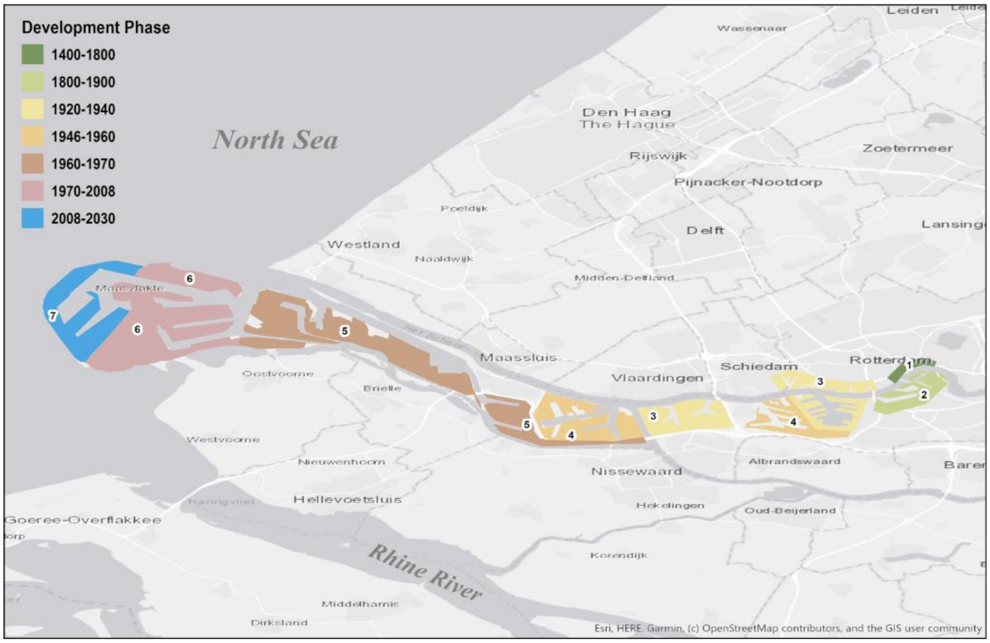
Chapter 3. Case Analysis

3.1. Port of Rotterdam (Netherlands)

3.1.1. Background and Status of Smart Port Introduction

Rotterdam Port is one of the largest ports in Europe and is located down the Rhine River and has developed into a major trading port since the early days due to its geographical advantage as a gateway to Europe. Rotterdam Port, which has maintained continuous expansion and development except during the French occupation in the early 19th century, has grown into the fifth largest port in the world to handle bulk cargo and the 11th largest container cargo in Europe (Notteboom, Pallis, & Rodrigue, 2021)

Figure 2: Evolution of the Port of Rotterdam



Source: https://porteconomicsmanagement.org

At the same time, the world's first unmanned automated terminal, ECT (European Container Terminal), was introduced in 1993, and in 2015, it succeeded in unmanned the inner wall crane operation, building the most advanced automated port (Korea Maritime Institute, 2017). This early interest in automated ports stems from the explosion of cargo volume in Europe and the spatial constraints to accommodate it as free trade increased in the 1990s. In addition, shipping companies have continued to research and develop ways to achieve maximum efficiency in a short period of time in terms of port operation as they actively utilize ship size as an element of economies of scale and barriers to entry. D.Visser, a Dutch port expert, emphasized the importance of automated ports earlier, saying that major shipping companies today demand port services for ships of 20,000 TEU (Twenty-foot equivalent unit) or higher, and that without automation of container terminals in port investment, it will not be possible to achieve the productivity needed to maximize investment returns. In addition, the operation of the yard transfer and unloading automation system of the terminal was promoted to prepare for high labor costs, population decline, and aging population. Rotterdam Port operates a total of 14 terminals, including five major automated container terminals, which have accumulated considerable trial and error and know-how through long-term automated terminal operations and reduced labor costs by more than 30% compared to existing terminals (Cho, Won, & Choi, 2014). In addition, the use of existing fossil fuels has been limited and port equipment such as electric power-based Quay Cranes (QCs), Automated Guided Vehicles (AGVs), and Automated Stacking Cranes (ASCs) has been developed and utilized in an effort to reduce operating costs and reduce carbon dioxide emissions. In the end, Rotterdam Port's conversion to a smart port was driven by the need to improve terminal productivity, seek countermeasures against manpower supply and management difficulties due to large ships, and establish an eco-friendly port in response to climate change.

Rotterdam Port established an organization called "SMARTPORT" to build a smart port to take charge of the roles of investment, performance, management, and public relations in various R&D. In particular, the organization is promoting joint projects with various partners such as local governments, private companies, research institutes and universities to transform Rotterdam Port into the best smart port by incorporating the latest technologies and knowledge into port operations.

To this end, a long-term vision roadmap was established for four sectors: Smart Energy & Industry, Smart Logistics, Future-proof Port Infrastructure, and Innovation-ecosystem. Individual projects in the roadmap are projects currently under research or in the commercialization stage.

Table 8: Rotterdam's Roadmap of Smart port development

Category	Objective	Program	Project
Smart Energy & Industry	Sustainable and Optimized operation of petrochemical Clusters	- Proliferation of Wind Power - Electrical Energy Conversion	- Power-2-Fules - Electrons to Chemical Bonds (E2CB) - System integration Energy
Smart Logistics	Delivering Reliability and Efficiency in the supply chain	- Digital Logistics - Automated Logistics	- IoT4Agri: Internet of things and Agrologistics - STAD and Catalyst: connected automated transport
Futureproof Port Infrastructure	Port Development to Increase Safety and Minimize Environmental Impact	- Minimizing Dredging by Navigating the Seabed Surface - Data Collection via sensors in the cabin	- Climate change and inland navigation - External effects on the port – trends and developments - Quay walls of the future with sensors providing data
Port Strategy	Strategies for the sustainable Development of Rotterdam Port	- Innovative business Environment - Trend Analysis and R&D	- Next Generation Waterfronts - World Port City Index – port-related business clusters - Benchmark innovative ecosystems

Source: Chung (2018); Smart Port website (2022)

3.1.2. Operational Aspects of Smart Port

The smartization of Rotterdam ports has progressed step by step with the expansion of the port size and region. Since the first unmanned automation terminal, ECT (European Container Terminal), was built in 1993, the most state-of-the-art APM Maasvlakte II terminal and Rotterdam World Gateway (RWG) have been opened by unmanned the inner wall crane in 2015. Instead of converting the existing terminal into an automated terminal, a new terminal was built to introduce automated equipment while minimizing friction with port workers. If the container is placed on the automatic transport vehicle (AGV) through an unmanned safety crane remotely controlled by the central control room from the moment the ship docked, AGV transports the container to the storage space using autonomous driving. When AGV arrives at the automated yard, the automatic stacking crane recognizes AGV arrival and automatically picks up the container and loads it into an empty storage space. In this way, vehicles carrying containers are also powered to not use existing fossil fuels, and each vehicle determines whether the battery is remaining, moves to a charging place, replaces the battery, and performs automatic charging. All of these processes are automated and the manager in the office monitors and controls the movement of all automated equipment in the port in real time. Through this, it is said that more than 50% of efficiency improvement was achieved compared to the existing terminals in the up and down operation of containers (Korea Maritime Institute, 2017).

In addition, Rotterdam Port Authority decided that building a digital ecosystem that can share real-time information between port logistics entities (shippers, carriers, and terminal operators) is the most important to increase operational efficiency, and built a Port Community System (PCS) that shares all port operation data in real time to improve productivity. In order to ensure that the collection and exchange of these data are compatible with other ports, standardization projects are also being carried out through cooperation with international organizations such as IMO's standard terminology, GS1 (International Organization for Distribution Logistics), and UK Hydrographic Office (Korea Maritime Institute, 2019).

In addition, Port Rendezvous of Nautical and Terminal Operations (PRONTO), a port optimization information application, is introduced to predict the optimal Estimated of Time Arrival (ETA) and Estimated Time of Destination (ETD) through data collection of port stakeholders. As a result, it is said that the average port waiting time for ships arriving at Rotterdam Port has been reduced by about 20% (Lee, 2020). As the number of platform users of Pronto has increased rapidly and the services provided have diversified, it has developed into PortXchange, sharing data of related subjects in the entire process of entering and leaving ships, and promoting standardization work. Through this, shipping companies can expect to reduce port call time, reduce bunker and charter costs, and reduce CO2 emissions, and container terminals can improve processing time and reduce waiting time to increase terminal utilization. This predictability is very important in the process of landing and unloading ships because a series of port work processes are carried out sequentially. The Routescanner application provides door-to-door services through ports, roads, and railways to cargo owners around the world. All inland transportation, freight trains and short-haul operators in northwestern Europe are connected and link them to shipping lines. Through these services, international transportation has become more visible and convenient to use. To date, the global container transport plan has been a complex puzzle for ship owners and carriers. This is because information on the connection of transportation routes, railways and roads is often incomplete or transparent. Accordingly, Rotterdam Port has signed information-sharing agreements with 20 global container ports based on the Routescanner application and is striving to grow into a platform for maritime transport. The Boxinsider application, which provides real-time tracking information for containers, is designed to provide cargo-related information to shippers and forwarding companies in a user-friendly environment to establish an optimized land transport plan based on terminal handling schedules. This provides the advantage of being able to do a lot of work in advance, reducing the additional work that occurs, and the means to avoid congestion at the terminal gate (Won & Cho, 2020). For more sophisticated information acquisition and efficient operation, plans are also underway to digitize the 42km area within Rotterdam Port using IBM's IoT and cloud technologies. It aims to track all movements in the port using various sensor devices and RFID (Radio-frequency identification), detect climate changes in real time, and construct information optimized for safe and rapid berthing and operational efficiency of shipping companies. As part of these projects, digital dolphin is being promoted (Chung, 2018). The digital dock is equipped with sensors on the dock walls, which identify the ship's port of call and provide accurate information on weather conditions at the surrounding sea, providing the best time to approach the ship's dock. In addition, it is possible to minimize the physical inspection of the aging inner wall and increase the efficient use time of the inner wall. Checking the exact state of the quay wall and scanning the shape of the quay wall are important factors for autonomous ships to recognize the shape of the quay wall through data communication in the future and to approach it unmanned. By accumulating and utilizing these data, it aims to have commercial unmanned ships docked in ports by 2030. In the same context, it is possible to accumulate data for selecting ships suitable for mooring as well as the condition of the ship by installing a smart mooring line and measuring the pressure applied to the bollard in real time. Through this, it is possible to expect a cost-saving effect of facilitating the maintenance of facilities and increasing the lifespan of the facilities.

The port, which was out of people's interest, became a high-tech competition and a stage for new business opportunities began with efforts to solve problems and innovate, breaking away from existing repeated practices. In particular, Rotterdam Port made great efforts to create an innovative ecosystem to this end. PortXL, a representative marine innovation accelerator business, provides three months of incubation opportunities every year to find innovative business models around the world. In this process, it provides an opportunity to access a network of mentors, investors, companies, and sponsors to shape the business model. In the stage of embodying the actual business after the incubator period, it has signed agreements with Antwerp Port and Singapore Port to help enter the port as well as opportunities in the form of test bad in the port. Every year, about 10 new venture companies are selected for the PortXL program and contribute to the creation of an innovative ecosystem in Rotterdam Port through an incubator (Port of Rotterdam, 2022).

