Article

Study on the Relationship between Port Governance and Terminal Operation System for Smart Port: Japan Case

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Abstract: Background: To improve port productivity, safety, and sustainability, the use of information and communication technology is being promoted as a smart port. The utilization of a terminal operation system (TOS) is important for advanced port operations, and it is necessary to organize the issues and characteristics of the TOS. Methods: The characteristics of TOSs introduced in Japan and those widely introduced in Europe and Southeast Asia will be investigated and discussed according to the port management system in Japan. Results: Japanese TOSs are characterized by a lack of automated functions, such as ship loading plans, and by the fact that they are designed to allow the crane driver to select the order of operations, which may be attributed to a system wherein stakeholders are segmented and on-site decisions are emphasized. The promotion of smart ports in Japanese-style ports requires a system for information linkage between stakeholders. Conclusions: TOS capabilities for smart ports should be implemented according to the characteristics of port management in each region, and the studies conducted in this paper are useful in examining port system implementation strategies.

Keywords: port; terminal operation system; smart port; port management

1. Introduction

Driven by the trend of globalization, the volume of trade between nations has increased significantly. Ports play an important role in transportation networks and economic systems [1]. The port and maritime industry is in the fifth stage of its evolution: paper-based ports, digitized ports, integration of port areas, integration of ports and cities, and, today, integration with the global supply chain [2]. Since the 2010s, container ports have evolved as “smart ports”, and influenced by Industry 4.0, the term “Port 4.0” has become a trending topic in the port industry [3]. Barbar et al. defined smart ports using automation, environment, and intelligence [4]. Automated container terminals (ACTs) are a typical example of smart ports, and the ACT operating environment has been improved through the application of smart equipment and systems such as automated guided vehicles (AGVs), automated stacking cranes (ASCs), and terminal operation systems (TOSs). It has been observed that automated container handling equipment does not possess sufficient capacity to flexibly adjust system operation in the face of disturbances such as weather conditions, traffic congestion, and equipment failure, which could affect the overall efficiency of the terminal, and technologies such as digital twins have been proposed as a solution to this problem [5]. The concept of green growth and green port policy was introduced to reduce the environmental impact of ports and promote economic development while ensuring climate and environmental sustainability [6]. There have been several efforts toward im-
proving energy efficiency and protecting ecosystems and the environment in the port operation and management process [7].

Chenhao et al. highlighted that the development of smart ports is driven by the emergence of new technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), 5G networks, and block tuning, in addition to the demand for digitized and automated solutions that operate 24 h per day due to increasing freight volumes coupled with a shortage of skilled personnel [1,8]. A TOS is a computational management system that is responsible for all processes in the terminal based on the different elements of the container terminal (information and communication technology (ICT) systems, container handling equipment, infrastructure, terminal operator performance, etc.). It is a key element that improves the performance of container terminals and reduces their carbon footprint [9]. The port communication system (PCS) is another important part of the port information system, an inter-organizational system used to enable commercial services and the exchange of information between the port and its customers and various stakeholders such as forwarders, shipping companies, importers, exporters, and customs [9].

The upgradation of these PCSs to smart ports in Japan is being promoted by the Port and Harbor Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism, along with private port operators, their contractors, and port transport companies. A few representative examples of systems categorized as PCSs include Cyber port [10], which began operating in 2021 as an electronic system for port logistics procedures, CONPAS [11], a reservation system developed to reduce congestion in front of container terminal gates and shorten the time container trailers spend in the yard, and Colins, a system for centrally sharing container logistics information among terminal operators, shippers, ocean freight forwarders, carriers, and other related businesses.

The TOS, which manages terminal operation processes, has been introduced by port managers and port operators in Japan, and the improvement and upgradation of TOSs is currently left to these operators. This paper summarizes the characteristics of Japan’s port authority (PA) system based on its historical background, and it compares the system functional characteristics of the TOS introduced in Japan with those of TOSs widely introduced in Europe and Southeast Asia. It then discusses the relationship between the issues and features of Japan’s TOS and the port operation and management system, and it provides recommendations for smart ports.

A distinctive feature of this study is the organization of the functions required for TOs in the global trend of smart portization to clarify the characteristics of the Japanese TOS system through comparison with advanced TOSs in other countries. Further, this study establishes the relationship between the current status of the TOSs in Japan and the port authority system in Japan, and it suggests the direction of the TOS for “Japanese-style” smart portization.

The detailed research flow of this study is shown in Figure 1. First, the literature review surveys studies on smart ports and TOSs based on the authors’ subjective views. The literature is analyzed in three categories and proposes a TOS concept and functions for a smart port. Then, with reference to the smart port TOS functions, an interview survey about Japanese and worldwide TOSs is carried out to clarify some of the differences. At the same time, the port governance model is also organized with reference to the results of the subjective literature review and the visiting interviews of the authors. Finally, the relevance of the TOS survey results to port governance is discussed and suggestions for improvements are made.

The remainder of this paper is organized as follows. In Section 2, we highlight previous studies on smart ports, describe their trends, and discuss the functions required for TOSs. In Section 3, we summarize the port operation and management system in Japan. Section 4 compares the TOS systems in Japan and overseas and discusses their differences from the perspective of smart ports. In Section 5, based on the contents up to Section 4, we discuss the characteristics and issues of Japanese port operation and management systems and TOS. Section 6 provides the conclusions of this study based on the aforementioned factors.
2. Literature Review

2.1. Review of Research on Smart Ports

There has been extensive research and development of smart ports, specifically with respect to three main technology areas—automation, electrification, and digitalization [8]. This paper reviews studies on research and development for smart ports, especially those related to digitization, categorizes them according to the three following areas, and then discusses the functions required for TOSs: 1. Research on container terminal stacking planning, container handling equipment optimization, energy consumption optimization, and container terminal operations from a software perspective, including TOSs and digital twins. 2. Research on management strategies for container terminals and research on efficiency improvement and trends related to the entire supply chain. 3. Research on the advancement of TOSs and container terminal operations through IoT and ICT technologies (mainly hardware implementation and information linkage outside the container terminal).

