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Logistics of *Smart Port* in Ukraine: Problems and Prospects in the Conditions of Sustainable Development

Logistyka *inteligentnych portów* w Ukrainie: problemy i perspektywy w warunkach zrównoważonego rozwoju

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Abstract

Every day, the global logistics industry faces new challenges – both due to the Russian invasion of Ukraine and due to economic instability in global markets. The pandemic and the disruption of traditional supply chains are forcing companies to change their production geography. Accelerated digitization of people's and companies' livelihoods is contributing to the transformation of classical logistics, and in the end, those players who create an environment of additional services for delivery support, thereby forming resilience to risks, are winning. In this regard, there is a need to develop theoretical and applied aspects of the transition of port logistics to sustainable development through the introduction of *smart port* technologies that contribute to the achievement of a number of sustainable development goals, such as: 1: no poverty, 2: zero hunger, 3: good health and well-being, 8: decent work and economic growth, 9: industry innovation and infrastructure, 11: sustainable cities and communities, 12: responsible consumption and production, 13: climate action, 14: life below water, 17: partnerships for sustainable development.

The theoretical basis of the research was scientific works of scholars from different countries and periods in the field of logistics, sustainable development, individual provisions of international framework documents, including the UN Conference on Environment and Development's Agenda for the 21st Century, the Declaration on Environmental Protection, and the Johannesburg Declaration on Sustainable Development. Official data from the ports of Gdansk, Rotterdam, and Hamburg, the International Association of Ports and Harbors (IAPH), the World Ports Climate Initiative (WPCI), the World Bank, and the Administration of Seaports of Ukraine (USPA) were used as initial information for analysis and concluding. As a result of summarizing the theoretical and methodological foundations of logistics, the article proposes the *Conceptual Model of the Subject Area 'Smart Port'*, the quintessence of which lies in the symbiosis of the paradigms of scientific and technical development and sustainable development. This made it possible to expand the existing scientific basis of the transport logistics and transport systems sphere. The prerequisites for the emergence of the *smart port* are analyzed. The leading container ports of different generations are grouped.

Special focus is on Ukraine, one of the largest grain exporters in the World. The prospects for the transition of Ukrainian ports to the fourth category (generation) of development are outlined. To successfully implement the strategy for the development of Ukrainian seaports for the period up to 2038, an optimization management model for logistics processes was developed based on the concept of a gaming approach.

Key words: sustainable development, logistics, sustainable logistics, transport logistics, transport system, smart port

Streszczenie

Globalna branża logistyczna każdego dnia staje przed nowymi wyzwaniami – zarówno w związku z rosyjską inwazją na Ukrainę, jak i niestabilnością gospodarczą na światowych rynkach. Pandemia i zakłócenie tradycyjnych łańcuchów dostaw zmusza firmy do zmiany geografii produkcji. Przyspieszona cyfryzacja źródeł utrzymania ludzi i firm przyczynia się do transformacji klasycznej logistyki. Ostatecznie zwyciężają ci gracze, którzy tworzą środowisko dodatkowych usług wspierających dostawy, kształtując w ten sposób odporność na ryzyko. W tym zakresie istnieje potrzeba opracowania teoretycznych i aplikacyjnych aspektów przejścia logistyki portowej do zrównoważonego rozwoju poprzez wprowadzenie technologii *inteligentnego portu*, które przyczyniają się do osiągnięcia szeregu celów zrównoważonego rozwoju, takich jak: 1: brak ubóstwa, 2: zero głodu, 3: dobre zdrowie i samopoczucie, 8: godziwa praca i wzrost gospodarczy, 9: innowacyjność i infrastruktura przemysłu, 11: zrównoważone miasta i społeczności, 12: odpowiedzialna konsumpcja i produkcja, 13: działania na rzecz klimatu, 14: życie pod wodą, 17: partnerstwa na rzecz zrównoważonego rozwoju.
Teoretyczną podstawą badań były prace naukowe uczonych z różnych krajów i okresów z zakresu logistyki, zrównoważonego rozwoju, poszczególne zapisy międzynarodowych dokumentów ramowych, w tym Konferencji ONZ ds. ochrony oraz Deklaracja z Johannesburga w sprawie zrównoważonego rozwoju. Oficjalne dane z portów w Gdańsku, Rotterdamie i Hamburgu, Międzynarodowego Stowarzyszenia Portów i Przystani (IAPH), World Ports Climate Initiative (WPCI), Banku Światowego oraz Administracji Portów Morskich Ukrainy (USPA) wykorzystano jako wstępne informacje do analizy i wnioskowania. W wyniku podsumowania teoretycznych i metodologicznych podstaw logistyki w artykule zaproponowano *Model koncepcyjny obszaru przedmiotowego 'Smart Port'*, którego kwintesencją jest symbioza paradygmatów rozwoju naukowo-technicznego i zrównoważonego rozwoju. Umożliwiło to poszerzenie istniejącej bazy naukowej z zakresu logistyki transportu i systemów transportowych. Przeanalizowano przesłanki powstania *inteligentnego portu*. Wiodące porty kontenerowe różnych generacji są pogrupowane. Nakreślono perspektywy przejścia ukraińskich portów do czwartej kategorii (generacji) rozwoju.
Szczególną uwagę poświęcono Ukrainie, jednemu z największych eksporterów zbóż na świecie. W celu skutecznej realizacji strategii rozwoju ukraińskich portów morskich do 2038 roku opracowano model zarządzania optymalizacją procesów logistycznych oparty na koncepcji podejścia gamingowego.

