9. PORTS DIGITIZATION - A CHALLENGE FOR SUSTAINABLE DEVELOPMENT

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Abstract

The paper aims to determine the importance of each dimension and sub-dimension of a digital port, in order to prioritize them to obtain a perspective on the digital solutions needed to be implemented in Romanian river-sea ports, based on the views of the stakeholders in the context of sustainable development. The importance of each dimension/sub-dimension was determined using the AHP (Analytical Hierarchy Process) method. The results revealed that port operations are the most important, followed by the environment, safety and security, energy, and staff training. The ranking of the dimensions/sub-dimensions characteristic of the analyzed ports allowed identifying the digital solutions useful for the technological transformations and management practices necessary for digitizing.

Keywords: smart port, AHP, digital port dimensions, global priorities

JEL Classification: C02, C88, O33, Q55

1. Introduction

The environment and natural resources are strategic areas for any country, where investments are needed, both for human health and because they are not sufficiently exploited compared to their potential. The progress of human society involves costs because the exploitation and consumption of natural resources generate side effects with increasingly severe implications for the environment. In the port sector, human activities involve high consumption of resources and

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pollution, which, from an environmental perspective, require socio-economic actors to comply with some essential rules needed to achieve sustainability and sustainable development: the polluter pays; efficient waste management; promoting green energy (Turcanu (Marcu), 2022).

A critical factor in achieving sustainability goals is digital technologies. Among these may be: 5G technology, the Internet of Things (IoT), artificial intelligence (AI), and cloud computing technology, which can remotely monitor pollution and optimize the use of energy and natural resources, real-time Wi-Fi location systems, the platform for collecting data from port sensors, etc. (Fernández et al., 2016; Molavi et al., 2019; Zhou et al., 2020; Turcanu (Marcu), 2022).

Digitization is the best solution for optimizing port operations, and the use of technology is the first step in accessing digitization. It allows all data to be provided in real-time to all stakeholders to increase efficiency and efficacy (Turcanu (Marcu), 2022).

Ports are considered strategic centers of economic activity that link water transport with land transport, thus being drivers of economic development (Buiza-Camacho et al., 2016; Karli et al., 2021). Due to the growing volume of the transactions, in the long-run sustainable management of ports is needed, both for the environmental interests and for the economic and political interests of a country. To meet these expectations, one of the targeted developments is smart ports (Paulauskas et al., 2021b; Turcanu (Marcu), 2022). The concept of the smart port has developed from the desire to reduce pollution and greenhouse gas emissions, in order to create a more attractive port environment where pollution can be controlled (Liao et al., 2016; Turcanu (Marcu), 2022).

Given that the needs of each port differ, applications for smart ports must be compatible with their characteristics, which makes it necessary to analyze the ports.

An attempt at digital transformation, while innovative and valuable, can fail if several different dimensions/sub-dimensions and perspectives are not considered and if individual benefits are not understood across the port community (Turcanu (Marcu), 2022).

Although ports are usually resistant to change, due to the emergence of new technologies and systems that provide solutions to the many problems they face, this perception is gradually changing, leading the port sector to a more connected future (Turcanu (Marcu), 2022).

The Romanian river-sea ports are Galati, Tulcea, Sulina, Braila. The Danube is a maritime river from Braila to its discharge into the Black Sea. On this portion, the Danube has a great depth, which allows the navigation of maritime vessels, whose draft (immersed depth) is greater than that of river vessels. The conditions necessary for the development of rivers-sea ports have in view good cooperation between all members of the port community, consisting of administrations, authorities, customs commissioners, river transport operators, terminal operators, logistics service providers, quality control companies and shipping companies, shipbuilding, etc., which ensures the proper functioning of the ports.

The transition to the smart port for Romanian river-sea ports is much more important today due to the demands of global trade, which means a large volume of fast-moving goods, high-capacity ships, increasingly complex, geopolitical problems, operational congestion, and safety and security issues (Turcanu (Marcu), 2022).