First, in a study on the soft aspects of terminal operations, such as stowage planning and placement of container handling equipment at container terminals, Damla et al. formulated the integrated port container terminal problem (IPCTP), which integrates container terminal operations to optimize STS crane scheduling and stacking locations in the yard for vessel loading operations. They showed that this problem can be solved using a constraint programming (CP) solver [12]. A recent study formulated the logic for determining the stacking location when containers are delivered to the yard, verified the stacking location determination according to three steps (identifying container attributes, selecting candidate stacking bays, and determining stacking bay) through simulation, and showed an improvement in handling costs compared to the current situation [13]. To determine the location of the delivering container, some studies used online optimization based on GMM clustering to construct a logic for determining the stacking position in the yard based on the ship loading plan [14].

One of the key topics for determining the unloading container location is to minimize container re-handling by considering the arrival order of the outbound trucks. Sebastián et al. proposed a method for predicting container stay time in the yard based on data analysis and a method for developing an unloading container stacking plan that minimizes container re-handling based on a mathematical model [15]. The concept of smart stack strategy (SS), which utilizes an approach of eliminating container re-handling by making the stacking area of the unloading containers a dedicated area for each customer, was also proposed in a recent study [16]. In case studies in Mexico and Italy, increasing the number of double moves, where containers are inbound and outbound at the same time, reduces
the number of trucks entering the yard and evens out the timing of their arrival, thereby reducing truck congestion in the yard and improving operational efficiency [17].

The aforementioned approaches, including the formulation of container stacking planning and the proposal of efficient concepts, have been the subject of many previous studies. Container stacking planning is one of the functions of TOs in container terminal operations, and these studies are considered to contribute to the improvement and enhancement of TOs. Several studies have focused on the functions of TOs, e.g., the integrated terminal operation system (ITOS) aimed at improving the efficiency of container terminal operations [18], in addition to studies that categorize the functions of TOs based on the opinions of a panel of experts and evaluate the functions that should be emphasized by means of the analytic hierarchy process (AHP) [19].

Digital twins are also an important topic for improving the efficiency of container terminal operations from a software perspective. For example, Kan Wang et al. proposed a digital twin concept consisting of five layers: (1) physical, (2) data, (3) model, (4) service, and (5) application [20]. Robert Kiar et al. reviewed the history and current status of the digital twin, broken down by application domain and purpose. They organized the composition of the port digital twin. They insist that ports are one of the nodes in the supply chain and are part of a smart city closely related to urban transport and maritime logistics. They further stated that unifying the data exchange protocol between these various players is important. They also demonstrate how the digital twin could be applied in ports, including the vessel, yard operations, hinterland transport, and equipment aspects such as lighting and monitoring container handling machinery [21]. Some research cases have analyzed the scheduling logic of ASC on digital twin models [5] and the optimization of the energy consumption of ASC by applying Q-learning [22].

Many studies have focused on management strategies for container terminals, and some have analyzed the efficiency and trend studies related to the entire supply chain. The current status of ports and priorities for management strategies has been analyzed using various methods. For example, the efficiency of ports in developed and emerging countries was compared using DEA (data envelopment analysis method) [23], a hierarchical analysis process incorporating fuzzy techniques. This technique assessed priorities for port improvement strategies [24]. Further, factors affecting the serviceability of terminal operations were investigated, and a multi-criteria decision-making method was used to compare and assess the serviceability of 12 container terminals in India [25]. Barbara T.H. Yen et al. defined 13 indicators in the three categories of environment, automation, and intelligence as indicators for the quantitative evaluation of smart ports, and they used the AHP, the delineation analysis method (DEA), and Tobit regression analysis to assess the impact of each indicator on port performance [4]. Ignacio et al. review the current state of new technologies for smart ports and summarize how ports and terminals are developing specific projects in the new era of smart ports and Port 4.0 [3]. Othman et al. investigated the state of preparation and adaptation to the introduction of smart port technology and its impact on achieving and improving sustainability in Egyptian ports. They investigated the potential extent to which Egyptian ports could adopt smart port practices and technology adoption to achieve and improve sustainability [26].

Carbon emission policies should also be considered in port and supply chain modeling. Eslamipoor proposed a model to reduce carbon emissions by optimizing the allocation of vehicles to drivers and destinations while reducing the costs associated with deliveries to a minimum through multi-objective modeling [27]. Elsewhere, Eslamipoor et al. proposed a mathematical model for the vehicle routing problem (VRP) with the pick-up and delivery of goods to different depots [28]. The model aims to minimize costs and customer waiting times. When considering port strategies, it is necessary to take a supply chain management perspective and consider the optimization of such land transport deliveries.