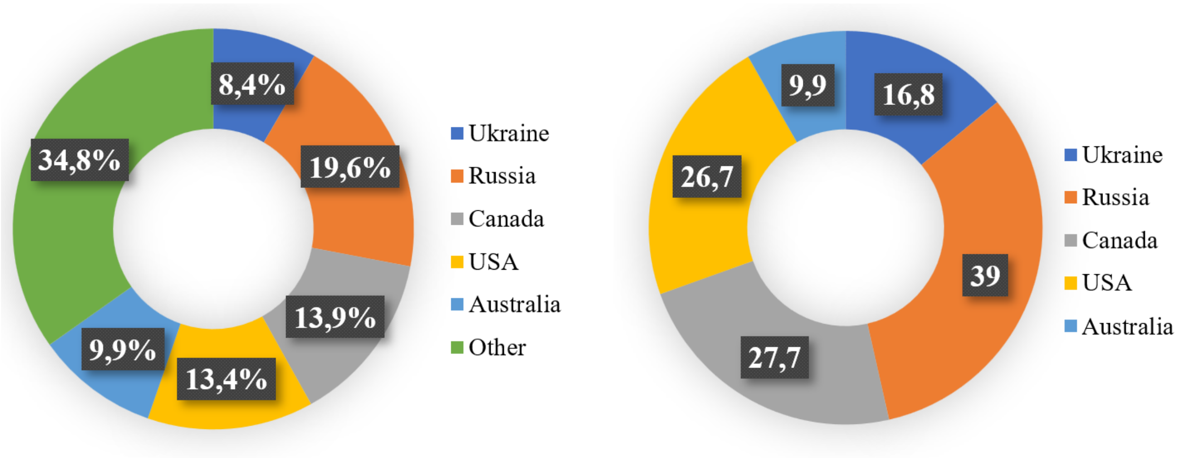
Słowa kluczowe: logistyka, zrównoważona logistyka, logistyka transportu, system transportowy, inteligentny port, zrównoważony rozwój

1. Introduction

The Agenda for sustainable development until 2030, including its 17 goals (SDGs), represents a comprehensive program of action that sets new requirements in the economic, social, and environmental spheres. Despite progress in implementing the agenda, the results often deviate from the scale of the tasks set for countries to achieve the SDGs. This is due to some factors, the impact of which cannot be stopped, and predicting them is quite difficult. The activation of efforts is especially relevant in the context of responding to the consequences of the COVID-19 pandemic and the war in Ukraine. In this regard, the SDGs are of paramount importance in defining the contours of post-crisis recovery, which is intended to transform the economy into a more environmentally friendly and inclusive one, thereby ensuring the sustainability of territories.
It is obvious that despite the negative impact of risk factors, the world continues to experience rapid changes in information and communication technologies (ICTs). Emerging changes affect network technologies, computing, and communication devices, as well as data processing. As a result, information technology is increasingly being used in all areas of human activity. Among the actively developing areas of scientific research are *smart homes, smart cities, smart transportation systems, smart ports, smart containers* and so on.
The presented research results are devoted to transportation logistics, which is considered a complex, independent system with its laws of functioning, the components of which are moving cargo flows, types of transport used, transportation process technologies, as well as infrastructure. Even though the port and container transportation industry is often considered conservative, new technologies, systems, and innovative solutions, in our view, quickly penetrate this sphere of activity, especially in the last decades, contributing to the qualitative transformation of this sector.
According to official data from the Port of Gdansk over the past 6 years, the volume of cargo handling at the port has increased by 83%. The result for 2022 was the best in the history of the enterprise, but as of February 2023,

the volume of cargo handling increased by another 68.2 million tons, indicating a sustainable growth trend (Port Gdańsk, 2023). The efficiency of the transshipment of the Port of Gdansk is directly related to the implementation of *smart port* technologies, as well as the modernization of 5 km of universal docks, which are used for current transshipments and directly provide the ability to handle additional volumes of cargo. The implementation of such large-scale measures was carried out thanks to one of the largest investment projects, *Modernization of the fairway, expansion of docks, and improvement of navigation conditions in the Inner Port*, with capital expenditures of over 595 million zlotys or USD 133.7 million. The project was financed by 85% of the European Union through the CEF instrument (Port Gdansk, 2023).

It is well-known that around 90% of goods in world trade are transported by sea, with most of them in containers, of which there are about 400 million in the world (International Transport Forum, 2023). Ukraine, being one of the largest grain exporters (Figure 1), as shown in 2022-2023, has had a significant impact on world exports, which has also been reflected in certain indicators of sustainable development. In peacetime, about 75% of Ukraine's external trade passed through ports (GMK. Centr, 2023).



Share in world export, % Export volume, million tons

Figure 1. Largest exporters of wheat, source: (Statista, 2023)

Currently, the seaports of Mariupol, Berdyansk, Skadovsk and Kherson, which are located in temporarily occupied territory, are closed and require restoration or modernization. Also, Ukraine cannot use the Dnieper River for logistics since the Kakhovka lock has been captured. Other ports, although not occupied, are completely blocked by the Russian Navy and are a mine hazard.

The blocking of Ukrainian ports by Russia led to a reduction in grain supplies, which affected global price increases, and also negatively affected food security, thereby making it difficult to achieve Goal 1: the elimination of poverty and Goal 2: the elimination of hunger, sustainable development. According to the United Nations Report on Sustainable Development Goals for 2022, the crisis in Ukraine has led to food shortages for the poorest populations in the world. In addition, the sharp rise in food prices has affected 47% of countries. From January 2020 to March 2022, the price of wheat increased by 145%. By July 2022, prices had decreased but remained 45% higher compared to January 2020. Approximately one in ten people in the world suffer from hunger, with one in three lacking regular access to adequate food (UN, 2022).

In this context, the relevance of the chosen research direction is unconditional and explains the interest of the author's team in this issue. Considering that Ukraine is facing post-war reconstruction, we consider it necessary to propose a series of author's developments that will allow traditional Ukrainian ports to become modern, thus creating a range of advantages that will help retain and increase competitiveness on both the European and global markets by meeting the increased demands of customers.

2. Methodology

The presented research results were obtained during the implementation of the R&D 0121U110906 *Methods and means of managing the development of port systems and service enterprises in transportation*; R&D 0120U002195 *Methods and tools for business process analytics of entrepreneurship entities in the transport and tourism sectors;* and the departmental topic 02011 *Optimization of transport and logistics systems and technologies in the infrastructure of the Zaporizhzhia region*, which is ongoing. As a result, a scientific foundation was formed, based on the work of scientists dedicated to the analysis of world trade and its prospects, research on maritime transportation and cargo, priorities in sustainable development in the context of further implementation, in the Ukrainian space, of the theory of the *smart port*. These include P. Achurra-Gonzalez, P. Angeloudis, N. Goldbeck; T. Lakshmanan;

