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DIGITALIZATION OF OPERATIONAL MANAGEMENT OF SEAPORTS

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ЦИФРОВІЗАЦІЯ ОПЕРАЦІЙНОГО МЕНЕДЖМЕНТУ МОРСЬКИХ ПОРТІВ

The relevance of the research is shaped by the rapid development of digital technologies and the globalization of the world economy, within which seaports face the necessity of constantly improving the efficiency and adaptability of their operations. In particular, this need arises from the increase in global trade volumes and the intensification of competition in the maritime sector, which require ports as complex infrastructure systems to ensure seamless and efficient processing of vessels, passengers, and cargo. Considering the outlined specifics, as well as the central role of ports in the global economy, the digital transformation of their operational management becomes an essential condition for their successful functioning. Thus, the article aims to identify the features of digitalization in the operational management of seaports. The research highlights that the digitalization of ports requires more than just implementing individual technologies. It involves

creating an integrated system that covers all aspects of port operations, from planning and managing vessel traffic to handling cargo and maintaining security control. In this context, a seaport has a rather complex operation related to servicing vessels, passengers, and cargo. Note that the digitalization of planning and coordination involves creating schedules for vessel arrivals and departures, allocating berths and docking points, planning transshipment operations, and coordinating the activities of all participants in port operations. This process is essential for improving the efficiency, throughput, and competitiveness of ports. The digitalization of cargo handling processes in ports involves the reception, storage, and dispatch of various types of cargo, the use of specialized equipment, and the quality control of cargo processing. It is a pathway to enhancing their efficiency, throughput, and competitiveness in the global market. The digitization of vessel servicing processes involves tugging vessels, docking them at berths, disconnecting them from berths, supplying vessels with water, fuel, and provisions, and organizing ship maintenance work. It has been demonstrated that this process aims to enhance the efficiency, safety, and competitiveness of ports in the global market. The digitization of maritime security control involves ensuring the safety of personnel and vessels, preventing accidents, and protecting port areas. This process aims to enhance protection, optimize operations, reduce costs, and improve overall port efficiency.

Актуальність дослідження зумовлена стрімким розвитком цифрових технологій та процеса-ми глобалізації світової економіки, в умовах яких морські порти стикаються з необхідністю по-стійного підвищення ефективності та адаптивності своїх операцій. Зокрема, ця потреба вини-кає через зростання обсягів світової торгівлі та посилення конкуренції в морській галузі, що вимагає від портів, як складних інфраструктурних комплексів, забезпечення безперервної та ефективної обробки суден, пасажирів і вантажів. З урахуванням зазначеної специфіки та клю-чової ролі портів у світовій економіці, цифрова трансформація операційного менеджменту стає необхідною умовою для їх успішного функціонування. Отже, метою статті є визначення особ-ливостей цифровізації операційного менеджменту морських портів. У дослідженні підкрес-люється, що цифровізація портів передбачає не просто впровадження окремих технологій, а створення єдиної інтегрованої системи, яка охоплює всі аспекти діяльності порту: від плану-вання та управління рухом суден до обробки вантажів і контролю безпеки. Морський порт, як суб'єкт господарювання, має складну структуру діяльності, пов'язану з обслуговуванням су-ден, пасажирів та вантажів. Констатовано, що цифровізація процесів планування та коорди-нації охоплює складання графіків прибуття і відправлення суден, розподіл причалів і стикуваль-них місць, планування перевантажувальних робіт, а також координацію дій усіх учасників пор-тових операцій. Цей процес є ключовим фактором підвищення ефективності, пропускної здат-ності та конкурентоспроможності портів. Цифровізація процесів обробки вантажів у портах охоп-лює приймання, зберігання та відправлення вантажів різних типів, використання спеціалізова-ного обладнання, а також контроль якості обробки вантажів. Такий підхід сприяє підвищенню ефективності портів, їхньої пропускної здатності та конкурентоспроможності на світовому рин-ку. Цифровізація процесів обслуговування суден охоплює операції з буксирування, шварту-вання, від'єднання від причалів, забезпечення суден водою, паливом, провіантом, а також організацію ремонтних робіт. Доведено, що цей процес спрямований на підвищення ефектив-ності, безпеки та конкурентоспроможності портів на світовому ринку. Цифровізація контролю безпеки морських портів охоплює безпеку персоналу та суден, запобігання аварійним ситуа-ціям і охорону території порту. Цей процес спрямований не лише на підвищення рівня безпеки, але й на оптимізацію операцій, зниження витрат та покращення загальної ефективності роботи порту.