Third, with the recent advancement of information and communication technologies such as 5G, the development of sensing technologies, information collection, and utilization at ports using the Internet of Things (IoT) and information linkage between container
terminals and their external parties, such as port communication systems (PCSs), hold great significance. Leonard et al. investigated information systems in ports from academic and practical perspectives [29]. This research introduces the National Single Window (EDI system for submission of trade documents, etc.), vessel traffic services, gate systems (reservation and automated processing), PCSs, TOSs, damage check systems, port roads, and traffic control information systems as the information systems, which are currently used at ports. This research also pointed out that location positioning using differential GPS (DGPS) and container and vehicle recognition by RFID, OCR, and wireless sensor networks are essential technological elements that support such information systems. Amine Bouhlal et al. surveyed trends in various sensors and monitoring technologies using IoT technology in container terminals [30]. Their study focused on the Internet of Ships (IoS) and discussed the need for a standardized data-sharing platform that allows port authorities, shipping companies, customers, and others to share information. They also stated that a digital platform that can collect real-time information from vessels, cranes, AGVs, etc., is essential for smart ports to become a reality.

This study investigates the functions of TOSs used in ports, summarizes the differences between TOSs in Japan and the rest of the world, examines the relationship with port policy systems, and makes suggestions for a smart port. Few previous studies on smart ports have interviewed vendors regarding the functions of the TOS system actually used in ports and mentioned their background, which is a feature of this study.

2.2. TOS Functions for Smart Ports

Based on a thorough review of the studies mentioned above, this paper proposes the TOS function shown in Figure 2 as a TOS function for smart portization. In addition to inventory control, operation planning, and operation control functions that are conventionally provided by TOSs, this new TOS will possess data integration functions with smart gates, PCSs, and IoT data collection functions, and will mediate such data with the digital twin platform and ECS to contribute to operational efficiency and automation. In other words, TOSs can serve as the center of smart ports, controlling information transfer and container handling operations. Before moving on to the discussion on TOSs in view of the above, the next chapter describes studies on port governance systems.

![Figure 2. Overview of TOS functional configuration for smart port.](image-url)

3. Port Governance and Container Terminal Operations in Japan

3.1. Characteristics of Container Terminal Operations and Port Governance in Japan

In Japan, the Port and Harbor Law was enforced in 1950, soon after the end of the war, and with the firm intention of the GHQ, the Japanese government only had supervisory authority, and the right to manage ports was given to local public bodies. Containerization in Japan began in 1969, and the Keihin and Hanshin Outer Trade Wharf Public Corporation was established in 1967 mainly because the Port Law did not allow exclusive use by
shipping companies and due to the need to raise funds for the massive cost of constructing container terminals. The container terminal was leased to shipping companies under the Wakasa Ruling of 1969, and it operated as a terminal for the exclusive use of shipping companies [31]. Foreign shipping lines also participated in the exclusive lease program, but port operators were only permitted to contract out work due to the small capitalization. However, since the 2000s, port operators have been increasingly participating in terminal operations, and their participation in container terminal operations in the form of joint leasing has become more prevalent. Further, even terminals dedicated to shipping companies began to sublease to port operators or to be leased jointly by shipping companies and port operators [32].

It is said that the international competitive power of Japanese ports began to decline in the 1990s [33]. After the designation as a central and core international port in 1995, the Super Central Port Policy, aimed at the quantitative and geographical allocation of container ports, was enforced in Japan in 2001. Port reforms were underway in several regions worldwide by this time, and many countries had converted to landload ports [34,35]. With the rise in global terminal operators (GTOs) and their global expansion [36,37], the Japanese port policy aimed to counter the activities of these GTOs [38]. Therefore, a domestic mega terminal operator (MTO) was developed to achieve port costs and services superior to those of major Asian ports as a joint venture of domestic port operators [39]. In 2004, the Keihin Port, Isewan Port, and Hanshin Port were designated as Super Hub ports and several MTOs were established, but the de facto stove-piping between port operators continued, and integrated operation by MTO could not be realized in these ports. Later, the structure of port management and operations changed with the port operating company (POC) system with the International Container Strategic Ports Policy. A POC is a joint-stock company that leases multiple terminals from the port authority and operates them integrally, and the POC leases each terminal to a terminal operator (TO). The contractors of POCs mainly include shipping lines and port operators. The management structure is the port authority (PA)-POC-TO, a rare two-tier structure in the world, but in reality, the PA emphasizes that it does not sufficiently operate from a private sector perspective. POCs are not designed the same way as MTOs, but the port management companies of international strategic ports, which are positioned at the highest level under the Port Law, are state-owned enterprises (SOEs) wherein the government invests in addition to the port authority [40].

Japanese ports have neither commercialized or corporatized the PA system through port reforms nor separated the PA management function from the private sector, as in China, Korea, and Taiwan [41,42]. Port management has been conducted in Japan by local administration [43]. Although there is an increasing trend toward private sector engagement through the management company system, particularly in large ports, most container ports are public terminals [40]. Therefore, the market for port operations wherein private companies can participate is limited, and participation is limited to POCs, their investors, and TOs that lease terminals from POCs. Although the investors in the port management company mainly consist of local companies from a variety of industries, they do not substantially participate in port operations, and terminal operators are limited to port operators and shipping companies. Some overseas shipping companies have leased terminals, but port operators are limited to domestic companies, and the fact that no GTOs have entered Japanese ports is a significant feature [44].

The environment wherein Japanese port operators operate as TOs is less competitive, in addition to the fact that only a few overseas TOs have entered the port operation business. Historically, container terminals in Japan began with dedicated terminals operated by shipping lines, and this style has been kept even after port operators became operating entities. Further, the existence of dedicated and semi-dedicated container terminals is one of the characteristics of Japanese ports [45–47].