Z. Munim, H. Schramm; T. Bjorner; D.J. House; Y. Popova, A. Galkin, V. Kyselov, T. Kniazieva, M. Kutsenko, N. Sokolova; H. Alyami, Z. Yang Riahi, S. Bonsall, J. Wang; Boichenko E., Martynovych N., Shevchenko I.; Vivchar O., Popovych O., Kasianenko O., and others.
The information base of the study was Ukrainian and European Union regulatory legal acts, official reports of state and regional authorities, international organizations, and research by domestic and foreign scientists, in terms of logistics regulation and sustainable development. In particular, key scientific, methodological, and practical conclusions were based on international framework documents, including the Report of the United Nations Conference on Environment and Development *Agenda for the Twenty-first Century*, the Declaration on Environmental Protection, and the Johannesburg Declaration on Sustainable Development. Official data from the ports of Gdańsk, Rotterdam, Hamburg, the International Association of Ports and Harbors (IAPH), the World Ports Climate Initiative (WPCI), the World Bank, and the Administration of Seaports of Ukraine (USPA) were used as the initial information for analysis and conclusions.
The following scientific methods were used during the research: historical-logical (when distinguishing generations of ports); general scientific knowledge (when establishing the essence of the categories *smart port* and *sustainable logistics*); system approach (when developing a conceptual model of the subject area *smart port*); logical analysis, induction, deduction (when establishing the cause of the emergence of a *smart port*, determining the prospects for Ukrainian ports to transition to the fourth category (generation) of development); systematization (when grouping leading container ports by generations); elements of game theory (when forming a model for optimizing the management of logistics processes).

3. Findings and Discussion

3.1. Theoretical discussion
Based on general scientific research methods (analysis, synthesis, induction, deduction, analogy), the lack of balance between the components of sustainable development in the works of many 20th-century scientists has been established, as well as the fact of business focus on achieving economic goals at the expense of environmental and social ones. P. Achurra-Gonzalez, P. Angeloudis, and N. Goldbeck (Achurra-Gonzalez, Angeloudis, Goldbeck, 2019) describe the existing theoretical and applied contradictions between traditional and green logistics. In the studies of T. Lakshmanan (Lakshmanan, 2011) Z. Munim, and H. Schramm (Munim, Schramm, 2018), scientists identify the main shortcomings of existing models of sustainable development, including the static nature and insufficient emphasis on the dynamics of the development process; fragmentary connections between aspects of sustainable development (ecology, economy, and society); the complexity of practical implementation of the concept of sustainable development due to the multitude of constraints and contradictions in its goals.
Among Ukrainian scientists, there is an active discussion regarding the appropriateness of applying the concept of port activity. Moreover, contemporaries of Ukrainian science in the field of logistics, overwhelmingly consider the English or French concept, choosing as an argument its applicability, advantages, and disadvantages, as well as the presence of competition between ports, which determines two alternatives. Thus, in the absence or presence of insignificant competition, the port can take a monopolistic position in the market, which may harm consumers of port services. To avoid such a situation, regulation is applied by the state, which is the basis of the French model. In contrast to the French model, the English one is applied in cases where ports are in a competitive struggle (Remzina, 2016).
However, according to the authors of this article, the choice of the model for conducting port activities in Ukraine should be made by analyzing several key influencing factors, at least over the past five years, since the forecast data for the results of implementing innovations make up ½ of the analyzed period (Makridakis S., Hibon M., 2000). That is, if there is data over five years, the forecast period (short-term) may be no more than 2-2.5 years. In addition, it is quite difficult to apply any one concept in its pure form, due to cultural, economic, political, and other peculiarities of countries that determine the quantity and quality of ports and their range of services provided. For example, France has about 70 seaports and river ports, three of which are the largest in Europe: Port of Le Havre, Port of Dunkirk and Port of Fos-sur-Mer (IAPH, 2023).
Due to its geographical location, Great Britain has always been considered the largest maritime power. There are about 90 ports on its territory, 10 of which are large and the biggest are: Port of Felixstowe, Port of Hull, Port of Southampton, Port of Thamesport and Port of Tilbury (IAPH, 2023).
All these differences require additional analysis of the experience of various countries, the use of a differentiated approach in the development and implementation of both the concept of port activity and the concept of *smart port*.
It should also be noted that logistics remains one of the main sources of pollution, accounting for about 20% of global CO_2 emissions (WPCI, 2023). Therefore, without environmental sustainability, supply chains will not be economically sustainable. Based on the above, the purpose of the article is to develop theoretical and methodological approaches to the development of smart port logistics in the context of sustainable development.

3.2. The concept of the smart port domain

First of all, it should be noted that in the studies of modern scientists, such concepts as smart city, smart home, smart factory, etc. have been used. It is important to pay attention to the fact that the structure of these concepts is common in the approaches to defining their genesis. Firstly, it is the presence and use of innovative information and communication technologies, that is, the paradigm of scientific and technical development. Secondly, it is the provision of the paradigm of sustainable development. Thus, the smart port is a fully automated seaport that uses innovative technologies created based on artificial intelligence, combined with a centralized system that monitors, collects, and analyzes data, and optimizes processes, which contributes to prompt decision-making at the operational and managerial levels.

Based on all of the above, the smart port should be understood as a fundamentally new model of a logistics system created based on a symbiosis of the paradigms of scientific and technical development and sustainable development (Fig. 2).

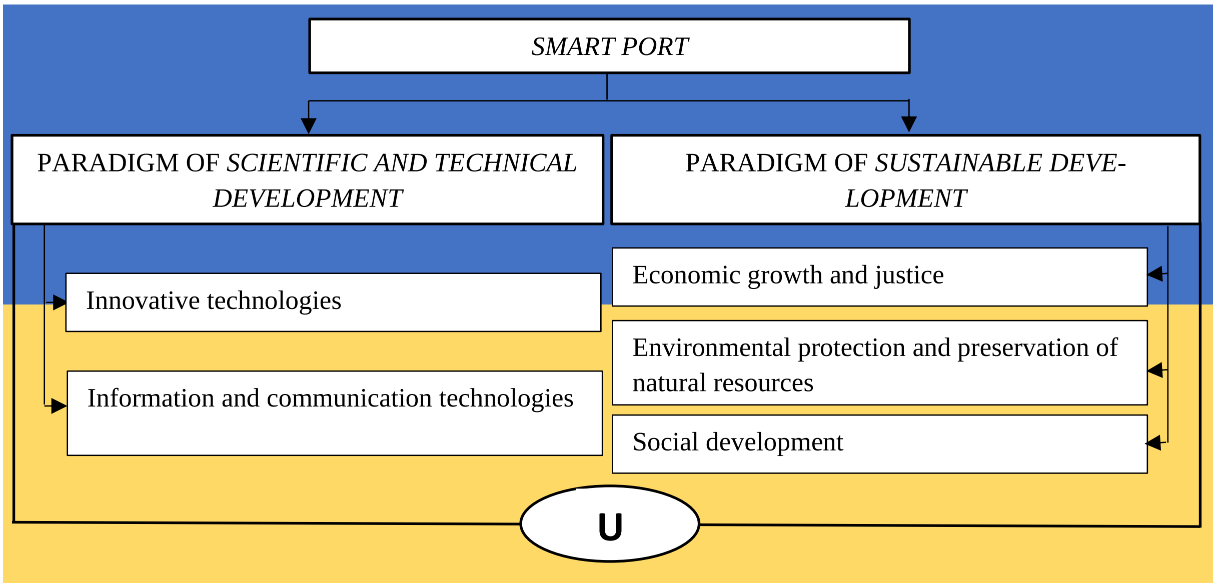


Figure 2. Conceptual model of the subject area *smart port,* source: author's own work