3.1.3. Environmental Aspects of Smart Port

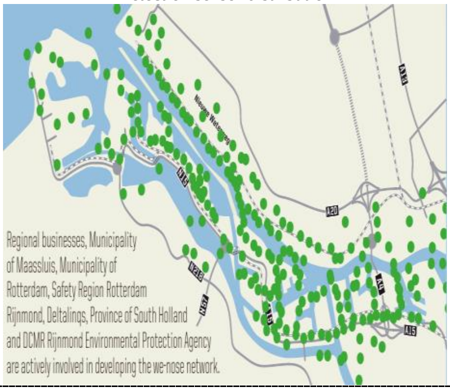
Unmanned automated ports seek to electrify all facilities in the port, thereby minimizing the generation of pollutants. In the case of Long Beach Port in the U.S., it was announced that various pollutants decreased by more than 84% per TEU after operating a fully unmanned automated terminal (Korea Maritime Institute, 2017). In the case of Rotterdam Port, the Carbon Footprint System and alternative maritime power (AMP) are being used to promote more active pollutant reduction policies. Through this, it aims to reduce carbon dioxide emissions by more than 50% compared to the previous one by 2024 (Port of Rotterdam, 2022). At ports, carbon footprints indicate the amount of carbon dioxide generated when processing 1 TEU of containers, and are a system that tracks and manages carbon emissions by emission source. The Rotterdam Port Authority expects that through the carbon footprint system, subjects using ports will be able to promote competition through comparisons between ports with interest in the environment. Previously, electricity generated by the ship's own generator was used while the ship docked at the port, which caused various environmental pollutants to be discharged and worsened the port's environment. To solve this problem, it is evaluated as an effective technology to reduce air pollution by receiving power from land while ships docked at ports using AMP technology. Positive recognition from the community is very important to create a more sustainable port. To this end, Rotterdam Port is also making great efforts to improve the quality of the residential environment around the port. It measures and monitors noise and odors from port operations as well as efforts to reduce pollutant emissions from ships and unloading equipment, discloses them, and provides information online so that everyone can check the air quality of the area in real time. Electronic measurement equipment called "E-nose" is installed at 250 locations in the port to detect changes in air composition and early detection of emission of harmful substances to monitor environmental quality. Through this, the goal is to provide an attractive port experience for local residents, port workers, and visitors (Port of Rotterdam, E-noses 2022)

Figure 3: Electronic nose (e-nose) Operation

1. DETECTING SMELLS
Some substances are toxic, dangerous or unpleasant. ‘The sensors in the e-nose take measurements of odorous and odourless gas compounds in the vicinity.’

2. COMPARING SMELLS
The measured gas compound is compared with the chemical ‘fingerprints’ of known compounds recorded in a central database.

Detection sensor distribution



3. CHANGING SMELLS
The sensor registers changes. These are flagged up in the Environmental Agency’s control rooms and at the businesses in the vicinity. The Agency investigates the report, which may mean visiting the site. If necessary, a so-called environmental report is issued to inform local residents.

4. COMPANIES
Companies also have their own e-noses on site.
This enables them to take measures early on, such as adapting production processes.

Source: www.portofrotterdam.com

In addition, the relatively recently completed RWG terminal is building an eco-friendly terminal through the use of natural energy such as triple glass, heat storage facilities, ceiling and floor heating of buildings in the terminal as well as electric power of unloading equipment.

3.1.4. Energy Aspects of Smart Port

The common characteristic of ports located in Europe is that they are deeply interested in climate change and environmental sustainability. As a result, the Port Authority of Rotterdam announced an aggressive CO2 reduction plan. The CO2 generated by the port was reduced by 75% by 2025 compared to 2019, and a target of reduction of more than 90% by 2030 (Port of Rotterdam, 2022). To this end, the fuel of patrol ships in the port is converted into biofuels. In addition, to reduce emissions in the relevant shipping industry sector, efficiency increases through optimal logistics processes, coastal power use, and bunkering of clean fuels such as LNG and methanol are short-term alternatives. In the long run, to achieve CO2 neutrality in the Netherlands itself by 2050 and transition to clean energy-based ports without pollutant emissions, Rotterdam Port Authority has established a Cluster Energy Strategy and is making fundamental changes in terms of energy use and transport. To this end, four major energy conversion areas were selected and six key projects were selected. The first is the construction of a hydrogen connection pipeline starting at Rotterdam Port (Port of Rotterdam, HyTransPort.RTM 2021). The HyTransPort.RTM pipeline construction plan is a pivotal project in which domestic hydrogen and hydrogen energy imported from abroad are transferred to Rotterdam Port and transferred to northwest Europe, with the focus on future transition to a hydrogen-based society. Through this, the role of Rotterdam Port in the future hydrogen-based society will become more important. The second is the Delta Corridor project, which is to expand the connection line to neighboring countries, including Germany, by utilizing transport facilities based on Rotterdam. Through this, it is expected to serve as an energy hub for northwest Europe by serving as a channel for circulating energy sources such as hydrogen, CO2, LPG, and propylene. It is a large-scale project that can greatly contribute to carbon neutrality by connecting industrial complexes scattered nearby with four pipelines to freely transfer hydrogen fuel and transported collected CO2 to a reservoir in the North Sea. To this end, companies such as Shell, BP, and Chemelot, private companies, and local governments participated in the plan to complete the laying of pipelines by 2026. In the project, Rotterdam Port will serve as a hub for energy transfer and will connect each industrial complex to supply hydrogen. This will facilitate the transition to eco-friendly energy and will play a key role in the CO2 reduction goal set by the EU by 2030 (Port of Rotterdam, Hydrogen in Rotterdam, 2022).

The third project is leading to energy production and consumption in ports in an effort to create sustainable ports. It plans to build a total of 7.4 GW wind power generation facility near the North Sea by 2030. Through this, the plan is not only to produce and use electricity on its own, but also to accelerate the transition to eco-friendly energy use by using hydrogen from oil refining gas. In the process of producing hydrogen, it is also trying to solidify the image of a green port by using an eco-friendly method. The fourth project is the Porthos(Port of Rotterdam CO_2 Transport Hub and Offshore Storage), which uses technology to collect CO2 emitted in ports to reduce CO2 emissions and stores CO2 in the North Sea. By 2050, a CO2 capture project is being implemented in the port, which can have immediate effect in accordance with the Netherlands' clear plan to declare emission neutrality. The fifth is the WarmtelinQ project, which supplies heating to 16,000 nearby households by utilizing residual heat used and emitted from commercial facilities such as refining facilities in ports, contributing to suppressing the use of natural gas. It will include a project to supply heating heat to households, offices, and greenhouses by expanding infrastructure to recover more heat in the future. By expanding this, a pipeline laying project is underway to smoothly transfer residual heat in the port and aims to supply heating heat from Rotterdam Port to Hague. The last project is H-vision. As a project aimed at developing plants to produce and transport low-carbon hydrogen that can be used as fuel in the industry, three product pipelines are planned for low-carbon hydrogen production and emission and industrial residual gas supply.

In addition to these major projects, extensive and detailed plans have been established and implemented for the transition to hydrogen neutrality and carbon-based economies.

Table 9: Energy Transition Projects

Pillar	Projects
1. EFFICIENCY & INFRASTRUCTURE	▫ 16,000 households receive heat from Pernis ▫ CO2 storage under the North Sea (Porthos) ▫ Heat network: heating houses and greenhouses with heat from industry ▫ Start of construction of heat pipeline between the port of -Rotterdam and The Hague ▫ Offshore grid Hollandse Kust (zuid) Alpha and Beta ready for use ▫ Pipelines between the Netherlands and Germany
2. A NEW ENERGY SYSTEM	▫ Wind turbines in the port area ▫ North Sea Wind Power Hub ▫ Hydrogen pipeline through port of Rotterdam ▫ Green hydrogen for BP refinery ▫ Green hydrogen plant Uniper ▫ Importing blue ammonia ▫ Port of Rotterdam Authority's contribution to the energy transition ▫ Shell to start building Europe's biggest green hydrogen plant ▫ Study for commercial-scale hydrogen imports ▫ Electrification of industrial processes ▫ Production of green hydrogen at SIF in 2023 ▫ Hydrogen projects in Rotterdam ▫ Several Rotterdam terminals to be ready for hydrogen imports by 2025
3. A NEW MATERIALS & FUEL SYSTEM	▫ Full recycling of contaminated building materials ▫ Recycling batteries from electric vehicles ▫ Sustainable aviation fuel and renewable diesel ▫ Neste invests € 1,9 billion in renewable products refinery ▫ Biorefinery UPM ▫ Xycle starts construction of its first plastic recycling plant ▫ Gidara Energy will convert non-recyclable waste into advanced biofuels
4. MAKING LOGISTICS CHAINS MORE SUSTAINABLE	▫ Inland shipping on batteries ▫ Emission-free inland shipping ▫ Shore power trials for sea-going vessels ▫ Digitisation leads to lower energy consumption ▫ Green shore electric facility for Boskalis ships in Waalhaven ▫ Air Liquide and Port of Rotterdam Authority: hydrogen road transport ▫ MAGPIE, smart green ports of the future

Source: www.portofrotterdam.com

3.1.5. Safety and Security Aspects of Smart Port

The Port Authority of Rotterdam is making a number of efforts to maintain Rotterdam as the safest port (Port of Rotterdam, Port security 2022). First of all, in order to minimize the risk of safety accidents, a Port Security Officer (PSO) is designated to have the authority and responsibility for safety-related work. The PSO exercises full authority on behalf of the mayor of the local government on safety issues in ports, identifies the risk factors of ports, and establishes, implements, and supervises annual safety plans. In addition, safety rules within the International Ship and Port Facility (ISPS) stipulated by the International Maritime Organization (IMO) are applied to port operations to minimize risks. The ISPS assessment team consisting of police, customs and port authorities periodically assess the safety of the port and submit assessment reports to the PSO in relation to the safety plan. In addition, the MOBI platform has been in operation since 2019 to check all requirements and regulations necessary for the operation of safe ports and to easily request and confirm the issuance of certificates necessary when entering and leaving the port. Port users can check and respond to the security level currently applied with the MOBI platform, take necessary measures, and check the process of processing requests in transparent and real-time. The MOBI platform is also linked to other ports in Europe, providing the advantage of one-stop administrative processing when moving between ports. In addition, in the event of an emergency such as a ship accident or fire in a port, Rijnmondveilig.nl is also operating a service that spreads the risk to port users as well as nearby residents and provides reliable information by ordering countermeasures in real time. Through this, it is possible to grasp the response status of firefighting, first aid, police, local governments, and port authorities at a glance.