Based on the data in Table 1, a hierarchy of the importance of these ports can be made. Thus, the port of Galati ranks first, followed by Tulcea, Braila, and Sulina.

Table 1. Share of the total volume of goods handled in the river-sea ports in total goods handled in the period 2015-2021 (thousands of tons)

Port name	*Year*						
	2015	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
Galati (loaded)	1617	1449	1072	1095	1845	1532	1846
Galati (unloaded)	2673	2939	2437	2380	3293	3724	4000
Galati (transit)	3022	3338	3193	3369	2842	1695	2048
Galati (total)	7312	7726	6702	6844	7980	6951	7894
Braila (loaded)	533	553	377	371	933	290	485
Braila (unloaded)	289	289	176	283	299	328	367
Braila (total)	822	842	553	654	1232	618	852
Tulcea (loaded)	34	40	15	6	21	17	16
Tulcea (unloaded)	1479	1514	1320	1794	1654	1208	1316
Tulcea (total)	1513	1554	1335	1800	1675	1225	1332
Sulina (loaded)	-	8	-	-	-	-	-
Sulina (unloaded)	-	-	16	-	-	-	-
Sulina (total)	-	8	16	-	-	-	-
Total cargo handled in Romanian ports	**74553**	**76779**	**75225**	**644356**	**86362**	**77738**	**85241**
Total transit	**5558**	**5388**	**5258**	**5034**	**4787**	**3211**	**3663**

Source: https://insse.ro/cms/ro/tags/transportul-portuar-de-marfuri-si-pasageri.

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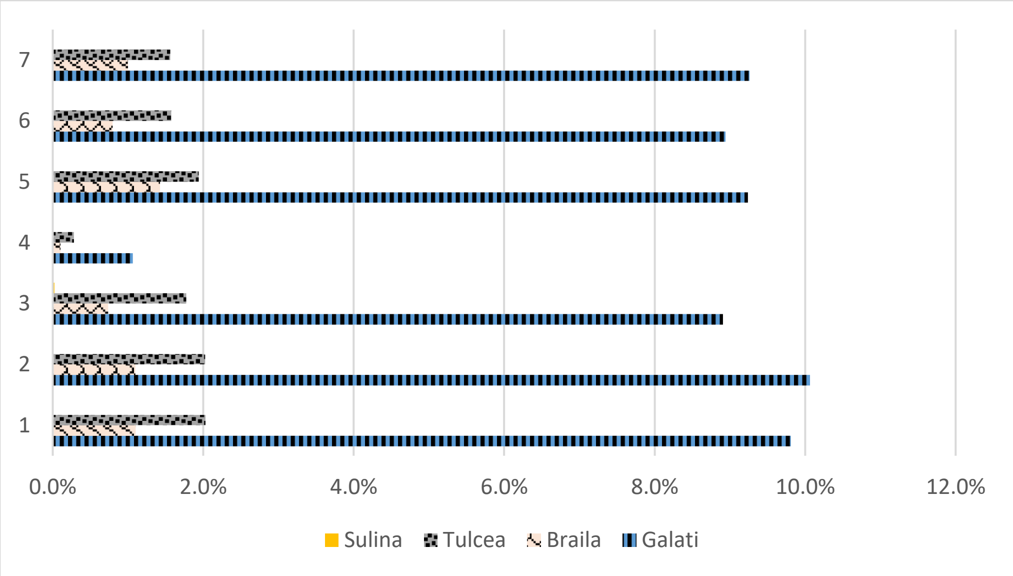


Figure 1 shows the share of the total volume of goods handled in river-sea ports in the total of goods handled in Romanian ports in the period 2015-2021.

The study carried out in the paper refers to four river-sea ports in Romania, but the results can be used for ports with similar arrangements. In many countries, there are already ports where digital technologies and digital operations management systems have been successfully implemented. Based on these considerations, the research question (RQ) is: How can we get a perspective on the digital solutions needed to move to the smart port starting from the classification of the dimensions and sub-dimensions of the selected ports?