It should be noted that the paradigm of sustainable development is based on the postulates of the theory of equilibrium, according to which any development should be aimed at achieving a state of equilibrium. It can also be said that any activity of economic entities should be ensured through a harmonious combination of a state of equilibrium, which implies stability on the one hand, and a state of change, which ensures development, on the other hand. Therefore, the state of stability can be expressed in the form of an equilibrium state, the achievement of which is facilitated by the processes of change and development (Boichenko, Martynovych, Shevchenko, 2021).

J. Elkington defines *corporate sustainable development* as an approach to the activities of economic entities aimed at creating long-term value based on comprehensive management of economic, environmental, and social factors. The economic aspect is understood as a concept reflecting the financial indicators of the company, aimed at analyzing the company's contribution to the development of the national economy and the implementation of its economic strategy. The social aspect is considered as the company's activity in the field of labor protection, preservation of public health, social programs to assist the population, compliance with human rights, etc. The environmental aspect determines the protection and preservation of the environment. This component of sustainable development is aimed at reducing the anthropogenic impact on the environment (Johannesburg Declaration on Sustainable Development, 2002).

At the national level, sustainability is considered in the interrelation of its three components. Firstly, this is economic growth and justice, which involves the application of a comprehensive approach to stimulating long-term economic growth. Secondly, it is the preservation of natural resources and environmental protection, which involves finding economically acceptable solutions to reducing resource consumption and reducing the environmental pollution. Thirdly, this is social development – such as providing the population with jobs, food, educational, medical, cultural, and communal services; careful treatment of cultural heritage; observance of the rights of various population groups, including providing opportunities for all members of society to participate in decision-making, etc. (Johannesburg Declaration on Sustainable Development, 2002; Environmental Declaration, 2002; Agenda 21)

The development of innovative technologies based on modern scientific achievements and their wide implementation in all spheres of activity opens up new horizons for their application. Due to its technological innovations resulting from the Fourth Industrial Revolution (Industry 4.0), modern ports have succeeded in transforming the established ways of organizing and managing the logistics system, which contributes to the achievement of Goal 11: sustainable cities and towns, Goals 12: responsible consumption and production, Goals 17: partnership for sustainable development; as well as in improving working methods, increase labor productivity, including by reducing downtime, optimizing the path, ship parking, unloading and loading cargo, etc., thereby ensuring the achievement of Goal 8: decent work and economic growth. (Galkin, Popova, Kyselov, Kniazieva, Kutsenko, Sokolova, 2020).

The main components of a *smart port* can be called the presence of a *smart infrastructure* and *smart logistics of cargo transportation*. *Smart infrastructure* is provided by digital technologies, used to automate port operations, and contributes to increasing port productivity. It ensures an uninterrupted, unimpeded, and optimized flow of moving assets, such as automatic transport vehicles, cargo trucks, and so on. All this has a positive impact on the achievement of the above sustainable development goals, as well as Goal 9: industry innovation and infrastructure. *Smart Logistics* supports the automatic movement and handling of containers using unmanned (autonomous) cranes and equipment; facilitates communication between port users; provides access to the global port logistics system, the port community network, which strengthens partnerships for sustainable development – Goal 17; organizes monitoring of energy consumption; automates the system of customs procedures; provides access to a geographic information system, etc., thereby bringing closer the achievement of Goal 7: affordable and clean energy and Goal 9: industrialization, innovation and infrastructure. In addition to automated systems for calculations and mobile asset management, logistics is reflected in the creation of transport portals built on the principle of bulletin boards and ranked primarily into two categories - vehicle owners (freight carriers) and transport company users. They can be used to quickly search for automotive transportation and find partners in the field of forwarding services (Bjorner, 1999).

It is important to note that with the increase in transportation volumes in the global logistics system and the intensification of competition between companies, the importance of ensuring the safety and environmental friendliness of the flow of goods is increasing. This contributes to the actualization of the tasks of sustainable development of logistics systems. Sustainable development of *smart port* logistics systems means that planning and organization of goods flows should not contradict the priorities of environmental protection and public health of society (Goal 3: good health and well-being), and should not lead to irreversible natural changes and depletion of irreplaceable resources (Goal 13: climate action, Goal 14: life below water). The sustainability of the *smart port* logistics system is based on a triad of postulates:

- meeting the needs of society in conditions of environmental safety, while preserving public health, with equal opportunities within and between generations (SDG 1: End poverty in all its forms everywhere, SDG 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture, SDG 3: Ensure healthy lives and promote well-being for all at all ages);
- being efficient and accessible, offering a wide range of transportation options, supporting a productive economy (SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation, SDG 11: Make cities and human settlements inclusive, safe, resilient, and sustainable, SDG 12: Ensure sustainable consumption and production patterns, SDG 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development);
- contributing to the reduction of harmful emissions and waste into the environment, noise pollution, the reduction of consumption of non-renewable resources, rational consumption of renewable resources and land use, and effective disposal and reuse of waste (SDG 6: Ensure availability and sustainable management of water and sanitation for all, SDG 13: Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy, SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development) (Kumar, 2015).

3.3. Prerequisites for the emergence of a 'smart port'

The prerequisites for the emergence of a *smart port* can be considered the existing changes in the field of logistics systems. In the conditions of globalization of world trade, ports are traditionally divided into four categories (generations), the classification of which is based on assessments of port activity according to criteria such as port development strategy, the scale of activity, management, and diversification of activities (House, 2016). The evolution of port development is presented in the figure 3.