Drone, an unmanned aerial vehicle, is being used effectively in a large port area. There is no limit to the scope of use, including water pollution and fire prevention, port area monitoring and security monitoring (Port of Rotterdam, Flying in the Port Area 2022). In addition, since aviation areas, which were not previously considered as port areas, are included in the port management scope, the Rotterdam Port Authority introduces an air traffic control system called the Unmanned Traffic Management System (UTM) to manage drone traffic. In addition, by setting up U-Space airspace, all users of this airspace must follow operating rules and use UTM services. In this way, the institutional preparation and operation system for the use of drones was complete. Under this foundation, modern drones can regularly fly in-port aviation, support port operations, as well as carry small cargoes such as refrigerated medical supplies, ship parts, or cargo samples.

Concerns about cyberattacks are also growing in preparation for the trend of automation, computerization, and networking in port operations. To respond to this, the Cyber Attack Reporting Center has been established and operated since 2018, and all entities in the port are obligated to report in accordance with Port Security Act Regulation (EC) no. 725/2004 and ISPS rules, and port authorities can take measures according to their importance (Port of Rotterdam, Safe port 2022).

The Port Health Authority Rotterdam (PHAR) was already established in 2009 to manage infectious diseases that can be transmitted to ports (Port of Rotterdam, Port Health Authority 2022). In order to manage these professional areas, we maintain close cooperation with local medical organizations, local governments, and other institutions, and strive to prevent the spread of international infectious diseases in accordance with the International Health Regulations (IHR) protocol enacted in 2005. To this end, emergency plans are regularly updated in case of infectious diseases, and quarantine facilities and medical services are provided for members who need quarantine.

3.1.6. Implications

In the case of Rotterdam ports, due to constraints such as narrow port areas and high labor costs, they have been promoting the automation of ports at an early stage with keen interest. It has the highest level of technology and operational know-how in the automation sector, as it was selected as a port with "world-class port infrastructure" at the World Economic Forum for the seventh consecutive year. In addition to this, it has increased its availability, including various operators, global shipping companies, and carriers, in the information platform area currently in operation, and is leading data standardization in alliance with global ports in the United States and Asia. The revitalization of various participation is the core of the consolidated economy and is understood as a stepping stone for the preoccupation of the port operation platform in the future, and it seems to be making the most of the advantages of leading ports that have developed the smart port field. Another notable point of Rotterdam Harbor can be seen as the composition of a vast and elaborate plan. Using individually developed technologies to construct an operating system, present a long-term vision explaining future goals to be finally integrated in the future, and various detailed projects to implement them are enough to make us expect the advancement of smart ports. In the process of promoting detailed projects, it involves various operators, provides business opportunities, and crosses regional and national boundaries to maximize the potential of gateway ports, not limited to Rotterdam ports. The short-term port operational efficiency improvement plan and the transition to a long-term hydrogen-based portal are visions that show the potential for port growth beyond the physical port area.

Deep interest in the environment and countermeasures have clear advantages in future smart port operations. In the maritime transportation sector, where economies of scale are now realized, several global shipping companies have monopolized market share, increased their influence, and rejected competitors. The reason behind these global shipping companies' active green management, such as the use of eco-friendly fuels and the construction of eco-friendly ships, is the possibility that if they are eliminated from eco-friendly competition in the future, they can lose trust from customers and be excluded from their solid cartels. In this context, eco-friendly ships can be attracted in leading ports that have built eco-friendly ports early, and stable supplies and growth can be expected as members of such cartels. In particular, the fact that ports in Asia are only focused on operational efficiency and cost reduction, so they are negligent in environmental aspects, which can shift to future strengths in high-cost ports.

Another interest in Rotterdam Port is the construction of an innovative ecosystem. It has established an innovative incubator system in the port, constantly discovering new startups, and emphasizing a virtuous cycle of new technologies flowing into the port. If the core value of smart ports is innovation in the future, the gap between ports with innovative ecosystems and ports that do not will not narrow.

3.2. Port of Hamburg (Germany)

3.2.1. Background and Status of Smart Port Introduction

The port of Hamburg opened in the 12th century and developed into the core city of the Hanseatic League in the 13th and 16th centuries, and became Germany's largest trading port in the 19th century, functioning as a hub for cargo ships and passenger ships between central Europe and the United States. Unlike other ports, Hamburg Port is characterized by port facilities located in the center of the city, not outside the city, and has been able to develop reciprocally in narrow spaces while streamlining land use and optimizing logistics processes based on cooperation between the Hamburg state and the port industry. In the 20th century, container terminals were created preemptively to continue their growth, and it is recognized as the third-largest trading port in Europe and the 20th-largest in the world in terms of container throughput, but its ranking continues to decline (Busan Port Authority, 2021). This is because competitive ports in the surrounding northern Europe have expanded and automated port facilities in recent years, and they have a cost advantage over Hamburg ports because their cargo handling is fast, efficient, and port usage fees are also low. In particular, the Alliance, 2M, and Ocean Alliance formed by shipping companies after the 2008 economic crisis acted like cartels, intensifying competition among ports, and Hamburg Port, which is less competitive in facilities and prices than new ports, was hit harder. In addition, local residents and environmental groups have resisted the Hamburg port expansion plan, and they have focused on port automation as part of their efforts to solve these problems and have established a port development plan with efficient port operation and harmonious development with the community as a priority.

Figure 4: Port of Hamburg in geography

Source: www.hafen-hamburg.de

Container Terminal Altenwerder (CTA) in Hamburg Port, Germany, is an eco-friendly automated terminal with the city of Hamburg investing EUR 300 million for infrastructure and HHLA, the operator of the terminal, and partner Hapag Lloyd (global shipping company and 25.1% stake). It began developing terminals in 1997 and began operating fully unmanned automated container terminals for the second time five years later in the world in 2002 (Cho, Won, & Choi, 2014). It has grown based on the geographical advantage of being the gateway to Eastern Europe and the huge import and export volume of Germany.

Hamburg Port's smart port policy is being promoted as a 'smartPORT' project to optimize traffic and cargo flow in the port by utilizing state-of-the-art information technology solutions. Hamburg Port Authority is leading the smart port policy of Hamburg Port. Hamburg Port's intelligent port management system is based on smartPORT and consists of 'smartPORT energy' and 'smartPORT logics' (Hamburg Port Authority, SmartPORT 2022).

Table 10: Concept of smartPort in Hamburg

Category	**Goal**	**Content**	**Project**
smartPort Energy	Reducing energy consumption and minimizing environmental	▫ Promoting the use of renewable energy ▫ Minimizing pollutant emissions by reducing energy consumption	▫ Wind Farm sites: sustainability & Expansion ▫ Cross company use of waste heat

	impact	▫ Use of eco-friendly and innovative transportation	▫ Alternative power for heavy duty traffic (LNG, electricity)
smartPort Logistics	Optimizing supply Chain and improving transport network efficiency	▫ Improving the efficiency of traffic flow in terminal ▫ Efficient intermodal transport linkage ▫ Optimum freight transport	▫ Smart maintenance ▫ Port road management center ▫ Intelligent application of tomorrow

Source: Korea Maritime Institute, 2018

The purpose of this system is to modernize and improve the information technology infrastructure to minimize the traffic impact on citizens while aiming for efficient operation of ports and regional economic development. The Internet of Things-based approach is applied to adjust the impact of port operations on ship, rail, and road traffic. More than 300 sensors will be installed on roads to monitor traffic in port areas and track wear on bridges, and traffic and parking information will be provided to drivers through digital signs and mobile apps. SmartPORT energy aims to reduce energy consumption, emissions, and costs. In order to promote efficient use of resources, the focus is on innovative mobility concepts, renewable energy sources, and energy efficiency. And smartPORT logics is an important link in the global supply chain and focuses on increasing the economic efficiency of Hamburg Port. The three elements of traffic flow, infrastructure, and cargo flow are composed of ecosystems and approached in economic terms, and the Intermodal Port Traffic Center is the basis for networking traffic flows of sea transport, rail transport, and road transport. Logistics managers, carriers, brokers, etc. can choose the most efficient means of transportation for cargo, and use the latest information technology to collect, analyze, and process data to ensure transparency at all stages of the supply chain and enable early intervention in hazardous situations. SmartPORT logics includes an information and communication platform called 'SPL' that connects all stakeholders involved in the logistics chain. The purpose of this service is to distribute traffic on port-linked roads and optimize cargo flow. ‘It was developed on a cloud basis by SAP and T-Systems and consists of web and mobile applications. Ports can comprehensively grasp traffic conditions, so traffic conditions and container transportation can be adjusted through information such as expected arrival time, and drivers can obtain traffic and destination-related information through mobile smart devices. In addition to SPL, SmartPORT logics includes purpose-built applications such as Port Monitor, transPORTrail, smartSWITCH, and Port Road Management. Port Monitor is a port control room software that aggregates, processes, and displays information from various port data collection and communication systems and comprehensively manages the latest information on ship traffic at ports. TransPORTrail is an information system that links all data on railway vehicles and cargo for railway transport companies, Hamburg Port Authority, and port terminals, with the aim of optimizing train scheduling and improving rail transport efficiency. SmartSWITCH is a real-time information system that uses sensors to monitor the status of railway and track converters, effectively using railway rail infrastructure, enabling advance notification of traffic conditions and failures, and establishing good maintenance plans. Port Road Management is a traffic control system for port-linked road networks based on detectors and sensors, with intelligent traffic management LED electronic bulletin boards, contributing to dynamic traffic control and improved parking space utilization in road congestion, and reducing fuel consumption and emissions (Won & Cho, 2020).

3.2.2. Operational Aspects of Smart Port

Hamburg Port is an urban port that is difficult to expand space, and roads in urban areas frequently stagnated due to increased traffic due to the increase in port traffic. In order to solve these port issues, DIVA (Dynamic Information on Traffic Volumes in the Area of the Port) is developed to provide comprehensive information such as road traffic situation, bridge blocking time, construction site information, flood warning, and container terminal loading and unloading situation in real time. In addition, DIVA provides convenience for transportation-related workers by providing traffic conditions in nearby areas and parking space information in terminals when truck drivers access the port through the web and mobile devices. This DIVA system is evaluated as an integrated system capable of dynamic scheduling considering waterways, ship movements, ship berthing and terminal work, road and rail traffic situations and information, and is evaluated to have improved port operational efficiency by 40% (Korea Maritime Institute, 2019). Above this, port authorities identify the origin and destination of the container moving in the port through automatic radar identification and RFID, what cargo is, when is the expected delivery time, and how to load and unload the cargo. Besides, the processing time may be minimized by optimizing the route of the cargo and the processing schedule of the cargo through data mining. This information could be shared with all port entities related to cargo movement through the integrated cargo information platform.