In order to carry out this study, experts from the port authorities of the four Romanian river-sea ports have been contacted in order to evaluate the main dimensions/sub-dimensions of the digital port from the perspective of the transition to digitization. This paper aims to highlight the most adequate digital solutions for Romanian river-sea ports starting from the specifics of these ports. The originality of the paper consists of the presentation of some potential scenarios and their benefits as it results from the identified digital solutions.

This paper is presented in sections, as follows: literature review- section 2; research methodology- section 3; results and discussion-section 4 and conclusions.

2. Literature Review

In the literature, the notion of a digital port appears under different names such as an autonomous port, an intelligent port, a robotic port, etc. The digital port is an ecological port that can optimize the logistics flow automatically and autonomously using energy efficiently through the use of 4th generation technologies, such as automation, AI, IoT, ICT (Information and Communication Technology), etc. (Buiza-Camacho et al., 2016; Yang et al., 2018; Sullivan et al., 2019).

One of the critical aspects of digitization is the continuous flow of data, which is able to ensure real-time transport management and monitoring (Inkinen et al., 2019; Czachorowski et al., 2019; Paulauskas et al., 2021a; Turcanu (Marcu), 2022).

A number of authors refer to digital transformations necessary for ports to optimize their activities and competitiveness. Thus, according to Heilig et al. (2017a), the success of digital transformation is influenced, both by the advanced technologies and methods used, but especially by the way in which organizational aspects are adapted to technological changes, stating that "digital technology is a means, not just a goal". The authors have presented a theoretical and conceptual framework of a game and they have demonstrated how it could develop tools and methods that can support strategic decision-making to achieve digital transformation in seaports. In the vision of Buck et al. (2017), the process of digital transformation in ports aims at optimally connecting the ports with their environment, and globally all the ports between them. Research by Heilig et al. (2017b) showed that ports were affected by technological change and that all requirements related to costs, efficiency, security, sustainability, and digital innovation became vital to their competitiveness. Therefore, an indispensable factor in the competitiveness of ports is the adoption of information technology (IT) and information systems (IS) (Turcanu (Marcu), 2022). This helps communication and making decisions on increasing the productivity, efficiency, and safety of port procedures. The study showed that the degree of digitization varies greatly among ports. As a result, the authors believe that several stages of development are needed for digital transformation.

Port IT systems are also discussed by Kapkaeva et al. (2021), in the case of the port of Hamburg, where the authors suggest that port information systems and digital technologies play an important role in collecting and distributing information to all actors involved.

The European Council for Maritime Applied R&D (ECMAR) (2017) has expressed concern about the significant technological advances made due to the speed of innovation, which can help address environmental challenges and increase operational productivity in ports. ECMAR has referred to the competitiveness of ports, saying that it is influenced by the ability of ports to cope with environmental legislation, energy efficiency, safety, and security, but especially development and innovation at a much more technologically advanced level (Turcanu (Marcu), 2022). This involves digitizing ports, which will ensure a global connection, a competitive maritime sector, an efficient internal market, and a sustainable marine environment. Sullivan et al. (2019) stated that digitalization in the maritime sector involved the integrated implementation of digital processes and technologies for the construction of innovative digitally connected ships, increasing the efficiency of port operations, solving traffic congestion problems in ports, and ensuring a sustainable environment.

Issues related to how port activities affect the environment, such as water and air pollution and waste disposal, were discussed by Lam and Notteboom (2014). The authors investigated port management tools and the extent to which they were used to encourage the development of green ports. For this, an exploratory and comparative analysis was performed, taking into account the range of tools available to the port authorities and the functional activities in the ports. The main ports that were studied and compared were Singapore, Shanghai, Antwerp, and Rotterdam. The results revealed that ports are particularly mature in applying standard environmental regulations, and in the case of European ports compared to the Asian ones studied, port authorities had a higher level of influence in terms of environmental policy-making. The impact of ports on the environment was discussed by Chiu et al. (2014). The authors pointed out that the impact comes from the port activity and from the ships calling at the port, but also from the emissions from intermodal transport networks serving the port. The importance and priority of the factors for the operation of an ecological port were investigated in the case of the first three ports in Taiwan. Based on the results obtained following the investigation in the paper, a guide can be provided for the port industry in order to build and operate a greener port. Karli et al. (2021), referring to pollution caused by ports, stated that sustainable management of ports became necessary to prevent massive pollution of water and air, which meant their transformation into smart ports.