The market for the cargo handling industry, which emphasized order in the industry after World War II, has been liberalized through a change to the registration, licensing, and permit system. However, the vertically organized hierarchy of shipping lines, prime
contract TOs, and subcontract TOs at each port has been maintained to the present day, and a peaceful market environment has been maintained by adhering to internal regulations that require vessel scheduling to be based on prior agreement between shipping companies, the Japan Harbor Transportation Association, and the dockworkers’ union.

A lack of foreign TOs may be attributed to the Super Central Port Policy. Among Asian countries, China, Korea, and Taiwan introduced privatization policies and accepted foreign GTOs to improve the efficiency of port operations and port development, while Japan was concerned with the development of MTOs, which are domestic TOs comparable to GTOs. As a result, MTOs were not grown and the Super Central Port Policy is said to have failed. This is because port officials lack an understanding of international affairs and the flexibility to change the conventional practice because of their domestic view [33], which has been pointed out as why independent TOs could not develop as an industry in Japan [48].

In light of the route dependency often discussed in port innovation, it is easy to understand why the Japanese port industry has followed its conventional style, considering that Japan used to be more competitive than ports in other Asian nations and had a constant share of the international port market. On the other hand, the Japanese government’s failure to recognize the urgency of reformation and decisively implement it has been criticized as contradictory to other Asian nations that have shown powerful leadership [33]. Due to the lack of separation of PA functions in port governance and the fact that an MTO, which was aimed for in the port revolution of Japan, has not been realized due to route dependency, port operation by private companies has not been cultivated as an industry. As a result, GTOs have not engaged in the port operation market in Japan, and a majority of companies have not been active in the global market [49].

The POC system is currently applied in large ports handling most of Japan’s container cargo, and TOs (shipping companies and port operators) are subleased from POC-operate CTs. However, the two-tiered PA-POC-TO structure and the historical order of the port transport industry make the scope of rights and discretion among stakeholders complex. Thus, these factors significantly impact the introduction and development of TOSs. On the other hand, except for large ports, CTs have been developed as public work projects and are still public terminals operated by local governments, and there is no private sector perspective on port operations. This further affects the introduction and development of TOSs.

3.2. Hierarchical Structure of Port Cargo Handling Stakeholders

Table 1 shows an example of the hierarchy of port cargo handling stakeholders in CTs to which the Japanese POC system is applied, and Table 2 shows the seven port transport businesses defined in the Port Transport Business Law. In the port exemplified in Table 1, all CTs are long-term leased by the harbor manager to the POC, and each CT in the port is lent by the POC to the borrower shipping company or port operator. The port management or port operation purchases gantry cranes, but the CT is mainly operated by the CT operator, a private company licensed as general port transport services, even if a shipping company leases the terminal. However, the gantry crane is owned, leased, used, and operated by different entities because the crews of the port cargo handling operator company board and operate the cranes under the license of the port cargo handling operator. On the other hand, cargo handling machinery in container yards, such as cranes, top lifters, chassis tractors, and TOSs, are generally purchased by CT operators and operated by crews of the cargo handling company. In addition, maintenance and repair of cargo handling machinery is performed by the CT operator or contractors commissioned by the CT operator. Due to the historical background mentioned previously, the scope of work of each entity in Japanese port cargo handling is divided, as shown in Table 2.
Table 1. Stakeholder hierarchies in shipping company dedicated terminals at international strategic ports and international hub ports in Japan.

<table>
<thead>
<tr>
<th>Function</th>
<th>Actual Business</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port management</td>
<td>Governmental authorities</td>
</tr>
<tr>
<td></td>
<td>Ministry of Land, Infrastructure, Transport and Tourism</td>
</tr>
<tr>
<td></td>
<td>Confirmation of port plan, quay maintenance</td>
</tr>
<tr>
<td>Harbor manager</td>
<td>Local government</td>
</tr>
<tr>
<td></td>
<td>Development of port plans, development of cargo handling areas</td>
</tr>
<tr>
<td>Port operation</td>
<td>Port operating company</td>
</tr>
<tr>
<td></td>
<td>Third Sector Corporation</td>
</tr>
<tr>
<td></td>
<td>Borrowing of administrative assets and loans to CT operators</td>
</tr>
<tr>
<td></td>
<td>Asset introduction and management</td>
</tr>
<tr>
<td>CT operation and cargo handling</td>
<td>CT lessee</td>
</tr>
<tr>
<td></td>
<td>Shipping company</td>
</tr>
<tr>
<td></td>
<td>Long-term lease and exclusive use of CT</td>
</tr>
<tr>
<td>CT operator</td>
<td>General port transportation business company (stevedore)</td>
</tr>
<tr>
<td></td>
<td>Operation of CT Installation of cargo handling machinery and TOS</td>
</tr>
<tr>
<td>Cargo handling company</td>
<td>Port cargo handling operator company</td>
</tr>
<tr>
<td></td>
<td>Operation of cargo handling machinery</td>
</tr>
</tbody>
</table>

Table 2. Types of Japanese port cargo handling companies.