In first-generation ports, which dominated until the 1960s, various types of port activities or separate production units functioned in relative isolation from each other. They served as an intermediary between sea and land transport in the transport chain of goods movement from the place of production to the place of consumption. Capital investments in these ports were mainly directed toward the development of port infrastructure related to shipping handling, wagon handling, and warehousing operations.

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transport in the transport chain of goods movement from the place of production to the place of consumption. Capital investments in these ports were mainly directed toward the development of port infrastructure related to shipping handling, wagon handling, and warehousing operations. Currently, many ports in the world can be classified into this category, the management of which is usually focused on solving problems related to the cargo handling and storage process. It is traditional for such ports to have their communication, documentation, and statistics system, often not comparable to the accounting systems of their clients.

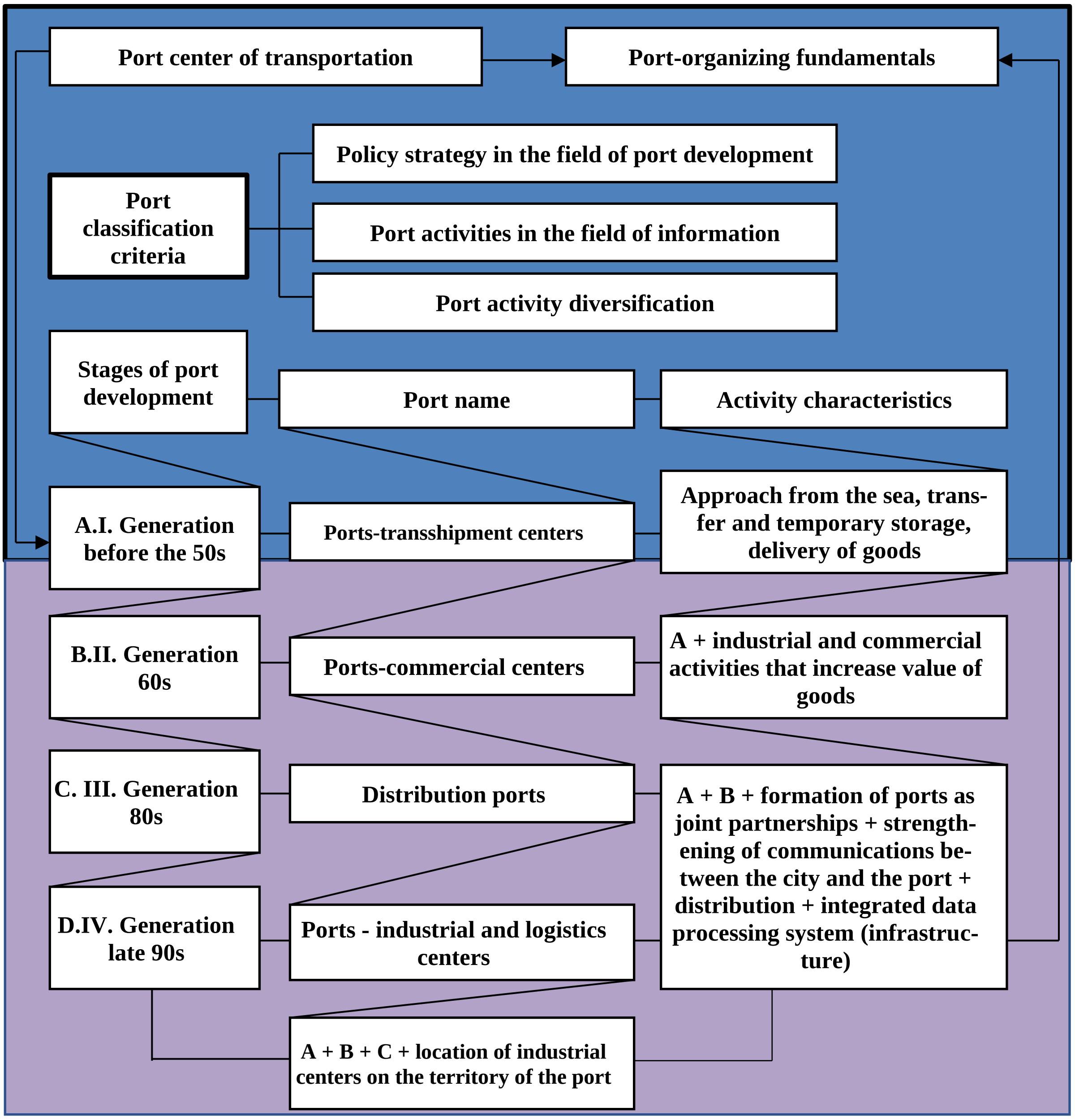

Figure 3. Evolution of port development in the 20th century, source: compiled by the authors based on (UNCTAD, 2018)

Second-generation ports, which emerged in the 1960s, are associated with the intensive growth of international trade and the import of raw materials. Such ports are transportation, industrial, and commercial service centers. They are oriented towards a diversification strategy of services, which aimed to provide not only stevedoring but also industrial, commercial, and other services. The management in second-generation ports links the cargo handling process with the process of production and distribution of manufactured goods. The level of organizational integration provides close links with transportation and trade partners for the industrial processing of goods in a location accessible to the port. It should be noted that such ports are highly dependent on the surrounding city and its resources, as well as the transportation infrastructure.

The concept of third-generation ports, which emerged in the 1980s, not only involves the handling of cargo and the provision of related services, but also the creation of an efficient logistics platform. Fourth-generation port activity, which emerged in the late 1990s and early 2000s, is associated with the large-scale development of

Table 1. Key Characteristics of Leading Container Ports of Different Generations, source: Compiled by the authors based on data (MOVERDB, 2023)