An important aspect of the port sector is energy consumption, an essential component of the whole process. For the correct management of energy consumption, it is necessary for the port authorities to implement energy and environmental management systems, which lead to a better knowledge of the activities and to the planning of strategies aimed at efficient energy consumption (Pavlic et al., 2014). Achieving energy efficiency in ports, where possible, can be met by implementing renewable sources in their various forms (tidal energy, solar energy, geothermal energy, electricity), with positive effects on the environment (Acciaro et al., 2014). The increase in energy consumption and energy costs and their impact on port activities were studied by Buiza et al. (2015). The authors defined the concept of a smart port based on information found in public resources on Mediterranean container ports. They made a description of their situation from the perspective of the smart port. The results that were obtained led to the conclusion that, in addition to the lack of public data on the concept of a smart port, there were some shortcomings and barriers to the development of smart ports. Among them were: limited waste and gas management, limited technologies, limited adoption of standards, lack of control over the level of energy consumption in ports, and lack of control over the costs associated with this consumption. As a solution to the problems faced by these ports, the authors mentioned the possibility of defining a unique indicator, the value of which should indicate the degree to which a port is considered "smart".

Within ports, operations are very important due to the large number of cargo handling equipment, trains, vehicles, and ships, which generate pollutants with negative effects on the environment (Alves de Moura and Goulart de Andrade, 2018). In the study conducted by Kenyon et al. (2018), the problems associated with inefficient port operations were investigated, and solutions were suggested. The results showed that ports could improve their return on investment by simplifying operational processes. Bilal et al. (2018) proposed a system for automating the port-to-ship delivery process to ensure transport reliability and safety. The authors presented a detailed framework for system and subsystem architecture, making it possible to automate this process. Logistics plays an important role in port activities. Thus, Bergqvist and Zandén, (2012) stated that ports were important for global logistics because they directly influenced logistics service providers through their decisions. Therefore, those managing port activities need to plan these activities together with inland logistics activities, so that there is a possibility to choose water transport instead of road transport, thus obtaining lower costs and environmental impact. Through efficient internal logistics planning, better economic performance, as well as environmental performance can be achieved, which brings the port closer to the digital port. Gurumurthy and Bharthur (2019) explored the transformations in the port and logistics sector in India following the global and local economic restructuring along with the emergence of digital automation and digital intelligence, analyzing the nature of these changes in the sector.

Many studies on port management use the AHP method, developed by Saaty (1987). Thus, Chou (2010) developed a model, which simulated the behavior of port users in the choice of ports by identifying the importance of each factor that influences these choices. Based on this study, port managers can establish practical operating strategies to improve the competitiveness of ports. Based on the results obtained from the survey of industry experts, Yuen et al., (2012) determined the relative importance of the factors that determine the port's competitiveness. The paper by Pak et al. (2015) aimed to identify the factors that influenced the safety of navigation in ports and the extent to which all these factors affected the safety of ports from the perspective of ship captains. The Fuzzy AHP method was used in the research, which allowed the assessment of the importance of the factors and the classification of the security levels of the targeted ports in Korea. In response to problems in ports, they adopt technological solutions, but new approaches to planning and managing operations and the implementation of such solutions are the transitions to digital ports. Buiza-Camacho et al. (2016) adopted the concept of a smart port by analyzing the operational, energy, and environmental fields, with the help of a group of experts, using the AHP method. The study concluded that technology, automation, and intermodality were the most important factors for a smart port. Karli et al. (2021) used the Fuzzy AHP method to rank the dimensions and sub-dimensions of the Filyos port in Turkey, based on which they outlined some suggestions for the development of a smart port.