<table>
<thead>
<tr>
<th>Name of Business</th>
<th>Business Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>General port transportation business</td>
<td>Receives and delivers cargo on behalf of the consignor at the consignment of the shipper or ship operator. Cargo handling on board, cargo handling at the wharf, barge transportation, and raft transportation are performed in an integrated manner by this company.</td>
</tr>
<tr>
<td>Port cargo handling operator</td>
<td>Loading or unloading cargo to vessels. Deliver cargo transported by ship or barge to a handling yard, cargo handling or storage at a cargo handling yard.</td>
</tr>
<tr>
<td>Raft transportation business</td>
<td>Carriage of cargo at ports by ship or barge, and towing of barges.</td>
</tr>
<tr>
<td>Tally business</td>
<td>Calculation of the number of cargo or certification of delivery of cargo.</td>
</tr>
<tr>
<td>Appraisal business</td>
<td>Certification, investigation, and appraisal of shipping cargo</td>
</tr>
<tr>
<td>Weighing business</td>
<td>Calculation or certification of the volume or weight of cargo</td>
</tr>
</tbody>
</table>

3.3. Comparison of Port Management and Operation Systems in Japan and Other Countries

To compare Japan’s CT operation style with that of other countries, the situations at Dubai Port in the United Arab Emirates (UAE) and Bangkok Port and Laem Chabang Port Terminal D in Thailand are shown in Table 3. The shaded cells in the table indicate private companies.

One of the research perspectives in port management is the classification of port governance models. A widely used port governance typology is that of the World Bank [50]; four types of ports are listed: service ports, landload ports, tool ports, and private ports, based on the level of privatization. Container terminals in Japan are generally classified as tool ports in that the public sector is responsible for the infrastructure and superstructure, while the private sector is responsible for the operations. This paper compares three types of terminals other than tool ports from Southeast Asia and the Middle East.

DP World (DPW) in the UAE is a private company that was established in 2005 and is a global terminal operator currently operating 72 terminals in 42 countries [51]. The Port Authority of Thailand (PAT) was established in 1951 as an organization under the jurisdiction of the Ministry of Transport of Thailand, and it manages five ports: the international ports of Bangkok and Laem Chabang and the regional ports of Chiang Saen, Chiang Kong, and Ranong [52]. Hatchson Port Thailand (HPT) consists of Thai Laem Chabang Terminal and Hatchison Laem Chabang Terminal, which operate Thai ports as private companies under CK Hutchison [51]. In each case, there are differences in the
boundary points of jurisdiction between the public and private sectors, but within each sector, they constitute a single business entity. On the other hand, Japan’s port operating companies were introduced after the 2011 revision of the Port and Harbor Law, and they are semi-private, third-sector companies in which the national government, local governments, and private companies invest [53]. A typical container port in Japan is classified as a tool port from the perspective of the port governance model, but it is characterized by the fragmentation of operators within the public sector and even within the private sector, as shown in Table 3.

Table 3. Comparison of container terminal management systems in each country. The gray color in the table indicates private companies.

<table>
<thead>
<tr>
<th>Port governance model</th>
<th>Japan</th>
<th>UAE</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wharf construction</td>
<td>Goverment</td>
<td>DP World</td>
<td>PAT (Port Authority of Thailand)</td>
</tr>
<tr>
<td>Container yard construction</td>
<td>Local government</td>
<td>DP World</td>
<td>PAT</td>
</tr>
<tr>
<td>Installation of gantry crane</td>
<td>Port operating company</td>
<td>DP World</td>
<td>PAT</td>
</tr>
<tr>
<td>Borrowing of CT</td>
<td>Shipping company</td>
<td>Owned by DP World</td>
<td>Owned by PAT</td>
</tr>
<tr>
<td>Purchase of cargo handling machinery such as yard cranes and tractor heads</td>
<td>General port transportation business company</td>
<td>DP World</td>
<td>PAT</td>
</tr>
<tr>
<td>Maintenance of cargo handling machinery</td>
<td>General port transportation business company</td>
<td>DP World</td>
<td>Company hired by PAT</td>
</tr>
<tr>
<td>Purchase of TOS</td>
<td>General port transportation business company</td>
<td>DP World</td>
<td>PAT</td>
</tr>
<tr>
<td>Employment of cargo handling crews</td>
<td>Port cargo handling operator company</td>
<td>DP World</td>
<td>PAT</td>
</tr>
</tbody>
</table>


4.1. Overview of TOS

Container terminals store many different types of containers, like import/export, 20 ft or 40 ft, full or empty, and dry or reefer, and these containers are repeatedly moved using cranes and trucks. In addition, container terminal operators have many duties, such as planning the use of quays based on the schedule of container vessels and executing various trade-related procedures as agents of shipping companies.

Miguel Hervás-Peralta et al. suggested that the TOS can be defined as the software at the core of the terminal that plans, manages, and monitors all processes carried out at the container terminal (e.g., loading/unloading/transport/storage processes) and their surroundings (e.g., vessel and truck arrival plans, truck queues at the gates) They also noted that the installation of TOSs is one of the most difficult projects a terminal operator can undertake and requires a lot of effort from the operator [19]. Except for global terminal operators with their own proprietary TOS, one realistic option for terminal operators seeking to introduce a TOS is a customized system based on a suite of TOS packages offered by various companies around the world.