Table 11: Digital Port Vision in Hamburg

Vision	Description
1.NAVIGATION IN REALTIME	Real-time use of port-related traffic for all port users including bridge closure, parking and important infrastructures.
2. SHORE POWER FROM RENEWABLE ENERGIES	Operation of land power supply system through renewable energy supply.
3. INTELLIGENT RAILWAY POINT	Sensors attached to the tracks provide a variety of information about train use, including intersection conditions and wear.
4. THE MOBILE ALL PURPOSE SENSOR	Mobile GPS sensor measures intelligent vehicle management and real-time information such as temperature, wind speed and direction, and air pollution in specific areas of the port.
5. SMART MAINTENANCE	Efficiency of facility maintenance process using mobile devices.
6. VIRTUAL DEPOT	Optimization of empty container operations using cloud-based systems.
7. PORT MONITOR	Various information in the port is collected and shared with stakeholders through integrated port management software.
8. E-MOBILITY IN THE PORT	Providing optimal infrastructure for electricity-based vehicle operation in ports.
9. PARKING FOR PROFESSIONALS	Providing an optimized parking space management system to avoid parking problems in non-port spaces.
10. RENEWABLE ENERGIES	Using bioenergy beyond wind and solar power.

Source: www.hamburg-port-authority.de

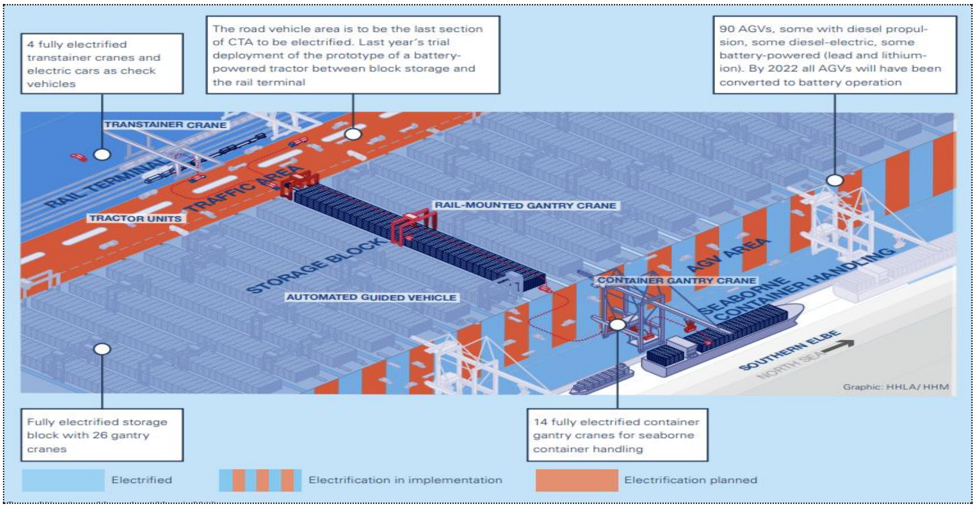
In terms of port operation, the area that the Port Authority emphasized the most was cooperative relations with various partners. The most important partner is Hamburg City, and the port is located in the middle of Hamburg City, so the city and port transportation system have been making efforts to connect because there is inbound traffic flow through the port city. Aside from these, it is building an integrated solution by forming various partnerships with technology providers for smart port development. Major IT solution providers for the corporation include Cisco, SAP, and Dutch Telekom. It is important to integrate different business processes, network links of various subjects, and various technologies that are applied exclusively between each subject in order to build networks between objects that interact with each other. It is also necessary to integrate various types of equipment, operating systems, and technical standards. To address this problem, the Port Authority and its partners have established a unified central intelligent system that can communicate with all devices connected in a common language. The Port Authority of Hamburg also focuses on open technology standards and ensure versatility so that we can continuously add new modules that can be integrated into existing systems through the platform.

Hapag-Lloyd will equip a real-time tracking device on the entire container fleet. After successfully introducing real-time monitoring of frozen container fleets with the IoT product Hapag-Lloyd LIVE in 2019, the shipping company will begin installing newly developed devices in all standard containers of 3 million TEU fleets. Hapag-Lloyd will continue to digitize container transport, while Hapag-Lloyd LIVE will be available to standard container customers through 2023. It is expected that this will provide real-time tracking data to all customers, providing full visibility into all container movements around the world. It can also detect delays early, automatically notify affected customers, and provide countermeasures in the early stages. Maximilian Rothkopf, COO of Hapag-Lloyd, noted that a real-time tracking approach would not only benefit customers but also change the landscape of the entire container transport industry. Devices can transmit data in real time from each container, making the supply chain more transparent and efficient. It can also provide location data based on GPS, measure temperature, and monitor sudden impacts on containers. Shipping container monitoring devices incorporate state-of-the-art energy harvesting technologies and low power consumption technologies to ensure a very long life with high-frequency data transmission (Hamburg Port Authority, ITS projects 2022).

3.2.3. Environmental Aspects of Smart Port

The Hamburg Port Authority started the Smooth Ports project in 2019 to cope with the growing environmental problems. This began with an emphasis on identifying measures and methods to reduce CO2 emissions at ports and is trying to find ways to shape them. To this end, it is seeking specific cooperation measures with nearby ports as well as cooperation with local government ministries. For example, customs procedures can be integrated at border checkpoints to reduce congestion and congestion of cargo trucks by reducing customs procedures when entering and exiting ports can be reduced. In addition, pollutants discharged during berthing by ships are a major source of pollution in ports, and efforts are being made to supply and use land power supplies to prevent this. Vessels on shore for unloading cargo emit nitrogen, sulfur oxides, fine particles, and CO2 because they have to generate their own power using diesel generators. This can dramatically reduce environmental pollutant emissions by utilizing land power produced from renewable energy such as wind and solar power, and ports around the world are rushing to supply land power. Hamburg Port will also be the first port in Europe to supply land power to cruise ships and large container ships from 2023, after applying the facility to cruise facilities for the first time in 2016. Through this, it is expected that EU regulations to reduce CO2 emissions by 55% will be achieved earlier. With this effort, HHLA, an automated container terminal in the Hamburg port, became the world's first CO2 neutral-certified terminal (Hamburg Port Authority, Current issues 2022). To this end, more than 90% of the automated guided vehicles (AGVs) operating in the terminal are converted from diesel to electricity-based equipment, and 14 gantry cranes for marine cargo handling, 52 portal cranes in container storage areas, and 4 rail cranes are also operated with eco-friendly electricity. Through this, CO2 emitted over 21 years was about 11,000 tons, which was 26% lower than the previous year. By 2023, all unloading equipment in the port will be converted to power-based equipment.

Figure 5: Electrification of HHLA's Container Terminal Altenwerderin Hamburg



Source: www.hafen-hamburg.de

Another strength of the port of Hamburg lies in rail transport. More than 50% of inland freight transport depends on rail transport, and rail transport is known to emit 25% of CO2 emitted by cargo trucks per Km. Rail transport is called Greenlogistics, and TX Logistics in Germany aims to provide complete eco-friendly logistics services by utilizing 100% of hydro, wind, and solar power for rail transport. The railway subsidiary of HHLA, the terminal operator, is also rushing to switch to eco-friendly electricity. Accordingly, it is possible to accelerate the realization of carbon neutrality by actively utilizing existing railways. For this, a digital platform called Railmybox has been developed to utilize cargo trucks in short distances and provide a service that allows users to easily find the best railway transportation route from a user's point of view. Accordingly, companies such as shipping companies, logistics providers, and forwarders are showing a lot of interest and cooperating in creating a sustainable transportation system.

Hamburg Port has converted loading and unloading equipment in ports into electricity-based automated equipment, and is also making concrete efforts to power cargo trucks in ports without pollution. To achieve this, it aims to renovate a total of 500 existing vehicles by 2024 in collaboration with Clean Logistics, which converts existing diesel-based cargo trucks into hydrogen-based electric trucks. In particular, in the case of container transport trucks, the conversion of hydrogen trucks is being promoted, focusing on the limited utilization of electric trucks due to the size. Infrastructure for hydrogen charging in ports is under construction, and the German government also aims to achieve neutral CO2 emissions in ports as soon as possible by deciding to subsidize the conversion of eco-friendly vehicles.

The Hamburg Port Authority's efforts to create eco-friendly ports can also be seen in attempts to establish a network that can exchange continuous knowledge with the private sector and promote sustainable marine technology development. The Sustainable Shipping Technologies Forum, which began in 2019, began as a partnership between Graz University and Port Corporation, and has now developed into an international eco-friendly transportation network with 600 people from 25 countries participating to share new research results and discuss next goals (Port of Hamburg, Green ports forum 2022).

3.2.4. Energy Aspects of Smart Port

Due to the geographical nature of the port of Hamburg being the closest port to the city, there has long been pressure from the community on the expansion of the port size and the emission of pollutants. These restrictions have driven the Port of Hamburg to build a port based on carbon dioxide neutrality and renewable energy. First of all, it is trying to supply electricity through solar power and wind power by making the most of the idle land in the port. Large and powerful wind power generators are installed in the port to directly supply electricity to tenant companies and freight carriers. Using this renewable energy power, CO2 emissions in ports are drastically reduced by supplying electricity to cruise ships and container ships through land power supplies. The goal is to double the dependence on renewable energy from now on, and to this end, Hamburg City is subsidizing the use of renewable energy such as wind power. More fundamentally, it has already formed a political framework for the Nordic hydrogen supply strategy in 2019, and plans have been made to build a self-sufficient hydrogen cluster around the port of Hamburg and adjacent areas by 2035 (Port of Hamburg, Launch of innovation cluster 2022). This is called the Hamburg Hydrogen Industry Network, which aims to supply the necessary hydrogen to the port and aviation industries. To this end, it receives 30% public funding from the EU's IPCEI (Important Projects of Common European Interest), and is pushing for a plan to build a "European Hydrogen Hub" that can meet demand from its own countries and European countries and export hydrogen with 700,000 euros from the German federal government. As a result, the transition to a hydrogen-based port is being promoted by utilizing a total budget of EUR 2 billion. Besides, a strategic energy partnership between the United Arab Emirates (UAE) and Germany is being signed to import hydrogen and hydrogen derivatives and to establish itself as a hub port for hydrogen distribution and transportation by utilizing a vast European network such as railway connections and complex land transportation routes.

In the transitional phase for the renewable and hydrogen-based energy, MSC, a major logistics carrier, continues to improve vehicle efficiency through the development of energy-saving solutions suitable for their vehicles, air lubrication technology, and data-based control systems to reduce the amount of CO2 per container transported. Moreover, it is taking the lead in reducing CO2 by using biofuels away from the existing diesel-based vehicle operation, and recently, efforts for carbon neutrality have been made by introducing liquefied natural gas (LNG)-based cargo vehicles. In line with this, Hapag-Lloyd is preparing to use biofuels instead of heavy oil with more than 18,000 TEU of container ship fuel. Not only can carbon dioxide emissions be reduced by converting large ships' fuels into eco-friendly fuels as well as land, but also efforts are being made to protect the environment at other levels by commercializing technologies for extracting biofuels from waste food oil or food waste. It is expected that this will reduce annual CO2 emissions of 14,000 tons (Port of Hamburg, World Premiere 2019).

Maersk, a Hamburg-based shipping company, has already ordered thirteen e-methanol-operable ships from Feeder Vessel, which will be in service from 2023, and twelve 16,000 TEU-class ships to be in service from 2024. To this end, it is planning to build a facility in the port that can produce 730,000 tons of e-methanol per year. e-methanol is considered the fastest and most feasible alternative to EcoDelivery fuel. The energy required for production, such as electrolysis, is derived from solar and wind power (Port of Hamburg, the world's first carbon neutral liner vessel by 2023 2021).