Key words: personnel safety; terminals; docks; port operations; accident prevention.

Ключові слова: безпека роботи персоналу; термінали; причали; діяльності порту; запобігання аварій-ним ситуаціям.

PROBLEM STATEMENT

The relevance of this research is shaped by the rapid development of digital technologies and globalization of the world economy, within which seaports face the need for constant improvement of efficiency and adaptability

of their operations. The growth of global trade volumes and increasing competition in the maritime industry require ports, as complex infrastructure facilities, to ensure the uninterrupted and efficient handling of ships, passengers, and cargo. Given the outlined specifics, as well as the core

key role of ports in the global economy, the digital transformation of their operational management becomes an essential condition for their successful functioning.

The digitalization of seaports is currently a global trend that continues to expand, covering an increasing number of docks, terminals, warehouses, and pilot services worldwide. Many large and medium-sized ports are actively adopting digital solutions to boost efficiency, security, and competitiveness.

For example, the ports of Scandinavia and the North Sea (Rotterdam, Hamburg, Copenhagen) are known for their ambitious digital transformation plans. Ports in China and Singapore are pioneers in adopting new technologies such as automation and artificial intelligence.

From the existing experience of port digitalization, it is evident that digital technology implementation increases port capacity, reduces operational costs, improves service quality, and ensures a higher level of competitiveness.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The study of theoretical and practical aspects of seaport management, especially the implementation of innovative technologies, is a significant area of scientific research internationally and in Ukraine. Scholars such as Morkunas V.Y., Pashen J., Boon E., Kulisheva O., Kotenko V., and Yakovtsev S. emphasize the importance of digital transformation in port management. At the same time, Melnyk O.M., Onyshchenko O.A., Vasalatiy N.V., Koryakin K.S., Pulayev I.O., Shchenyavskiy H.S., and others highlight the necessity of digital transformation specifically in the operational management of ports, as it encompasses all aspects of their activities, from vessel reception to customer service.

Thus, a detailed study of the features of digital transformation in the operational management of seaports is a relevant scientific task.

PURPOSE OF THE ARTICLE

The article aims to identify the characteristics of digitalization in the operational management of seaports.

THE PAPER MAIN BODY WITH FULL REASONING OF ACADEMIC RESULTS

The study highlights the high level of complexity in the operations of seaports related to servicing vessels, passengers, and cargo. To enhance efficiency and competitiveness, ports integrate digital technologies into every aspect of their operations. This process is a response to the growing volumes of global trade, changes in cargo structures, increasing economic demands, and heightened competition [1; 2].

Thus, the sustainable increase in global trade volumes is a characteristic feature of modern globalization. It leads to a rise in transportation volumes, which in turn results in the overloading of port infrastructure, slowing down the processing of vessels and cargo. It negatively impacts the cost of logistics operations and customer satisfaction.

Table 1. Problems of planning and coordination processes in seaport operations

Components complicating operational management	Features complicating operational management	Digital Technologies Addressing These Issues
Complexity and interdependence of processes	Planning in ports involves the coordination of a large number of interrelated processes, from the arrival of the vessel to the dispatch of cargo.	Integrated planning systems Real-time management systems Intelligent data analytics Mobile applications
Time constraints	Any delay in one of the processes can lead to a «domino effect» and disrupt the entire port's schedule.	
High cost of downtime	The downtime of a vessel in port is associated with significant financial losses for all participants in the process.	

Source: formulated by the author based on [1; 3].

Ports need to continuously expand, modernize infrastructure, implement new technologies, and optimize processes to avoid negative consequences.