No	Container port	Country	Location	Region	Area, km²
1	Shanghai	China	Yangtze River Delta	East Asia	3,619
2	Singapore	Singapore	Singapore Strait	Southeast Asia	6.200
3	Ningbo-Zhoushan	China	Yangtze River Delta	East Asia	9.365
4	Shenzhen	China	Pearl River Delta	East Asia	3.730
5	Guangzhou	China	Pearl River Delta	East Asia	6.879
6	Busan	South Korea	Korea Strait	East Asia	2.907
7	Qingdao	China	Yellow Sea	East Asia	6.133
8	Hong Kong	Hong Kong	Pearl River Delta	East Asia	2.790
9	Tianjin	China	Yellow Sea	Western Asia	131.0
10	Rotterdam	Netherlands	Rhine Delta	Europe	127.1
11	Jebel Ali, Dubai	UAE	Persian Gulf	Western Asia	134.7
12	Port Klang	Malaysia	Strait of Malacca	Southeast Asia	9.639
13	Xiamen	China	Taiwan strait	East Asia	18.90
14	Antwerp	Belgium	Delta of the Scheldt	Europe	120.7
15	Kaohsiung	Taiwan	Taiwan strait	East Asia	5.204
16	Dalian	Taiwan	Yellow Sea	East Asia	15.02
17	Los Angeles	China	US West Coast	North America	30.00
17	Hamburg	USA	Elbe river	Europe	43.31
19	Tanjung Pelepas	Germany	Strait of Johor	Southeast Asia	7.831
20	Laem Chabang	Thailand	Gulf of Thailand	Southeast Asia	10.41
21	Yokohama	Malaysia	Tokyo bay	East Asia	73.00
22	Long Beach	Thailand	US West Coast	North America	13.00
23	Tanjung Priok	Japan	Java Sea	Southeast Asia	10.28
24	New York/New Jersey	USA	East Coast USA	North America	~40.00
25	Colombo	Indonesia	Laccadive Sea	South Asia	4.856
26	Saigon	Vietnam	South China Sea	Southeast Asia	2.630
27	Suzhou	USA	Yangtze River Delta	East Asia	н/a
28	Piraeus	Sri Lanka	Aegean Sea	Europe	~39.00
29	Yingkou	Vietnam	Liaodong Bay	East Asia	~15.00
30	Valencia	China	Western Mediterranean	Europe	~6.00
31	Manila	Greece	manila bay	Southeast Asia	1.375
32	Taicang	China	Yangtze River Delta	East Asia	~80.00
33	Haiphong	China	Red River Delta	Southeast Asia	0.993
34	Algeciras	Spain	Strait of Gibraltar	Europe	1.032
35	Nhava Sheva	Philippines	Arabian Sea	South Asia	2.770
36	Bremen/Bremerhaven	China	River Weser	Europe	15.79
37	Tanger Med	Vietnam	Strait of Gibraltar	North Africa	3.650
38	Lianyungang	Spain	Yellow Sea	East Asia	н/a
39	Mundra	India	Gulf of Kutch	South Asia	5.400
40	Savannah	Germany	Savannah River	North America	12.40
41	Tokyo	Morocco	Tokyo bay	East Asia	63.25
42	Rizhao	China	Yellow Sea	East Asia	н/a
43	Foshan	India	Pearl River Delta	East Asia	0.313
44	Jeddah	USA	Red sea	Western Asia	12.00
45	Colon	Japan	Lemon bay	Central America	2.690
46	Santos	China	South Atlantic Ocean	South America	7.800
47	Salalah	China	Arabian Sea	Western Asia	10.71
48	Dongguan	Saudi Arabia	Pearl River Delta	East Asia	52.0
49	Beibu bay	Panama	Beibu bay	East Asia	n/a
Ports of the 1st generation		14%			
Ports II generation		35%			
3rd generation ports		31%			
Ports IV generation		20%			

container and mixed transport, as well as the rapid growth of international trade. The work of such port production centers is based on the principles of economic benefit and environmental safety, which can be considered a prerequisite for the formation of a new paradigm of sustainable development. Fourth-generation ports, as distribution ports, located at the junctions of transport routes, act as strategic centers of global trade flow.

As of 2023, according to the MoverDB ranking, the most significant ports in the world are as follows (Table 1). Almost 70% of them are second and third-generation ports.

The grouping of ports presented in the table provides grounds to assert that a generation is not determined by the size, tonnage, or period of operation of the port, which also explains the criticism of this approach by many authors. For example, the works of H. Alyami, Z. Yang, R. Riahi, S. Bonsall, and J. Wang (Alyami, Yang, Riahi, Bonsall, Wang, 2019) note that not every port should strive to become a third or fourth-generation port, as this may not be accessible to everyone due to objective conditions, and not everyone needs to do so because of their already successful long-term development (e.g., Shanghai, Singapore, Ningbo-Zhoushan). Moreover, it is rare to find a port that will fit into one classification (Siu Lee Lam, Lun, Bell, 2019).

3.4. The prerequisites for Ukrainian ports' transition to the fourth category (generation) of development

However, despite the logical and understandable criticism, the collective of authors of this article believes that the post-war recovery of Ukrainian ports should be oriented towards the standards of fourth-generation ports, which is due to several reasons. Firstly, Ukraine occupies a sufficiently advantageous geographical position, being located between the European Union and Asia, with established trade relations. Secondly, the country has already developed a diverse practice of private capital participation in port activities – from leasing and operation to privatization. Thirdly, there are prerequisites for internal competition due to the presence of enterprises in the ports that provide both similar and complementary services. Fourthly, the main service (cargo handling) can be divided into elements that can be performed by various participants in port activities (Muradian, 2015). Thus, the authors believe that the conditions for the transition to the fourth category (generation) of port development have been formed in Ukraine, the combination of which provides conditions for the formation and implementation of the *smart port* project. The potential of Ukrainian ports is also noted in the research United States Department of Agriculture (USDA, 2023) and is evidenced by the World Bank's Logistics Performance Index 2018-2019, according to which, in terms of the level of logistics efficiency of countries, Ukraine ranked 66th out of 160 before the full-scale invasion of Russia, rising 14 places in a year (Logistics Performance Index, 2019).

Several indicators of domestic statistics testify to the prerequisites for the sustainable development of ports in Ukraine. According to the Administration of Seaports of Ukraine (hereinafter referred to as AMPU), the handling of imported goods in 2021 amounted to 24 million tons, which is 1.5% more than the previous year; transit - 8.6 million tons, reflecting a growth of 14.3% (USPA, 2022). It has been established that the largest volumes of handling in 2021 were for grain cargoes and ore - 49.9 million tons (+3.9%) and 37.75 million tons (-14.8%), respectively. The handling of petroleum products in the past year increased by 82% and amounted to 1.93 million tons. The volume of handling construction materials in 2021 increased by 69.2% and amounted to 3.88 million tons.