3.2.5. Safety and Security Aspects of Smart Port

The Hamburg Port Authority uses drones to easily manage large port areas and prepare for future unmanned ports (Port of Hamburg, Its projects 2022). The Portwings project, one of the Hamburg ITS (Intelligent Transport System) projects, collects information such as sensors installed in port facilities from the central control tower and checks the operation status of ports in real time using unmanned drones (UAV, ASV, and UUV) in the sky, sea, and seabed. Through this, natural disasters and port accidents can be identified and prepared in a short time, as well as preemptively responding to the maintenance of port facilities. Hamburg Port Authority can utilize this advanced drone equipment to prevent and respond to unexpected terrorist attacks and expand the scope of surveillance in maritime areas. High-resolution images using unmanned drones can be transmitted in real time even in situations such as storms, tsunamis, and ship accidents, increasing the efficiency of port operations even in situations that require quick response. It is also expected that the maintenance cost of port operations can be drastically reduced by enabling intelligent infrastructure management such as regular maintenance and maintenance, facility structure inspection, and predictive maintenance in combination with the Internet of Things. In addition, Hamburg Port Corporation is responsible for maritime traffic safety by operating an unmanned water vehicle Echo 1, which can collect water channel data and record weather conditions in real time in the port area. This equipment is small at 1.65 meters and equipped with high-performance navigation and measurement functions, and can be operated in the range of up to 10 kilometers at the same time as satellite positioning systems and collision avoidance radars, making the entire port an active area. Through this, it is possible to have a monitoring system developed in terms of port safety and security.

Table 12: Smart Port Components in Hamburg

Title	Domain	Description
Landstrom	Environment	▫ Full distribution of land power systems to reduce ship emissions

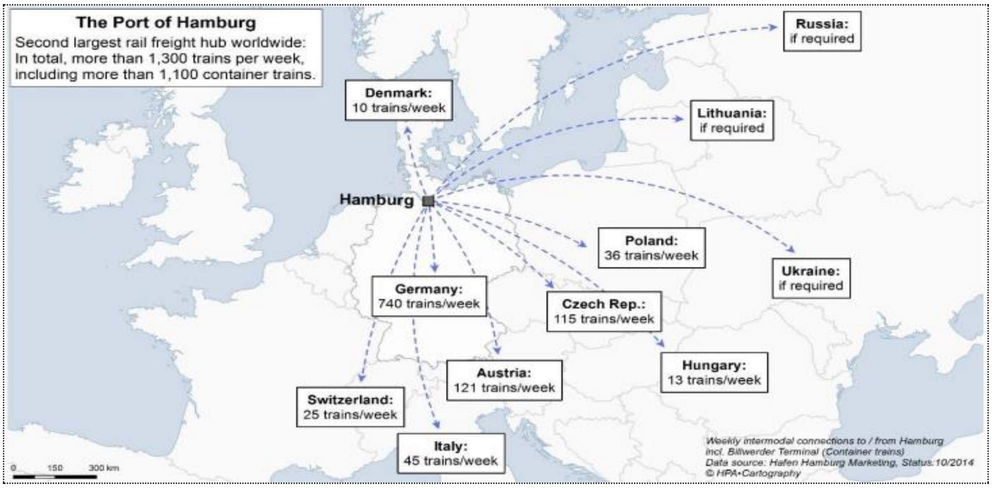
ITS Projects	Operation, Environment, Energy, Safety	▫ Mozart – Traffic signal control system using quantum-based optimization ▫ PORTWINGS – Intelligent disaster and port infrastructure management using drones and mobile sensors ▫ GREEN4TRANSPORT – Traffic flow control system using IoT ▫ Echo1 – Unmanned water vehicles for waterway data collection
Chain Port	Operation	▫ Inter-Country partnership between the world's best Ports – 15 ports including Los Angeles, Montreal, Busan, Shanghai, Singapore
Home Port	Environment, Energy, Safety	▫ Providing test-bed to experiment with future technologies in ports for start-ups and researchers
SANTANA	Operation	▫ Building test fields to connect public transport infrastructure and private logistics networks to digital networks

Source: hamburg-port-authority.de

3.2.5. Implications

The focus of Germany's Hamburg Port on developing smart ports is on harmony with nearby cities. In the meantime, the port has been emitting a lot of pollutants from ships entering and leaving the port, equipment working in the port, and trucks coming and going for inland transportation have caused traffic congestion, parking problems, and safety problems in nearby areas. Accordingly, while inducing the reduction of emissions through the electrification of loading and unloading equipment in the port, an intelligent traffic control system was developed to reduce vehicle congestion and make the most of the environmental resources. Therefore, efforts to improve in-port logistics can be seen in many sectors, and even now, as in Mozart and GREEN4TRANSPORT, we are continuing to invest heavily in traffic flow control, including in-port vessel entry and exit. It is also impressive that they tried to advance smartization by utilizing a wide range of railway networks, one of their strengths. Rail transport certainly has advantages in logistics flow, given the reduction of CO_2 and the reduction of traffic congestion in neighboring cities, and the lack of delay and low-cost, high-efficiency transportation. By clearly recognizing these strengths and developing rail transportation as a key means in smart port development plans, it was possible to have a clear comparative advantage in the process of smart port development over other ports.

Figure 6: Railway connection in Hamburg



Source: www.hafen-hamburg.de

Another characteristic of Hamburg ports is that they are leading the standardization of smart ports. To this end, cooperative relations with other ports have been emphasized since the early days, and according to the Chainport strategy, 15 ports joined by the current Smart Port Alliance were formed. Based on this, it is making the most of its advantages as an advanced smart port by leading data standardization and spreading its know-how. Hamburg Port seeks to solidify its leadership as a port that preoccupies standardized platforms in the future can monopolize all advantages such as sharing and spreading data and recreation of added value. To this end, it is playing a role in increasing the participation of global business leaders and scholars in the annual innovation forum at Hamburg Port and revitalizing business forums such as the SMM International Maritime Trade Fair to present the spread, spread, and continuous development direction of smart ports. The 2022 SMM, which recently closed, held in-depth discussions on carbon neutrality and technologies for energy conversion, and was well received by proposing a dedicated platform to spread networking and know-how. As such, advanced smart ports are drawing a big picture to break away from technological automation, cost reduction, and to prepare for future energy conversion, and to solidify their status as a standardized and leading port of smart ports.

3.3. Port of Busan (S.Korea)

3.3.1. Background and Status of Smart Port Introduction

Apart from the perception that the initial investment cost of automation terminal construction is expensive, the perception that the low terminal operation cost due to automation operation will bring back investment costs and profits in the future is spreading. As a result, in addition to European ports interested in automated ports early on based on high labor costs and limitations of regional expansion, Asian ports such as China and Singapore have also scrambled to build automated ports and even smart ports, and Korean ports are no exception. However, in the case of Korean container terminals, only Busan New Port remains at the level of semi-automation with automatic cranes applied in some yard work. In terms of automation, automatic transportation using the inner wall crane and unmanned AGV, which are the core of complete unmanned management, is impossible, so there is a disadvantage in terms of operating costs. In addition, in terms of the environment, it is fundamentally difficult to reduce pollutants by operating yard trucks that use diesel when transporting containers. In productivity, 30 move/hr per inner wall crane is only 65% compared to the targets of China (Cheongdo, Yangsan Port Stage 4) and Europe (RWG) (Korea Maritime Institute, 2017).

Accordingly, the Korean government added ICT-based high productivity, unmanned automation, and eco-friendly smart port construction plan to the 3rd National Port Basic Plan (2016-2025) and planned to develop next-generation smart port construction technology to lead the trend of smart port. In order to implement this in detail, the Ministry of oceans and Fisheries and Korea Marine Institute began to develop technologies to establish a completely unmanned automated unloading system. The direction of this system is beyond the unmanned automation terminal, and a pilot project for the development of concepts and the production of dynamic reduction models has been completed. In order to actually test this, it is scheduled to be operated on two berths after 2025 in line with the construction plan of the port for the pilot terminal.

In 2019, the Korean government jointly diagnosed the current status and problems of Korea, including the Ministry of oceans and Fisheries, the Ministry of Land, Infrastructure and Transport, and the Ministry of Science and ICT, drew detailed strategies and tasks to build smart marine logistics. As a follow-up measure, the Ministry of oceans and Fisheries has formed a smart maritime logistics promotion team to systematically implement the "Smart Maritime Logistics System" focusing on smart logistics infrastructure and linkage efficiency. In 2020, it was embodied as a "plan to smartize import and export logistics" and announced joint measures by related ministries. Here, strengthening the linkage of import and export logistics infrastructure, smartizing data-based logistics, training smart logistics personnel and creating a global digital-led logistics environment were developed as major tasks and detailed goals were set. In December 2020, the existing smart port development plan and various measures were included in the 4th ('21~'30) National Port Basic Plan, which is a binding long-term plan, so that preparatory work can be completed by 2030 and the operation of smart ports can begin in earnest. In April 2021, the "Smart Shipping Logistics Spread Strategy" was once again announced to solidify the development strategy into a smart port. This plan added several new technology development plans to the existing plan, considered the introduction of technologies related to safety accidents, and specified a clear schedule.

In terms of the level of development of smart ports, Korea's ports are evaluated to be half as smart as the world's best smart ports (Korea Maritime Institute, 2017). Most of the unloading process, except for the wired crane in the new port of Busan, is carried out by direct human intervention. In terms of environment and energy, unlike ports that are leading in pursuing zero CO2 policies by applying new technologies, Busan ports are still operating fossil fuel-based equipment, and the sharing of information in ports and the use of artificial intelligence are far behind. This is because Busan Port is handling more cargo than scheduled, so it is difficult to stop operating the docks and install new facilities, and there are some facts that it has weak domestic smart port-based technology, that it is not clear who is driving smart port technology development and officials, and finally, that there is high level of conflict in labor union due to the introduction of automation (KIMST, 2021). Therefore, in the following, I will review the development of smart ports, focusing on the factors currently planned and promoted by Busan Port.