The constant and sometimes rapid change in cargo structures (such as the increase in container shipments and the emergence of new types of cargo like liquefied gas, wind turbines, etc.) requires appropriate flexibility in port infrastructure and technological equipment. Ports must be prepared to handle various types of cargo, which necessitates investing in versatile equipment and flexible technological solutions.

The growing awareness of a sea port's responsibility for environmental conditions leads to increased ecological requirements for port activities. Ports must implement environmentally friendly technologies, such as wastewater treatment systems and alternative fuel types use, which require significant investments and the development of new solutions.

The increasing number of seaports and the intensifying competition among them compel ports to continually seek new ways to attract customers and enhance their appeal. Ports must offer clients a wide range of services, high-quality customer service, competitive rates, and rapid cargo processing.

It is worth noting that through the constant updating of equipment and software, a comprehensive transformation is taking place that encompasses all aspects of port operations, from operational planning and resource management to ongoing interactions with clients and regulatory authorities. Thus, this is a set of changes that manifest in the following areas: planning and coordination; cargo handling; vessel servicing; security control.

We observe the continuous evolution of technologies, which contributes to the comprehensive digitalization of seaports, encompassing all aspects of their operations. Therefore, to define the essence of this process, let's take a closer look at how digital solutions impact each of the aforementioned areas.

Indeed, the digitalization of planning and coordination processes involves the scheduling of vessel arrivals and departures, allocation of berths and docking spaces, planning of transshipment operations, and coordination

Table 2. Problems of cargo handling processes in seaports

Components complicating operational management	Features complicating operational management	Digital Technologies Addressing These Issues
Increasing demands for the speed and accuracy of cargo handling	Increasing transportation volumes, shortening delivery times, and raising customer demands for order accuracy	Internet of Things (IoT) Robotics Artificial Intelligence Blockchain Digital Platforms
Insufficient transparency and traceability of cargo handling processes	The absence of a unified information system, difficulties in data exchange among various participants in the process, and the risk of loss or damage to cargo.	
Not always effective resource utilization	Inefficient use of warehouse space, equipment, and human resources	
Heightened safety requirements for cargo handling in ports	Risk of cargo damage, unauthorized access, hazardous cargo.	
Increased demands for the environmental sustainability of cargo handling processes	Emissions of harmful substances, water pollution, noise pollution.	

Source: formulated by the author based on [1; 4–6].

among all participants in port operations (freight forwarders, stevedores, customs officials, etc.) [1; 3].

Thus, this process is a core factor in enhancing the efficiency, capacity, and competitiveness of ports. This area of operational management is important due to issues such as (see Table 1): the complexity and interdependence of business processes; time constraints; the high cost of downtime.

Digitalization of the planning and coordination processes in seaport operations addresses the outlined issues through [1–3]:

1. The creation of integrated planning systems based on a platform that consolidates all data about vessels, cargo, berths, and port resources. It allows for:

- the automatic scheduling of vessel arrivals and departures, considering all constraints and priorities;
- optimizing the allocation of berths and docking spaces;
- planning transshipment operations based on the characteristics of the cargo and equipment.

2. The creation of real-time management systems aimed at monitoring vessel movement, equipment status, and berth occupancy online allows for prompt responses to changes in the situation and adjustments to the plan.

3. Focusing on intelligent data analytics, specifically the application of machine learning algorithms for demand forecasting, anomaly detection, and process optimization.

4. The creation of mobile applications with options for accessing information about port operations for all participants via mobile devices.

China, as one of the global leaders in maritime transport, is actively implementing digital technologies in its ports. An example of successful digital transformation is the creation of virtual models of the ports of Shanghai, Shenzhen, and Ningbo-Zhoushan. These models allow for the simulation of various scenarios, optimization of logistics processes, and increased operational efficiency of the ports. Additionally, digitalization promotes transparency and security in data exchange among all participants in port operations.