According to Webinar Care, an online business site, nine products listed in Table 4 are the best TOS packages in 2024 [54]. A unique feature of these top TOSs is that they have been introduced in terminals worldwide; for example, the OPUS Terminal has been introduced in Spain, the UAE, Iran, Malaysia, the U.S., Brazil, and other countries, mainly in Asia.
Table 4. Examples of major TOS package products.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Company</th>
<th>Country</th>
<th>Introduced Area</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navis N4</td>
<td>Navis</td>
<td>U.S.</td>
<td>All over the world, especially in the U.S. and Europe</td>
<td></td>
</tr>
<tr>
<td>OPUS Terminal</td>
<td>Cyber logitec</td>
<td>Korea</td>
<td>Southeast Asia</td>
<td></td>
</tr>
<tr>
<td>GullsEye</td>
<td>GullsEye</td>
<td>Turkey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Master Terminal</td>
<td>JADE Logistics</td>
<td>U.S.</td>
<td>U.S., UAE, New Zealand, etc.</td>
<td>Group company of Navis</td>
</tr>
<tr>
<td>Hogia Terminal</td>
<td>Hogia</td>
<td>Sweden</td>
<td>Sweden, New Zealand, etc.</td>
<td></td>
</tr>
<tr>
<td>CommTrac</td>
<td>TBA</td>
<td>U.K.</td>
<td></td>
<td>For bulk and Ro-Ro terminals</td>
</tr>
<tr>
<td>CATOS</td>
<td>Total softbank</td>
<td>Korea</td>
<td>Asia, Europe</td>
<td></td>
</tr>
<tr>
<td>Mainsail</td>
<td>Mainsail</td>
<td>U.S.</td>
<td>U.S., U.K., etc.</td>
<td></td>
</tr>
<tr>
<td>Autostore TOS</td>
<td>TBA</td>
<td>U.K.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Since its inception at the Port of Tokyo’s Oi Wharf in 1973, TOSs have been widely used at container terminals in Japan, not only in large but also in smaller terminals [55]. Some examples of major TOSs installed in Japan are shown in Table 5, according to the Internet homepage information of Japanese container terminals and TOS vendors [56–60]. Many Japanese container terminals have introduced CTMS, and there are a few cases of global TOS packages, as shown in Table 4. However, global TOSs have also been introduced, mainly at terminals operated by overseas shipping companies [61].

Table 5. Examples of Japanese TOS package products.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Company</th>
<th>Introduced Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Terminal Management System (CTMS)</td>
<td>Mitsui E&amp;S</td>
<td>Tokyo, Kobe, Yokohama, Nagoya, and most of the major ports</td>
</tr>
<tr>
<td>Container terminal system</td>
<td>Mitsubishi Logisnext</td>
<td>Osaka, etc.</td>
</tr>
<tr>
<td>Container terminal operating system</td>
<td>Syscom</td>
<td>Shimonoseki</td>
</tr>
<tr>
<td>Integrated Container Terminal System</td>
<td>ADK fuji system</td>
<td>Akita, Sakata</td>
</tr>
<tr>
<td>PORT-IT Systems</td>
<td>Seiko IT solution</td>
<td>Hakata, Imari, etc.</td>
</tr>
</tbody>
</table>

4.2. Comparison of TOSs between Japan and Other Countries

In this paper, we conducted interviews with the persons involved in OPUS Terminal, a TOS package introduced mainly in Europe and Southeast Asia, and CTMS (Container Terminal Management System), which is widely introduced in Japan, as shown in Table 6, and we summarized the features and differences between the two systems, mainly in terms of TOS functions for smart ports, as described in Section 2.

Table 6. Summary of interviewees.

<table>
<thead>
<tr>
<th>Company</th>
<th>Class</th>
<th>Content of Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>System supplier partner company</td>
<td>Manager</td>
<td>Specifications of OPUS System</td>
</tr>
<tr>
<td></td>
<td>Chief</td>
<td></td>
</tr>
<tr>
<td>Port Cargo Handling System Supplier</td>
<td>Manager</td>
<td>Specifications of CTMS System</td>
</tr>
</tbody>
</table>
1. **OPUS Terminal**;

   OPUS Terminal is a TOS developed by Cyber Logitec in Korea. This global TOS product has been installed in container terminals across the world, mainly in countries such as Korea, Thailand, Malaysia, Indonesia, the UAE, the United States, Spain, and Brazil. A unique feature of OPUS Terminal is the ability to customize TOS functions in response to customer requests.

2. **CTMS**;

   CTMS is a TOS developed by Mitsui E&S and introduced in Japan.

   CTMS has been installed in many terminals in Japan, especially at the ports that handle a large volume of containers, like Tokyo, Kobe, Yokohama, and Nagoya.

   CTMS consists of a group of subsystems that are linked to each other via a database, and subsystems can be selectively introduced according to the situation of each container terminal and terminal operator [55].

4.3. **Results of Comparison of TOS**

   Interviews with stakeholders revealed two main differences between the TOSs:

1. **Automation of planning on ship loading**;

   This function plans which containers will be loaded in which slot on the vessel and in what order. When loading containers, containers are grouped by size, type, and port of discharge to minimize re-handling during unloading operations, and the plan is to stack the heaviest containers on the bottom for ship stability [14].

   In the OPUS vessel planning system, the operator only needs to specify the sequence order of each container, and the loading slot of the ship is automatically determined by the system. With this function, planning for a 10,000 TEU class vessel can be completed in approximately 30 min.

   In CTMS, although there are some support tools that provide logic for loading container planning, in many cases, loading slots are determined manually following each terminal’s operating rules.

   However, in some cases, loading plans are prepared by the shipping company, and in such cases, the TOS is required to receive and display the loading plans and modify them as necessary.

2. **Instructions to operators of container handling machinery**

   The onboard terminal is a system that provides crane and trailer operators with instructions for the work to be performed, and both the OPUS and CTMS provide these onboard terminal applications and communication systems. One difference between OPUS and CTMS is the difference in policies for selecting work. Figure 3 shows an example screen of the onboard terminal application of a rubber-tired gantry crane (RTG) for each OPUS and CTMS.