3.3.2. Operational Aspects of Smart Port

The Busan Port Authority plans to transform the container port in Busan Port, which is currently at the semi-automated level, into an automated port by 2030 when the new port is opened. To this end, the automated port is divided into four stages: a berth area, a transport area, a device field area, and an entry area, and a demonstration project for the introduction of technology is carried out. First of all, it plans to introduce nine unmanned remote-controlled dual trolley container cranes for inner wall cargo work and 46 fully automated transfer cranes for yard cargo work by 2023 in the new west container terminal stage 2-5. It set the goal of strengthening industrial competitiveness and becoming a leading country in smart port technology by leading the localization of loading and unloading equipment in cooperation with domestic manufacturers. In the transportation area, a project to develop an autonomous cooperative driving-based container terminal transport equipment and an automatic transshipment cargo transport system is underway. Additionally, the introduction of port circulation rails is being considered to prevent time delays and congestion due to transshipment cargo and empty containers between terminals. Through the realization of such technology, the company plans to minimize transshipment costs and time required to simplify the work system between terminals and improve it to a low-cost structure to maintain its competitiveness as a transshipment port. In the field of equipment, a total of 46 fully automated equipment will be produced and the existing operating system that is remotely controlled by humans will be improved to a system that automatically operates the equipment to dramatically improve terminal operation efficiency. In the entry and exit area, the existing method, which was used through visual inspection after the existing stop, is introduced to establish a system that recognizes vehicles and information as text and enters and exits without stopping. In order to achieve this goal, a vehicle carrying-out reservation system was introduced in June 2020 and expanded to establish a port logistics integration platform (chain portal). The chain portal is a port communication system consisting of a vehicle booking system, a transshipment shuttle system, and an integrated information inquiry system, which is based on blockchain technology, enabling high data reliability and real-time monitoring of unloading sites. The chain portal provides nine services:

port truck reservation system, transshipment transportation system, integrated information inquiry, big data service, port background complex system, disaster safety system, communication cooperation service, port administration support system, and Busan port statistics and any port user can access online and view and utilize necessary information in real time (Busan Port Authority, Chain portal 2020). The Busan Port Authority is also working on a project to build a digital twin platform to optimize operations and improve efficiency by integrating shipping, port, and logistics information. This technology combines various sensor-based smart logistics technologies to realize the same things and environment in virtual space, and 3D remodeling technologies for incoming and outgoing ships, port facilities, and logistics systems behind virtual space. It is a virtual platform that allows port stakeholders to share ships, terminals, logistics, terrain, and environment information in order to receiving optimal routes and exact operating hours through real-time geographic, ship-specific route analysis, port operation information, and monitoring of loading equipment. Moreover, logistics flow can be facilitated by calculating transportation route optimization information using cargo departure, arrival time, and urban traffic information through the linkage of ship and port operation information.

In order for the Busan Port Authority to develop into a leading smart port, the R&D field of related industries is the field of competency. To this end, "1876 Busan," a start-up support platform related to shipping and ports, is being established and fostered as a start-up base for win-win cooperation. It is investing to establish a virtuous cycle of technology development and introduction by providing space and funds for tenant companies and providing technology consulting and test beds (Busan Port Authority, Sustainable Management Report 2021).

Furthermore, a smart joint logistics center will be established at the rear site adjacent to the port to create an industrial ecosystem and create a high-value-added logistics center to create a high value-added logistics center. The smart joint logistics center combines advanced 4th industrial technologies such as robots, IoT, big data, and AI to increase the level of automation in the cargo warehousing and storage sectors and introduce an efficient operating system that can manage real-time inventory and predict cargo demand. In addition, various companies can jointly install and manage labor, transportation means, storage facilities and operating systems necessary for logistics activities to achieve maximum effect at the minimum cost. Through this, it is expected that logistics smartization will be possible to actively respond to environmental changes such as COVID-19, expansion of global e-commerce, and changes in logistics demand due to increased non-face-to-face transactions.

3.3.3. Environmental Aspects of Smart Port

The Busan Port Authority established an environmental conservation system for sustainable growth of Busan Port in accordance with strengthening environmental regulations domestically and abroad. First of all, by analyzing the main sources of pollution emission from ports, it was found that ultrafine dust and greenhouse gases from the use of oil by ships accounted for 93% and 59%, respectively. In the case of dock unloading equipment, one-third of the 1,400 equipment uses diesel, causing 6% of the total ultrafine dust and 39% of the total greenhouse gas generation, and resulting in port vehicles accounting for 1% of ultrafine dust and 2% of greenhouse gas. Accordingly, in order to solve serious environmental problems, a goal of reducing ultrafine dust by 70% by 2030 was set, and a challenging goal of realizing carbon neutrality in Busan Port by 2050 (Busan Port Authority, Sustainable Management Report 2021). To implement this, in the short term, the ship's designation of low-sulfur oil use zone (ECA), the emission reduction zone (VSR) incentive system through low-speed operation, and eight land power supply facilities (AMPs) were expanded to three new ports and quays 4 and vessels using these are encouraged to actively participate by exempting entry and exit fees, anchorage fees, and berthing fees. In addition, an eco-friendly LNG fuel-based yard tractor (Y/T) distribution project is implemented in the transitional phase for the construction of an unmanned smart port, and the Straddle Carrier (S/C) is converted to LNG-hybrid fuel-based equipment on the same line, and a pilot project is being implementing to install Diesael Pariculate Filter (DPF) for transfer cranes. Through this, LNG yard tractors are expected to achieve 100% reduction in ultrafine dust, 99% reduction in LNG-hybrid straddle carriers, and 80% reduction in transfer cranes. Further, 94% of business vehicles in the port have been replaced with eco-friendly vehicles such as electric and hydrogen cars, and the lighting tower in the port has been replaced with LEDs, which is expected to achieve an annual CO2 reduction of 1,500 tons. Port guidance ships are also replacing existing fossil fuel-based guidance ships with electric propulsion ships, minimizing the generation of air pollutants and contributing to the creation of business opportunities such as the spread of eco-friendly ship technology. Above this, it is striving to build an eco-friendly greenford by using 5.2 billion won to purchase eco-friendly certified products recommended by the government (Busan Port Authority, Sustainable Management Report 2021).

3.3.4. Energy Aspects of Smart Port

Busan Port's new and renewable energy self-reliance plan is connected to the carbon neutrality realization plan in 2050. To achieve this, the installation of solar power generation facilities is jointly promoted with Korea Southern Power Co., an electricity company, by utilizing warehouse facilities in the rear complex of Busan Port, and aims to complete a total of 300MW of solar power facilities. The 30MW is the amount of electricity that about 12,700 households in Busan can use annually, and it has an advantage in terms of efficiency in electricity production by utilizing the roof of a logistics warehouse. It is also promoting a project to discover eco-friendly new and renewable energy by utilizing the infrastructure of Busan Port. Through the seawater intake pipe, the terminal cooling and heating system was improved to eco-friendly facilities using seawater heat and has been in trial operation since 2020. This will gradually expand its application to a self-reliant energy system that can reduce greenhouse gases by 46% compared to existing fossil energy-dependent heating systems, reduce heating costs by 53% and energy consumption by 48% (Busan Port Authority, Sustainable Management Report 2021).

Challenges are also being attempted to commercialize the latest R&D technologies. The Busan Port Authority is promoting a project to develop and demonstrate a smart piezoelectric power generation system for port gates. It is a technology that converts and stores pressure and vibration energy generated by the weight of cars and cargo when container trucks enter and exit the terminal gate of the port, and provides a test space in the northern port to commercialize it.

In addition, in order to create a long-term hydrogen-based ecosystem, it will play a key role in building a hydrogen ecosystem in connection with the government's hydrogen economy policy. In order to meet the early conversion policy of hydrogen public transportation and respond to future hydrogen-based ships, Busan Ports Authority is investing in building hydrogen infrastructure in ports and working with SK E&C to build liquefied hydrogen supply and port hydrogen complex stations (Busan Port Authority, Sustainable Management Report 2021).

3.3.5. Safety and Security Aspects of Smart Port

The Busan Port Authority selects the task of "achieving ZERO in serious accidents by establishing a safety management system" and actively uses port safety R&D technology as a technology basis to achieve it (Busan Port Authority, Sustainable Management Report 2021). First of all, Busan Port Authority is piloting a new technology to prevent collisions that may occur during the unloading process by utilizing the four-channel camera technology introduced in reach stackers, a major unloading equipment. This can be integrated into the base technology of unmanned automation vehicle technology in the future and is expected to reduce the possibility of actual accidents in the transitional stage. It is also experimenting with the possibility of commercialization by using intelligent CCTV and lidar sensors to film corner casting adjacent to upper and lower containers and automatically classifying and informing normal, dangerous, and very dangerous alignment by applying artificial intelligence learning techniques such as deep learning. Busan Port terminal operators stack and store container cargo in multiple stores in the yard, and if the alignment between the upper and lower containers is inaccurate, there has been a possibility of safety accidents such as collapse due to gusts. If the technology is used as a countermeasure against this, it is expected that the accident can be prevented in advance by immediately identifying and responding quickly if there is anything wrong with the loading and alignment. This technology can be attached to regular operating vehicles such as yard tractors or port patrol cars, which are transport equipment in ports, to establish a real-time monitoring system. For the safety management of frequent construction sites in the port, port authority is trying to monitor and control instability and hazards by "introducing a smart safety management system" and fundamentally prevent safety accidents. The smart safety management system consists of smart safety equipment and safety education management integrated system such as smart safety wearable equipment worn by workers, construction equipment access warning system, and mobile/intelligent CCTV. Through this, it is expected that active and high-tech safety management will be possible. As an example of safety wearables, smart safety vests were provided to workers in the port, and when abnormalities such as self-tilting of workers are detected, the built-in airbag expands automatically and wraps around the worker's neck and upper body to mitigate impact and minimize damage. Workers can wear it on top of the work suit, and the acceleration detection sensor and airbag are built in to minimize damage in case of an accident. In the long run, a plan was established to integrate these individual new technologies into a smart port safety platform to eliminate potential accident factors and establish a system capable of supporting real-time on-site response (Ministry of Oceans and fisheries, 21 Smart Shipping Logistics Spread Strategy 2021). Through self-driving droids (sensing equipment) and artificial intelligence analysis technologies, new technologies are applied to enable pre-detection of disaster risks such as leakage of dangerous substances and fire and maintenance of digital twin-based port facilities are also being integrated to increase management efficiency.

Regarding port security, the 3S security hub platform was established (Port of Busan, Development of 3S security hub platform 2022). The main functions of this platform are intelligent CCTV, IoT communication equipment, and sensors to prevent security and safety accidents in ports, such as detecting abnormal behavior in ports, monitoring real-time shaded areas, controlling access to security zones, and ensuring data reliability. The platform with the latest technology has significantly improved monitoring accuracy by increasing port area monitoring accuracy, collecting and analyzing data, and improving the location tracking error range by 1/10.

Chapter 4. Conclusion

4.1. Results of Research

The effect of the establishment of smart ports on strengthening port competitiveness could be examined in various aspects. First of all, the advantages of automation and unmanned port operations are clear in terms of efficiency. In particular, from the perspective of handling standardized cargo such as container terminals, direct cost reduction can be expected due to an increase in hourly throughput due to automation and a decrease in employment manpower. In addition, visualization of port operations using the Internet of Things and systematization of unloading equipment according to A.I. can increase predictability and prevent port congestion in advance. The results of this automation showed tangible results such as reducing operating costs and strengthening operational efficiency, as in the cases of Rotterdam and Hamburg ports, which have pursued port automation earlier. Unlike Europe, which began as a countermeasure against high labor costs, despite low labor costs, Chinese ports are also making great efforts to fully unmanned automation of ports. Qingdao Port (QQCTN) predicted that this would reduce labor costs by 85% compared to existing ports and improve port operation efficiency by more than 30% (Korea Maritime Institute, 2017). Now, there seems to be no disagreement over the benefits of cost reduction and operational efficiency due to automation.