The digitalization of cargo handling processes in ports involves the reception, storage, and dispatch of various types of cargo (containers, bulk cargo, general cargo, etc.), the use of specialized equipment (cranes, forklifts, conveyors, etc.), and quality control of cargo handling. Thus, this is a path to increasing their efficiency, capacity, and competitiveness in the global market.

This area of operational management is important due to issues such as (see Table 2):

- increasing demands for the speed and accuracy of cargo handling;
- insufficient transparency and traceability of cargo handling processes;
- resource utilization is not always effective;
- heightened safety requirements for cargo handling in ports;
- increased demands for the environmental sustainability of cargo handling processes.

The digitalization of cargo handling processes in seaports addresses the outlined issues through [1; 4–6]:

1. The implementation of sensors for monitoring the condition of containers, temperature control, and the load levels of vehicles.

2. Automation of routine operations such as container movement, packing, and unpacking of cargo.

3. Optimization of transport routes, demand forecasting for port services, and automatic image recognition.

4. Ensuring transparency and security in data exchange, tracking cargo throughout the entire supply chain.

5. Creation of unified digital platforms for interaction among all participants in port operations, from freight forwarders to customs authorities.

Large American ports, such as Los Angeles and Long Beach, are pioneers in implementing comprehensive digital transformation. A hallmark of their approach is a systematic method to digital modernization, which involves not isolated solutions but the integration of various technologies. In particular, these ports actively utilize IoT technology for monitoring the condition of containers. Sensors installed on the containers provide continuous monitoring of their integrity, temperature, and other parameters, ensuring the preservation of cargo during transportation. Special containers with precise temperature control are provided for temperature-sensitive cargo. In addition, weight sensors allow for the optimization of vehicle loading, enhancing the efficiency of transport resources and reducing costs.

The digitalization of vessel servicing processes involves towing vessels, docking and undocking them, supplying ships with water, fuel, and provisions, and organizing repair work on the vessels [6–7]. Thus, this

Table 3. Problems in vessel servicing at seaports

Components complicating operational management	Features complicating operational management	Digital Technologies Addressing These Issues
Insufficient coordination between various port services	The lack of a unified information system and difficulties in data exchange between various services (pilotage, towing, customs, etc.) lead to delays and errors.	Automatic data exchange systems. Demand forecasting. Automation of routine operations. Electronic document management.
Long waiting times for vessels	Inefficient berth planning, delays in servicing, unforeseen situations (weather conditions, equipment breakdowns).	
High vessel servicing costs	Inefficient use of resources (tugs, energy, water), manual operations, accounting errors.	
Documentation errors	Paper-based documentation, risk of document loss, human error.	
Safety risks	Unauthorized access to the vessel, accidents, terrorist threats	

Source: formulated by the author based on [2; 6—7].

process aims to enhance the efficiency, safety, and competitiveness of ports in the global market [2]. This area of operational management is crucial due to issues faced by seaports, such as (see Table 3): insufficient coordination between different port services; long waiting times for vessels; high vessel servicing costs; errors in documentation; and safety risks.

The digitization of vessel servicing processes in seaports addresses these outlined problems through [6—7]:

1. Automatic data exchange systems, enable instant information sharing between all participants (vessels, ports, customs, agents). For example, AIS (Automatic Identification System) is used for tracking vessel movements and enabling electronic message exchanges between vessels and ports.

2. Demand forecasting enables the prediction of port workload, helping to more efficiently plan the use of berths, tugs, and other infrastructure. This minimizes vessel waiting times at anchorage.

3. Automation of routine operations increases task execution speed and reduces the number of errors. Examples include automatic mooring systems, robotic systems for cleaning vessels, and automated cargo identification systems.

4. Electronic document management reduces the time needed for document processing, ensures protection of information against loss and unauthorized access, and allows for tracking the movement of documents and responsible individuals.

The Port of Rotterdam, one of the largest in Europe, is a leader in implementing digital innovations. The port demonstrates how modern technologies can optimize vessel servicing [2].