   Figure 3a shows the work selection window of an RTG in the onboard terminal software of CTMS. Information such as the type of operation, container number, and destination is displayed in a list, and the RTG driver selects the next operation and presses “select” at the bottom right of the screen. In summary, in the onboard terminal software of CTMS, the RTG driver basically selects the next work to be carried out. Although the range of work displayed depends on the settings, all the work in the area for which the crane is responsible is shown on the screen, and the RTG operator selects the order to perform the work efficiently based on their experience.

   The OPUS application screen is shown in Figure 3b, where operation is carried out according to the schedule on the left-hand side. Detailed information on the work to be carried out next is also displayed simultaneously on the right-hand side of the screen. At the OPUS Terminal, the crane’s next work is indicated on the onboard terminal, and the driver carries out the loading/unloading operation following the order of instructions. These work orders are determined to ensure efficient operation based on the work schedule.
and traffic conditions in the yard, and the AI service function described below supports these decisions.

![Table 7](image)

<table>
<thead>
<tr>
<th>Function</th>
<th>Target</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crane working plan</td>
<td>Gantry crane</td>
<td>Learning the pattern of gantry crane operation schedule and support to make the operation schedule.</td>
</tr>
<tr>
<td>Yard planning support</td>
<td>Yard operation</td>
<td>Learning the pattern of container stacking and suggest the stacking plan.</td>
</tr>
<tr>
<td>YT congestion analysis</td>
<td>Yard Trailer</td>
<td>Grasp the traffic congestion situation of Yard Trailer and suggest routes to avoid traffic congestion.</td>
</tr>
<tr>
<td>Yard crane operation pattern analysis</td>
<td>RTG, RMG</td>
<td>Learning the pattern of yard crane operation and develop operation plan for yard crane.</td>
</tr>
</tbody>
</table>

5. Discussion

As described in Section 3, the port operation and management system in Japan is stratified into port management, port operation, and CT operation, and the work system for port cargo handling is also complicated due to its historical background.

The characteristics of Japanese port operations compared to those of foreign ports are the decomposition of the public sector and the private sector, as well as the stratification of the public sector and the private sector within their respective jurisdictions.
In terms of the decomposition between the public sector and the private sector, from the viewpoint of the port governance model, the landload model, wherein the operation of CTs is outsourced to private companies, as in the case of Laem Chabang Port, is widely applied in several regions worldwide. In Japan, the tool port model is the mainstream, with the port manager or POC installing the gantry crane.

The hierarchy within the public and private sectors is worth noting, and both the Dubai and Ram Chabang ports have a single private company to handle all aspects of stevedoring, from procuring equipment and TOS systems to hiring crews. Although the Port of Bangkok is operated by the public sector, it is similar to Dubai Port and Ram Chabang Port in that a single organization is responsible. However, in Japan, the structure is hierarchical, with shipping companies renting CTs, CT operating companies (prime contractors) procuring equipment and systems and managing overall port operations, and operating companies (specialized companies) performing the actual cargo handling operations.

Before describing the relationship between these port policies and the TOS, it should be mentioned that the TOS is introduced for the efficient operation of container terminals, and in Japan, the TOS is generally introduced by general port transportation companies, which are CT operators, and the actual operation is performed by cargo handling companies, which are lower in the hierarchy.

A comparative study of Japanese and foreign TOSs revealed that the Japanese TOSs differ from foreign TOSs in that the selection of work for container handling machinery is operator-driven, and automation in the planning of ship loading is not advanced. These functions are not due to system constraints but rather a policy in Japanese container terminal operations that prioritizes the decisions of on-site operators, and the system follows their decisions.

Another trend in smart ports is the automated container terminal (ACT). However, the level of control system required for TOSs differs between ACTs and conventional manual terminals. While conventional terminals generate work orders in batches, and the RTG operator can decide the order in which those orders should be executed, automated container terminals are more likely to have the TOS generate a shorter series of movement orders that include precise sequencing and timing [62]. It is also necessary to control the order in which the trailers enter the yard and to generate work orders according to that order [63].

The OPUS possesses the ability to indicate sequenced work instructions clearly and can support container terminal automation. On the other hand, to adapt to ACT in a CTMS with a human-centered work selection policy, the automated terminal must be equipped with an ECS that directs the movement of individual machines and coordinates the movement of single or groups of machines, in addition to the TOS [62]. The CTMS provides an automated equipment control system (AECS), which can determine the crane that will perform the work [64].

Although automation can reduce demand for workers and increase problems of unemployment, Japan has been a strong promoter of automation, being a step ahead of the rest of the world, and it has developed a highly competitive edge in manufacturing [65]. However, because many aspects of cargo handling planning at container ports are based on tacit knowledge that cannot be easily standardized, the judgment of the person in charge at the yard is considered to be important, resulting in a lack of automation in planning [66].

To maintain the Japanese style of container terminal operation, which prioritizes on-site decision-making and supports more efficient operations, enhancing the mobile terminal system that provides information to operators is effective. In addition, if the automation of cargo handling machinery is requested, an ECS should be installed.

Another reason for the lack of automation of planning and other functions in domestic TOSs is that major Japanese terminals were not required to become independent as profit-making entities due to the highly hierarchical nature of stakeholders, and the introduction of unique cargo handling operation rules and systems at each individual terminal created an environment that made it difficult for adjacent terminals to cooperate.
On the other hand, in regional ports with low cargo volumes and container ship arrival frequencies, port development has been carried out by local governments, and segregation has been made among multiple CT operators. There have been cases where yard space and container handling machinery are divided among different CT operators within a single container yard, and this has been considered to lead to a decline in productivity.