In terms of environment, it is closely related to internal and external environmental changes, and smart ports are attracting attention. Amid tightening global environmental regulations, the European Union has made its carbon-neutral goal a fait accompli by 2050. The port area is no exception, and continuous prosperity is impossible without the reduction of emissions, the realization of carbon neutrality, and the presentation of development directions based on the support of the local community. In the case of Hamburg Port, to first solve problems such as traffic congestion, civil safety threats, and discharge of pollutants in the port, Port Authority introduced a technology to control traffic flow, and tried to establish an uninterrupted process throughout the unloading operation using the Internet of Things. It tried to solve the existing problems by using the core technologies of the 4th Industrial Revolution, including securing parking spaces for trucks, establishing a pre-booking system to avoid congestion time concentration, and providing information that anyone can easily grasp the flow in the port. In addition, it is intended to reduce emissions and achieve CO2 neutrality early through the electrification and unmanned operation of unloading equipment in ports. In order to escape the dangerous and dirty image of the existing ports, water-friendly facilities in the ports have been expanded and actively opened, receiving much support from citizens. In the consideration of the environment, the smartization of ports is receiving wider support from port officials and civil society. In energy utilization, the smartization of ports is recognized as an opportunity for ports to create more added value and preoccupy the core location of future logistics functions. To this end, Rotterdam Port aims to establish a long-term roadmap for its function as a hydrogen hub and become an axis in charge of hydrogen production and distribution by utilizing nearby industrial complexes. It is converting the power sources of unloading equipment and ships that relied on existing fossil fuels into eco-friendly energy such as solar power, wind power, and tidal power. It is attempting to further expand the area of the port by introducing ships and trailers using hydrogen, which is the future energy. In the future, ports that preoccupy these locations can enjoy more opportunities for value-added creation and benefits as portals where cargo and people are concentrated. In practice, the changing status of ports lies in this long-term vision. If the previous port served only as a conduit for transporting cargo, the future smart port is a place where not only the flow of cargo but also the information added thereto is concentrated, and the energy to support it is supplied. The role of ports will expand functionally and physically. The technology foundation to enable this development is the value pursued by smart ports.

In terms of port safety and security, new smart port technologies have already been commercialized in several areas and are recognized for their utility. Intelligent CCTV, drones, and maritime unmanned ships allowed the control room to monitor and manage the overall appearance of the port. Existing ports had many restrictions on management by manpower alone due to their size and complexity. However, Hamburg Port is responding to unexpected accidents by checking the port's blind spots and overall safety through regular drone patrols. Unmanned ships continuously monitor changes in current and the situation of sediment under the surface, and calculate the period for ship navigation, safety accident prevention, and optimal dredging. Safety and security issues can directly reduce the loss of port closure due to accidents, and the value of safe and reliable ports in the long run is a very important factor in the shipper's choice of ports. In addition, Rotterdam and Hamburg ports are actively striving to introduce innovative technologies and spread knowledge. Rotterdam Port directly attracts startups and bancher companies in the port to provide a research space and a test bad for actual application. It is also promoting practical commercialization opportunities by strengthening collaborative relationships with universities and existing business leaders in the region. In the case of Hamburg Port, a large-scale conference is held every year to discover and share knowledge, and intellectuals and related companies from around the world are invited to try to spread knowledge. These efforts provided an opportunity for the physical space of a port to be transformed into an innovative space in an effort to maintain the initiative in the development and application of technology in the 4th Industrial Revolution. The relationship between smart ports and port competitiveness, development background, and detailed projects by port are compared between the three ports as follows.

Table 13: Port-to-port Comparison

Category	Harbors		
	Rotterdam	**Hamburg**	**Busan**
Background	- Increase in cargo volume - Space constraints/High labor costs - response to environmental regulations	- Intensifying competition among nearby ports - Low efficiency / High operating costs - Friction with the community over developments	- Competitive pressures in neighboring ports - Government-led development strategy for associated industries
Operations	- Full Automation/unmanned loading and unloading process - PortXchange (Portal) - Routescanner (Door-to-door service) - Boxinsider (Real-time Container trace) -Digital dolphin -PortXL (Knowledge Incubator)	- Full Automation/unmanned loading and unloading process - DIVA (Portal) - TransPORTrail (connection with railway) - Port monitor (control tower) - smartSWITCH (Rail flow control)	Less Automation/manned loading and unloading process - Chain Portal: Transshipment shuttle, Vehicle booking, Integrated information - Digital Twin platform - 1876 Busan (innovation incubator)
Environment	- Electrical Power of unloading equipment	- Smooth Ports Projects (logistics optimization)	- Alternative maritime power (incentive

	- Alternative maritime power - E-nose (Pollutant-detection) - eco-friendly building	- Alternative maritime power - Hydrogen-based freight truck	system) - Reduction of emissions through low-speed operation of ship - Diesel particulate filter
Energy	- 90% reductio in CO2 by 2030 / Carbon neutrality by 2050 - Cluster Energy Strategy (Conversion of hydrogen society)	- Renewable energy (solar / wind) - Hydrogen cluster / Hub strategy - Bio-fuel / e-Methanol for ships	- 70% reductio in CO2 by 2030 / Carbon neutrality by 2050 - Solar power generation using a warehouse roof - Development of Hydrogen Infra
Safety & Security	- MOBI Platform (Port Security portal) - UTM / U-Space (Drone Surveillance)	- Portswings (Drone surveillance) - Echo 1 (Unmanned water vehicle) -GREEN4TRANSPORT (Traffic flow control)	- Smart Port safety platform (detecting / responding with drone) - Container alignment system

Resource: Each port official website

The direction pursued by advanced smart ports is clear. Beyond simple automation and reduction of operating expenses, domestic ports are leading innovation competition to preoccupy key positions in the logistics ecosystem. In the 4th Industrial Revolution, efforts were made to change the port by applying key technologies, and accordingly, the port became a competition venue for high-tech technologies. Each country provides a test bed for demonstrating new technologies by opening facilities and infrastructure in ports. It provides incentives and supplies all necessary resources to attract companies and educational institutions with practical technologies and innovative ideas. Through this, competition for the generation and spread of knowledge is taking place, and the ranking battle to take the lead in leading technology development is fierce. At the same time, the area of the port is physically expanding. In the future, the port will be at the center of international logistics, also a power plant for renewable energy, and a hub for clean fuels such as hydrogen. Through this, each country dreams of a logistics hub that connects resources within the country and promotes exchanges between countries. This is because the winner of the final competition can solidify its status as a logistics portal in the region and monopolize the added value derived from it.

4.2. Policy Implications

The purpose of this study is to examine the cases of Rotterdam Port and Hamburg Port, which are leading the technological development and standardization of smart ports in the world, and to derive meaningful implications for Korea's smart port development strategy. Therefore, the main implications derived from the previous analysis are summarized as follows.

First of all, in terms of the long-term roadmap for smart ports, the development strategy announced by the Korean government still remains at a narrow range of port automation levels.

Table 14: Comparison of Smart Port development Plans in Korea

Strategies for Establishing a Smart Marine Logistics System (2019)	**Strategies on the Smartening of Import and Export Logistics (2020)**	**Diffusion Strategy of Smart shipping logistics (2021)**
1. Establishment of Smart Marine Logistics infrastructure 2. Support related industries and create jobs 3. Demonstration project and site demonstration	1. Strengthening the linkage of import and export logistics infrastructure 2. Smart logistics based on Data 3. Smart logistics personnel and businesses development 4. Leading the international digital logistics Environment	1. Development and diffusion of smart logistics technology 2. Securing Digital-Based shipping Logistics Safety 3. Revitalizing the shipping and logistics data Economy 4. Training of professional personnel and promoting public-private cooperation

According to the plan to establish a joint smart maritime logistics system by government ministries announced every year since 19, smart ports are recognized as a sub-concept of smart logistics systems. Therefore, smart ports, smart ships, and smart maritime communication are divided into sub-elements constituting smart maritime logistics facilities, and combined with the logistics information system to complete the smart maritime logistics system (Ministry of Oceans and fisheries, Smart Maritime Logistics System Establishment Strategy 2019). From this point of view, the scope of smart ports is limited, and it aims to be a smart port in a narrow sense that focuses on automation and efficient processing of unloading equipment. This is in contrast to the fact that advanced ports have not only linked maritime logistics and land logistics but also developed the possibility of smart ports that integrate information and create new added value from the physical portal of ports. In the case of Rotterdam ports, limitations in port handling capacity and high labor costs were the driving force of port automation, but after automation, the possibility of ports that can play a key role in logistics functions has been noted. Accordingly, the scope of automation has been expanded not only to urban areas linked to ports, but also to the role of overseeing maritime logistics and land logistics based on information and services provided by ports. Therefore, it is necessary to break away from the concept of smart ports to improve efficiency to reduce operating costs, define them as smart ports in a broad sense, and establish development plans.

In terms of operation, advanced ports are making efforts to link components, standardize data, and network beyond the spatial domain of ports. Through this, it is pushing to create new business opportunities beyond innovation in the port itself and to make the space of the port a key portal in the logistics chain. However, in the process of creating such a cooperative relationship, the role of stakeholders, including private companies as well as port management authorities, has been more emphasized. In the case of Rotterdam Port, major shipping companies Musk and CMA-CGM are deeply involved in the Port Call Optimization (PCO) project, which will be the basis for autonomous ships in the future, leading the standardization of information exchange. In the case of Hamburg Port, global IT companies such as Cisco, SAP, and Deutsche Telekom are participating as partners to introduce IoT technology. Korean Government is still sticking to the government-led development strategy, and the role of each port authority is insufficient. Instead of carrying out a top-down development plan with a smart maritime logistics promotion team within the government, each port authorities and private companies that have the closest interests in smart ports should form a consortium and present bold incentive conditions to pursue a virtuous cycle of field opinions and private technologies. In the same vein, for the successful settlement of innovative incubators such as "1876Busan", it is necessary to consider R&D fund execution measures that have undergone necessary or autonomous competition in the field, not rigid R&D methods. The advanced ports discussed earlier are making great efforts in terms of port sustainability, that is, environmental aspects. This is due to global environmental regulations, but it is also based on the practical aspect that the port space has caused environmental pollution. Korea's ports are also constantly in conflict with cities around the port on environmental pollution issues. In order to effectively respond to these complaints, the Busan Port Environment Improvement TF has been organized and operated since 2017. Rotterdam Port minimizes direct pollutant emissions by electrifying diesel-based unloading equipment, and further measures the air condition of the port in real time through the E-nose project and transparently opens it to citizens to develop the image of the green port and gain support from nearby cities and citizens. As such, extensive monitoring of ports is conducted using the latest IoT technology and environmental problems are actively solved by combining advanced technologies. In the case of Korea, diesel-based unloading equipment is still used and eco-friendly equipment is partially introduced, so it seems that a lot of time is needed to build a complete eco-friendly port. Another problem is that there is a plan to minimize pollutant emissions through the introduction of automated and unmanned equipment in the western container port of Busan, which will be newly created in 2030, but the improvement plan of existing ports is ambiguous. The bigger problem is that the introduction of eco-friendly techniques through individual technology applications is scheduled, but the transition to eco-friendly ports from a long-term perspective is not included in the development plan of the smart marine logistics construction system. There are insufficient visible plans such as short-term and long-term visions for carbon neutrality that Rotterdam and Hamburg Port have discussed earlier. In the short term, it is urgent to optimize logistics flows connected to ports and ports through intelligent management systems to reduce congestion and atmosphere, and to establish an integrated system to minimize energy waste. To this end, it is necessary to systematize smart port development strategies that are cut off between port authorities, share information between each other, and induce active participation of logistics-related shipping companies and carriers. In the case of Hamburg Port, it is taking a strategy to minimize the emission of environmental pollutants as well as the efficiency of logistics through the optimal combination with the existing railways. In this way, it is also necessary to consider the advantages of each port and develop the appropriate technical combination as much as possible.