For example, a vessel approaching the port is automatically identified using the AIS system. Artificial intelligence analyzes current loads and forecasts to determine the optimal berth for docking [7]. Next, the automatic mooring system ensures safe and efficient docking of the vessel. The entire process is accompanied by electronic document management and

data about the ship and cargo is stored on a unified digital platform, accessible to all stakeholders, from the ship's crew to customs authorities.

Digitalization of maritime port security involves processes aimed at ensuring the safety of personnel and vessels, preventing emergencies, and securing the port area. Thus, this process is aimed at enhancing security levels, reducing costs, and optimizing the overall efficiency of port operations.

This area of operational management is important due to issues such as (Table 4): increased safety requirements for personnel and vessels; complexity in preventing emergencies; significant efforts in securing the seaport area.

The digitization of safety control processes in seaports addresses outlined problems through [2—3]:

1. Early warning systems that analyze data from various sources (cameras, sensors) to detect signs of potential accidents.

2. Artificial intelligence that provides predictions of emergencies based on historical data. It can serve as the basis for facial recognition and access control systems.

Table 4. Problems of seaport security control

Components complicating operational management	Features complicating operational management	Digital technologies addressing these issues
Increased demands for the safety of personnel and vessels	Increasing number of regulations, the need for continuous safety monitoring, and the complexity of ensuring compliance.	Early warning systems for emergencies. Artificial intelligence. Drones
Complexity in preventing emergency situations	A large number of potential risks, the complexity of predicting emergency situations, and the need for rapid response	
Significant efforts required for port area security	Large areas, a variety of facilities, and the need for round-the-clock monitoring..	

Source: formulated by the author based on [2—3; 7].

3. Drones are used to inspect hard-to-reach areas and rapid response to incidents.

The ports of Singapore are a global leader in the field of digital security. One of the key elements of their system is an extensive network of surveillance cameras that covers the entire port area [2]. Thanks to the implementation of artificial intelligence, video data is analyzed in real-time [7]. AI algorithms can detect various deviations from normal operations, such as container falls, signs of fire, equipment damage, unauthorized access, and more. This approach ensures proactive safety monitoring and enables prompt responses to any incidents.

Digitalization of ports involves the isolated implementation of individual technologies, and integrated system creation encompasses all aspects of port operations [1; 6]. It is because all the highlighted areas of digitalization are closely interconnected. For example, optimizing planning (point 1) allows for more efficient organization of cargo handling (point 2) and vessel servicing (point 3). Moreover, safety control (point 4) is, in one way or another, an integral part of all processes [1—2; 7].

CONCLUSIONS FROM THIS STUDY AND PROSPECTS FOR FURTHER EXPLORATION IN THIS DIRECTION

The study emphasizes that the digitalization of ports involves the creation of an integrated system that encompasses all aspects of port operations — from planning and managing vessel traffic to cargo handling and security control. A seaport has a rather complex operation associated with servicing vessels, passengers, and cargo. In this regard, the following conclusions can be drawn regarding the features of digitalization in seaports:

1. The digitalization of planning and coordination processes involves scheduling the arrival and departure of vessels, allocating berths and docking points, planning cargo handling operations, and coordinating the activities of all participants in port operations. Thus, this process is a core factor in enhancing the efficiency, throughput, and competitiveness of ports.

2. The digitalization of cargo handling processes in ports involves receiving, storing, and dispatching various types of cargo, utilizing specialized equipment, and ensuring quality control in cargo handling. Thus, this is a way to enhance their efficiency, throughput, and competitiveness in the global market.

3. Digitalizing vessel servicing processes includes towing vessels, docking and undocking them, providing vessels with water, fuel, and supplies, as well as coordinating vessel maintenance work. Thus, this process aims to enhance the efficiency, safety, and competitiveness of ports in the global market.

4. The digitization of maritime security control involves processes to ensure the safety of personnel and vessels, prevent emergencies, and secure port areas. Thus, this process is aimed not only at enhancing safety levels but also at optimizing processes, reducing costs, and improving the overall efficiency of port operations.

Further research could focus on the development of intelligent port management systems based on artificial intelligence and blockchain, as well as the analysis of social and environmental aspects of digital transformation.

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