Along with positive dynamics during the analyzed period, there was a decrease in the handling of export cargoes, which decreased by 4% in 2021, and cabotage - 2.3 million tons, - 2.4%. In addition, in 2021, the seaports of Ukraine handled 153.076 million tons of cargo. This is 3.8% less than the 2020 figures (159 million tons), and 0.6% lower than in 2019 (160 million tons). Of these, 91.8% of the volume belonged to 5 seaports - Yuzhny, Mykolaiv, Chernomorsk, Odesa, and Mariupol (Fig. 4). These five ports are strategically important and attract significant interest among international operators and investors (USPA, 2022).

In 2021, the five largest Ukrainian ports exceeded the cargo turnover compared to the previous year: Chornomorsk by 25.63 million tons; +7.3%, Olvia by 5.14 million tons; +31.6%, Izmail by 3.9 million tons; +20.4%, Ren by 1.37 million tons; +74.3%, Ust-Dunaysk by 64.3 thousand tons; i.e. by 2.6 times. At the same time, the ports of Mykolaiv, Odesa, and Mariupol practically reached the indicators of the pre-COVID period. The cargo turnover of the port of Mykolaiv in 2021 amounted to 29.8 million tons (-1.1%), the port of Odesa - 22.55 million tons (-3.5%), Mariupol - 6.8 million tons (-2.3%) (USPA, 2022).

After the full-scale invasion of Russia into the territory of Ukraine, the activities of ports were suspended due to the mining of sea routes and the threat of piracy from ships of the Black Sea Fleet of the Russian Federation. As a result of 2022, the cargo turnover of Ukrainian seaports decreased by 61.4% compared to 2021 – to 59 million tons. The export cargo handling decreased by 59.5% YoY – to 47.8 million tons, and the import cargo handling - by 74.2%, to 6.2 million tons (USPA, 2022).

Despite this, the port of Yuzhny in January 2022 increased the handling of ore by 5% – raising turnover to 2.25 million tons and the total cargo handling by 37.9% – to 5.105 million tons. The port of Ren exceeded the cargo handling indicators by 5 times YoY – up to 6.82 million, the port of Izmail – twice, up to 8.89 million tons, and Ust-Dunaysk – by 12.3 times, up to 785 thousand tons. (USPA, 2022). The signing and extension until March 18, 2023, of the *grain initiative*, which allowed unlocking the ports of Big Odesa, became an undeniable achievement of 2022.

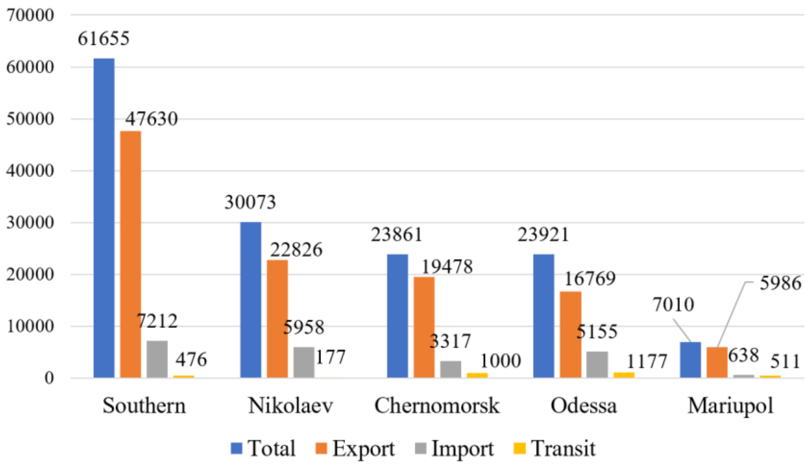

Figure 4. Cargo handling by major ports in Ukraine, 2022, based on: (USPA, 2022).

However, despite its unique logistics potential, the country is losing existing opportunities. This is partly explained by the situation in the global markets, the COVID-19 pandemic, the decrease in Ukrainian agricultural exports, and the war with Russia. All these risks do not contribute to the creation of favorable conditions for attracting large private investors, which negatively affects the attractiveness of Ukrainian ports, thus creating the prerequisites for the development of comprehensive measures for its activation.

3.5. The logistics of a ‘smart port’ as a tool for implementing Ukraine's sustainable development strategy

An overview of leading container ports of various generations (Remzina) revealed that the first full-fledged *smart ports* are already operating in Hong Kong, China, and Europe. Among them is the Ocean Gate container terminal in Xiamen, which can accommodate up to 200,000 tons of cargo. This is the first fully automated port terminal equipped with 5G. The fourth largest cargo port in China, Shenzhen, also uses a fully automated smart platform that operates thanks to 5G. Shortly, registration of foreign vessels in these ports will take place automatically, online. In addition, by 2025, China plans to introduce a single intelligent system that links all of the country's seaports.

Ports in Singapore and Malaysia use big data for screening systems, as well as for determining the type and history of imported goods movements. For example, the IBM Traffic Prediction platform in Singapore helps predict the arrival time of ships and peak hours to avoid traffic congestion. Drones and mobile applications are also planned to be used to improve cargo handling efficiency and prevent maritime accidents.

The first *smart port* in Europe is considered to be the port of Rotterdam (Netherlands). At the pier of the Hutchison Ports ECT Delta terminal in the Maasvlakte port area, the port administration installed a trial version of a *smart* mooring pole. Another successful example of the *smart port* project is the Port of Hamburg (Hamburg), based on which, to improve the efficiency of routes with limited traffic and to be able to handle large volumes of cargo, the Hamburg Port Management, in collaboration with SAP and Deutsche Telekom, created the *SmartPORT* platform as part of a pilot project (Port of Rotterdam, 2023; Port of Hamburg, 2023). The interaction of sensor technologies and information systems has led to a significant increase in the efficiency of port operations. Following the SmartPORT philosophy, the Hamburg port administration promotes sustainable economic growth. The *SmartPORT* platform includes two elements: the logistics platform *SmartPORT logistics* and the energy platform *SmartPORT energy.*

The *Smart port logistics* platform collects data such as the location of cargo ships, free parking spaces, terminal conditions, traffic jam notifications, and information about overhead bridges and accidents. The port traffic manager is in control of the entire port traffic situation. The parking dispatcher, operator, and expediter have individual access to the platform and, therefore, only to the relevant information depending on their role. Drivers of cargo ships are provided with information only about the geographic location of the berth and the waiting time.