In terms of energy utilization, there is an infinite possibility that renewable energy such as wind power and solar power can be produced by utilizing the large site of a port, the background site adjacent to it, and the surplus space in the water. In order to utilize this, it can contribute to the local economy through the development of new and renewable energy by actively cooperating with private power generation companies and attracting investment capital. In the case of Rotterdam Port, a 7.4MW wind power complex, which is equivalent to the size of a general power plant, is being built near the port, and a development plan is underway to supply the necessary power in the port as well as to nearby areas. Offshore wind facilities and solar facilities may be considered to be installed by utilizing idle spaces in the waters of the port where fishing rights are not established. It should also consider a fundamental shift in the role of ports by incorporating new technologies in terms of energy production and utilization. In particular, in preparation for the perfume hydrogen economy, Rotterdam and Hamburg Port are planning and realizing long-term plans to play a central role in the production, storage, and distribution of hydrogen in Europe. In the case of the Korean government, the hydrogen economy was selected as one of the three major investment areas in the Innovation Growth Strategy Investment Direction in August 2018, and the Hydrogen Economy Promotion Committee was formed, followed by the "Hydrogen Economy Revitalization Roadmap" in January 2019. It contains the vision and plan to become the world's leading hydrogen economy with hydrogen cars and fuel cells as two pillars (Policy brifing, Hydrogen Economy Revitalization Road map 2019). However, the logistics sector, where hydrogen fuel can be applied first, such as large ships and trucks, has close interests in ports and ports should play a key role, but it is not connected to the vision of Korean smart ports.

In port safety and security, IoT technology, Sensor technology, and advanced drone technology are in the spotlight. The safety management and security issues of ports are still labor-intensive areas that require a lot of manpower, and they are areas where the effects of technology replacement can be greatly enjoyed. Accordingly, in the case of Hamburg Port, all status information and variables in the port are collected and monitored in real time using aviation, sea, and seabed drones through the Portwings project. Rotterdam Port also establishes a U-space area to guarantee the operation of drones, while strengthening institutional aspects related to regulations. In the case of Korea, blueprints such as smart port safety platform and digital twin-based port facility management are presented, but detailed preparations seem to be insufficient in terms of the use of specific drone-based technology. Currently, domestic ports are classified as the highest-class security facilities under the Port Security Act, and free entry and exit control as well as photography are restricted. However, security accidents such as safety accidents and smuggling in ports continue every year, and there is an urgent need to establish an all-round monitoring system using newly introduced technologies. Therefore, it is necessary to ease security regulations so that unmanned equipment such as drones can be operated, tested, and collected information, and to convert the port space into a hub for business and logistics that can guarantee more free activities.

4.3. Limitations of Research

This study focuses on examining the case of advanced ports in depth and drawing implications for the future development direction of smart ports in Korea. Therefore, only two advanced ports in Europe were compared and analyzed with Busan ports, and the general characteristics of smart ports and the unique characteristics of the two advanced ports were examined. However, as can be seen from the discussion of smart ports, the concept of smart ports is still in its infancy, and there is no right direction for development. Therefore, referring to the case of advanced ports, it should be prioritized to accurately recognize the advantages and disadvantages of our ports and to establish our own appropriate direction using available resources. Next, it is true that advanced ports in Europe are developing and leading the concept of smart ports, but emerging ports in China and ports in Singapore and North America are also rapidly joining the smart port competition. In particular, in the automation sector, the discussion on Chinese ports may be more appropriate because Chinese ports stand out and are actually competing with us. However, in the case of ports located in China, the researchable public information is limited and there are practical difficulties in terms of applicability to domestic ports due to strong government-led development strategies. However, it is true that future follow-up studies need to analyze the strengths and weaknesses of ports in Asia and study ways to gain a competitive advantage. And when the concept of smart ports is established and specific performance indicators are calculated, discussions on the effectiveness of smart ports should be deepened through various quantitative studies.

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Abstract in Korean

본 연구에서는 최근 각광받고 있는 스마트 항만의 개념과 항만 경쟁력과의 관계를 고찰해 보고, 선진 스마트 항만에 대한 다각적인 분석을 통해 우리나라 스마트 항만 발전 방향에 대한 시사점을 도출하고자 하였다. 이를 위해 A. Molavi 외의 연구에서 확립된 스마트 항만 평가 척도의 4가지 측면, 운영측면(Operation), 환경측면(Environment), 에너지 측면(Energy), 그리고 안전과 보안 측면(Safety & Security)의 분석틀을 활용하여 스마트 항만 개발과 발전에 가장 앞선 네덜란드의 로테르담 항만과 독일의 함부르크 항만의 정책 분석을 시도하였다. A. Molavi 외의 연구는 측정 가능한 스마트화 지수를 발전시켜 각 항만의 스마트화 정도를 가늠하고 장단점을 파악할 수 있게 하기 위한 취지에서 개발되었다. 하지만 본 연구에서는 스마트 항만의 평가 척도를 활용하되 질적인 분석으로 접근하여 정책 활용 측면에서 유용한 시사점을 도출하는데 목적을 두었다. 또한 동일한 틀을 활용하여 현재 부산 컨테이너 터미널의 스마트 항만 발전 계획을 분석하고 발전방향 설정에 도움을 주고자 하였다.

우선 운영 측면에서 선진 스마트 항만들은 항만 내 하역 전 과정의 완전 자동화를 달성하였고, 이에 그치지 않고 항만 내 모든 과정을 4차 산업혁명의 첨단 기술들을 활용하여 무인화와 효율화를 추구하였다. 이 과정에서 A.I, IoT, 블록체인 등 4차 산업혁명의 핵심 기술들을 적극 활용하여 항만의 전체적인 모습을 변화시켜 가고 있으며, 비용절감과 생산성 증대 등 직접적인 효과뿐만 아니라 글로벌 물류의 핵심 구심점으로써 스마트 항만의 가능성을 발전시켜 나가고 있다. 이를 통해 항만 경쟁력 향상은 물론 물류 포털로써의 지위를 선점하기 위한 경쟁도 심화되고 있다. 환경 측면에서는 친환경 항만에 대한 관심이 증대되고 있다. 항만은 더 이상 도시와 분리되어 존재하는 독립된 영역이 아닌, 인접 도시 주민들과 상호 영향을 주고받으며 발전하는 호혜적인 관계를 구축해야 한다는데 공감대가 형성되고 있다. 이를 위해 그동안 항만 활동을 통해 야기되었던 환경 오염 문제를 줄이고 지역사회에 기여하기 위한 노력들이 활발히 진행되고 있다. 전력에 기반

한 친환경 하역장비로 대체하고, 선박의 연료를 친환경 연료로 전환하는 노력이 진행 중이다. 항만 내 유휴부지를 활용해 신재생에너지를 발전하고 인근 지역에 공급하는 방안과, 항만의 환경 문제를 IoT 기술을 활용하여 실시간으로 감시하고 공유하는 시스템을 구축하여 항만의 지속 가능한 발전을 의도하며 탄소 중립 사회로의 진전에 중요한 역할을 자처하고 있다. 에너지 측면에서는 스마트 항만이 미래 수소 사회의 핵심 공급 기지가 될 전망이다. 해상 물류와 육상 물류가 결합되는 기능적 이점을 활용하여 수소의 생산과 저장, 분배 등 수소 경제의 핵심 인프라를 항만 내 구축하고 항만 기능과의 결합을 시도하고 있다. 이를 위해 선진 항만들은 대규모 파이프 라인을 건설하는 프로젝트들을 진행하며 미래를 준비하고 있다. 안전과 보안 측면에서는 항만이 첨단 기술 활용의 경연장이 되고 있다. 항공 및 해상, 수중 드론 등 첨단 장비들을 활용하여 드넓은 항만을 가상 현실세계인 트윈 타워에 이식하고 인공지능에 의한 실시간 관리 감독이 가능한 시스템이 구축되고 있다. 항만 내 하역작업의 무인화는 안전사고의 위험을 획기적으로 줄일 수 있을 뿐만 아니라, 사각 지대가 없는 관리 감독도 가능해져 항만 내 재난사고와 밀입국 등의 문제를 근본적으로 변화시킬 것으로 기대되고 있다. 하지만 선진 스마트 항만에서 추구하는 근본적인 방향은 세계 물류의 핵심 포털을 구축하는 것이며 이를 위해 항만의 역할은 기존의 지역적인 한계를 넘어 기능적으로 그리고 물리적으로 팽창하고 있다.

우리나라의 경우 일찍이 자동화 항만의 발전을 시작한 유럽 항만은 물론 인근 중국과 싱가포르의 자동화 항만과 비교해도 뒤쳐지고 있는 것이 현실이다. 이를 만회하기 위해 중앙 정부 차원에서 “스마트 해상물류체계 구축 전략”을 수립하고 2030년 스마트 항만의 본격적인 운영을 계획하고 있다. 하지만 본 계획은 전반적인 물류 기능 중 하위 요소로 스마트 항만을 인식하고 있으며, 이는 스마트 항만을 자동화 항만이라는 좁은 측면에서만 바라보고 있는 것으로, 항만의 미래 잠재력에 대한 선진 항만들의 인식과는 큰 차이가 있다고 하겠다. 또한 스마트 항만의 발전 과정에서 민간 기업과 항만 이해관계자들이 적극적으로 참여하고 협력하여 스마트 항만의 모습을 그려가는 선진 항만과는 달리 우리나라의 경우 여전히 정부 주도 발전 방식

을 고수하고 있으며, 가장 주도적인 역할을 해야 할 항만 공사들의 역할이 미미한 것은 한계라고 하겠다. 그리고 향후 탄소 중립 사회로의 이행의무 등 환경적인 문제와 친환경 에너지로의 전환이 중요시되고 있는 시점에서 이에 대한 근본적인 전환계획이나 항만의 새로운 역할에 대한 고민이 부족한 것도 비교 연구를 통해 도출할 수 있었다. 유럽의 항만들과는 달리 수소경제로의 이행에 있어 항만의 핵심적 역할이 빠져 있다는 것은 스마트 항만에 대한 인식 부족에서 비롯된 것으로 보이며 이에 대한 정책적 개선이 필요한 것으로 보인다.

주요어: 스마트 항만, 무인화, 자동화, 물류 포털, 수소 경제
학 번: 2020-23854