Local ports, which account for most container ports in Japan, possess fragmented cargo collection regions, which may result in lower utilization rates. In such ports, the introduction of an advanced TOS may be rather costly and may not contribute to increased competitiveness. The competitiveness of a port, which is used as a criterion for shipping companies selecting the port of call, is based on the demand for cargo in the area, the port’s serviceability, and its cost [39]. An advanced TOS is efficacious in improving port serviceability and reducing costs. However, it does not contribute to the most crucial cargo demand. The benefits of TOSs with higher functionality are improved serviceability through more efficient cargo handling operations and more efficient planning work in terminal operations, which could be one of the solutions to the severe manpower shortage. In Japan, the declining birthrate, aging population, and labor shortage are serious, especially in rural areas, and system advancement can help mitigate these problems. Further, Japan’s regional ports are considered to be suitable for TOS advancement.

In addition, comprehensive data collection is essential for building a smart port that utilizes the digital twin. For example, in the five-layer smart port proposed by Kan Wanga et al., they describe the need to collect data from all directions of the container terminal in real time, as well as to integrate them [20].

The data required at each level of port management and operation are different, and the hierarchy of port management in Japan leads to complications in data transfer. For example, at a typical Japanese shipping company terminal, a gantry crane is owned by the port operating company, and the shipping company rents it and pays the lease fee. It is then operated by the CT operator under contract with the shipping company. However, the actual operation is performed by employees of the cargo handling company. For port operating companies such as gantry crane owners, crane uptime and maintenance history are important data for managing their assets. For CT operators, data such as crane loading/unloading speeds, utilization rates, or failure rates are important to maximize operation efficiency, and it is important for cargo handling companies to possess information on crane conditions during operation so as not to interrupt the container handling operation. Furthermore, maintenance companies that are contracted by port operating companies to maintain cranes require information regarding the crane’s operational status, failure history, etc., to perform maintenance work and repairs. Thus, different stakeholders require different data even for the same gantry crane information.

In collecting and utilizing these data for smart ports, the frequency and accuracy of data collection differs depending on the entity that introduces the system that collects the data. Further, those who invest in the system and attempt to collect and analyze data specialize in collecting and analyzing information that serves their own benefit and rarely collect and redistribute data needed by other stakeholders. This facilitates the need for a platform for sharing and freely accessing necessary information among hierarchical stakeholders for smart ports in Japan’s container terminals.

6. Conclusions

In this paper, we focus on TOSs, which are considered to play an important role in the smart portization of container terminals, and we discuss the functional differences and their relevance to port governance in Japan, citing two representative examples of TOSs, one of which is primarily implemented in Japan and the other in Europe and Southeast Asia.

The conclusions of this study are as follows.

• The port management and operation system at large Japanese ports is characterized by a complex hierarchy of stakeholders due to the historical background of port
development, and it differs from the unified management and operation system by a global terminal operator as seen in large overseas ports.

- Japanese TOSs differ from overseas TOSs in that the selection of work for container handling machinery is led by the driver of the machinery, and automation in container stacking planning and ship loading planning is not advanced. This may be attributed to the facts that on-site port cargo handling operator companies have led Japanese port operations, that port management was not required to become independent as profit-making entities due to the high hierarchy of stakeholders, and that each terminal has its own handling operation system and TOS, which has resulted in a lack of cooperation between adjacent terminals.

- Container terminals in Japan are characterized by the high productivity maintained by the skilled workers of port cargo handling operator companies, and the introduction of a mobile terminal system that provides instructions to workers is an effective way to take advantage of this.

- The upgradation of TOSs through the introduction of technologies such as digital twin platforms and AI and the automation of cargo handling machinery will contribute to the serviceability and cost aspects of ports but not to the demand for cargo.

- Comprehensive data collection is necessary for implementing digital twins or AI, which requires a platform to exchange the necessary information among multiple stakeholders.

- An analysis of the importance of the functional elements of TOSs in order to contribute to the definition of specific TOS requirements for smart ports can be a future research topic. Analysis of the costs and other issues and benefits associated with smart ports could be developed, and the ideal form of port policy could be considered using methods such as Pareto analysis.

- In Japan, the port communication system has been introduced mainly by the national government, and it can be an important information coordination infrastructure for smart ports.

Although the analyses and recommendations in this study are relevant to Japan, evaluating the relationship between port management systems and TOSs may apply to ports outside Japan. The TOS capabilities for smart ports should be implemented according to the characteristics of port management in each region, and studies such as those conducted in this paper are useful in examining port system implementation strategies.

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**Abbreviations**

List of acronyms and abbreviations.

- **ACT** Automated container terminal
- **CT** Container terminal
- **AGV** Automated guided vehicle
- **ASC** Automated stacking crane
- **TOS** Terminal operation system
- **PCS** Port communication system
- **IoS** Internet of Ships
GTO Global terminal operator
MTO Mega terminal operator
POC Port operating company
TO Terminal operator
PA Port authority
RTG Rubber-tired gantry crane
ECS Equipment control system

References
7. Sogut, M.Z.; Erdoğan, O. An Investigation on a Holistic Framework of Green Port Transition Based on Energy and Environmental Sustainability. *Ocean. Eng.* 2022, 266, 112671. [CrossRef]


47. Notteboom, T.E.; Parola, F.; Satta, G.; Pallis, A.A. The Relationship between Port Choice and Terminal Involvement of Alliance Members in Container Shipping. *J. Transp. Geogr.* 2017, 64, 158–173. [CrossRef]


60. Port-IT Solutions. Available online: https://www.seiko-itsolution.co.jp/port.html (accessed on 4 April 2024).

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