SmartPORT logistics-based traffic management aims to provide real-time information on transportation orders and movement conditions. This in turn contributes to optimizing movement in the port and on approach roads, reducing waiting time, and organizing freight flow. The SmartPORT logistics platform is equipped with mobile applications that allow freight ship drivers to access traffic and port services information (Port of Hamburg, 2023).

It has been justified that the implementation of digital infrastructure in the activities of the port of Hamburg can save 5 to 10 minutes per trip for one freight ship, resulting in a time savings of 3,000 to 7,000 hours per day for 40,000 trucks. As a result, the capacity of the port of Hamburg is increasing. Currently, the SmartPORT logistics platform is being implemented in the activities of other ports in Germany (Klaffke H., Mühleisen M., Petersen Ch., Timm-Giel A, 2017).

The development of maritime cargo transportation in Ukraine is facilitated by the changes adopted at the end of 2020 in the Strategy for the Development of Sea Ports of Ukraine for the period up to 2038, which are aimed, among other things, at attracting 50 billion private investments in the port industry and reaching cargo processing volumes of 209-265 million tons (Strategy). This strategy provides for the introduction of digitization in the field of maritime cargo transportation – the introduction of e-services in seaports, the implementation of the information system *Marine Window*, and integration with the European SafeSeaNet system. Within the framework of this strategy, scientists and practitioners in the field of logistics and transportation systems are actively developing methods and means of managing the development of port systems and service enterprises in transportation; methods and tools for analyzing business processes of entities engaged in entrepreneurial activities in the field of transportation and tourism, optimization methods for transportation and logistics systems, and technologies in the infrastructure of regional ports.
To successfully implement the development strategy of Ukrainian seaports until 2038, based on the concept of a gamified approach to coordinating logistics management processes, the authors have developed an optimization model that can be presented in the form of the following system:

$$R = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r} s_{ijk}x_{ijk} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{r} c_{ijk}t_{ijk} - min; \qquad (1)$$

$$\sum_{j=1}^{n}\sum_{k=1}^{r} a_{ijk}x_{ijk} - \sum_{j=1}^{n}\sum_{k=1}^{r} t_{ijk} = 0, \qquad i = \overline{1,m}; \qquad (2)$$

$$\sum_{j=1}^{n} t_{ijk} \le T_{ik}, \; i = \overline{1,m}; \; k = \overline{1,r}; \qquad (3)$$

$$\underline{X_{ijk}} \le X_{ijk} \le \overline{X_{ijk}}, \quad i = \overline{1,m}; \quad j = \overline{1,n}; \quad k = \overline{1,r}$$

$$\underline{t_{ijk}} \le t_{ijk} \le \overline{t_{ijk}}, \quad i = \overline{1,m}; \quad j = \overline{1,n}; \quad k = \overline{1,r} \qquad (4)$$

where, i – code of industrial zones for servicing cargo flows (i= $\overline{1,m}$);
j – code of serviced cargo flows (j= $\overline{1,n}$);
k – code of the time interval of the considered control interval (k= $\overline{1,r}$);
T_{ik} – working time reserve of the i-th zone during the k-th period;
a_{ijk} – specific resource intensity of serving the j-th cargo flow in the i-th zone during the k-th time interval;
x_{ijk} and x_{ijk} – respectively, the minimum and maximum volumes of the j-th cargo flow that must be served in the i-th zone during the k-th time interval;
$\underline{t_{ijk}}$ and $\overline{t_{ijk}}$ – respectively, the minimum and maximum allowable time of using the i-th zone to serve the j-th cargo flow during the k-th time interval;
s_{ijk} – is the unit cost of servicing the j-th cargo flow in the i-th zone during the k-th time interval;
c_{ik} – specific costs for the maintenance of the i-th zone during the k-th period;
x_{ijk} – volume of service for the j-th cargo flow in the i-th zone during the k-th time interval;
t_{ijk} – time of using the i-th zone to serve the j-th traffic during the k-th time interval.

Taken together, the author's proposals make it possible to increase the profitability of the port, which increases with the increase in its size and activity, which ensures the transition from a passive to an active development strategy based on a wide diversification of services and organizational integration. Important in this strategy is not only the focus on the integrated processing and distribution of information flows related to the maintenance of cargo flows, but also the provision of a reasonable environmental burden on the environment that does not exceed the restorative capacity of the biosphere, while achieving economic growth.

4. Recommendations and conclusions

Thus, based on the generalization of the theoretical and methodological basis, a comprehensive scientific problem of managing the logistics of a *smart port* under conditions of sustainable development has been solved in this article. Based on the conducted research, several conclusions and recommendations have been formed, the main ones of which can be summarized as follows:
The theoretical understanding of widely used concepts in the theory of sustainable development such as *smart city*, *smart home*, *smart factory*, etc. led to the idea of the need to revive port logistics in Ukraine based on *smart port* technologies. By analogy with established categories, it was concluded that a *smart port* is a fully automated seaport that uses innovative technologies created based on artificial intelligence and united within a centralized system that monitors, collects, and analyzes data, optimizes processes, and promotes prompt decision-making. Based on this, an author's conceptual model of the subject area of a *smart port* was developed, which represents a fundamentally new model of a logistics system created on the symbiosis of the paradigms of scientific and technical development and sustainable development, contributing to the implementation of a number of SDGs, such as: Goal 1: no poverty, Goal 2: zero hunger, Goal 3: good health and well-being, Goal 6: clean water and sanitation, Goal 8: decent work and economic growth, Goal 9: industry, innovation and infrastructure, Goal 11: Sustainable Cities and Communities, Goal 12: Responsible Consumption and Production, Goal 13: Climate Action, Goal 14: Life below water, Goal 17: Partnerships for the Goals.

The reasons for the emergence of a *smart port* were analyzed, and it was concluded that the emergence of this category is due to the evolutionary processes of port activities, including the transition of humanity to the concept of sustainable development. Four generations of ports were established, and leading container ports were grouped by generation, resulting in the discovery that approximately 70% are second and third-generation ports. It was proven that a generation is not determined by the size, tonnage, or period of port operation. Based on an analysis of the key performance indicators of Ukrainian ports, it was justified that the post-war recovery of Ukrainian ports should be based on the standards of fourth-generation ports, as they contribute to achieving the goals of sustainable development. The prospects for the transition of Ukrainian ports to the fourth generation of development were outlined. To successfully implement the strategy for the development of Ukrainian seaports for the period up to 2038, an optimization model for managing logistics processes based on a gaming approach was developed, which is oriented toward sustainable development.

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