3. Research Methodology

For an analysis of the ports in terms of the need for digitization, it is necessary to define the main dimensions and sub-dimensions, so that based on their quantitative importance to get a perspective on the digital solutions needed to be implemented, based on stakeholder views. Several papers (Liao et al., 2016; Molavi et al., 2019; Chen et al., 2019; Karli et al., 2021) discuss the main dimensions of the smart port, such as port operations, environment, energy, safety, and security. Starting from these studies, with the aim of identifying the digital solutions necessary for the Romanian river-sea ports, we first selected the most appropriate dimensions/sub-dimensions for the analyzed ports and prioritized them. In addition to the main dimensions of a smart port presented in the literature, in the case of the Romanian river-sea ports, a new dimension considered necessary by the authors refers to the training of the employees on how to manage a smart port and acquire skills and competencies for working with dedicated software. Based on the classification of these dimensions/sub-dimensions, the respondents indicated the priority digital solutions to be applied in these ports, which contribute to the optimization of port management and operations in the context of sustainable development, but also due to the (neclar – e nevoie de un subiect la due) extensive process of technological development of water transport. Starting from the identified digital solutions, three possible scenarios (case studies) are presented, with their benefits, which can be implemented in these ports. The AHP method proposed by Saaty (1987) was used to prioritize them. The necessary data were collected from two sources: a. interviews with members of the port communities; b. an online survey conducted for the port authorities in the analyzed ports.

The interviews aimed at collecting information necessary for the study of the four Romanian river-sea ports were conducted between February and April 2021. Based on the interviews conducted with each person, the respondents had the opportunity to present their own opinions and comments regarding digital solutions. A total of ten people from different companies involved in the port activity (Maritime Danube Ports Administration, Lower Danube River Administration, Romanian River Navigation Company) were interviewed. The experience of these respondents is between 5-10 years (three people), 11-20 years (four people), and over 20 years (three people). The data collected are representative providing a perspective based on the need to digitize these ports.

Data collected from the survey are discussed in accordance with the analysis tool (Digital Transformation Scoreboard, 2018) of the European Commission which presents the nine key technologies for digitization: (1) Social media; (2) Mobile services; (3) Cloud technologies; (4) Internet of Things (IoT); (5) Robotics and automated machinery; (6) Cybersecurity solutions; (7) Big data and data analytics; (8) 3D printing; (9) Artificial Intelligence. These nine key technologies for digitization are used as a basis for the necessary questions in conducting the survey, which aims to identify the future digital solutions needed for Romanian river-sea ports in order to digitize them. The survey was conducted electronically in May 2021. The open-ended questions helped the fifty respondents to clarify the answers provided. Respondents to the survey were the general, executive, commercial and operational directors of the four ports analyzed, the heads of services of the security offices, traffic monitoring, port operation, and their members, who had more than fifteen years of port experience. The data collected provides a grounded vision of leading the four ports to the necessary digital solutions. The questionnaire addressed to the fifty respondents includes the following questions: What is your field of specialization? How many years have you worked in the port field? In your opinion, what are the most important dimensions with the related sub-dimensions to be considered for the digitization of the Romanian river-maritime ports? In your opinion, what sub-dimensions are aimed at avoiding environmental pollution? What do you think about the digitization of the port from the perspective of employees? In terms of safety and security, what are the main sub-dimensions of the smart port? What are the sub-dimensions of the digital port in terms of energy consumption, given the sustainable development? Using Saaty's scale, please make pairwise comparisons between the identified dimensions of the analyzed ports, and between their sub-dimensions presenting the answers in a table. In your opinion, how would you classify the dimensions of the digital port, that lead to increased performance, using the Likert scale from 1 to 5, where 5- is extremely important; 1- is extremely unimportant? How interesting is your digitizing port? What is the level of digitization compared to other Romanian ports? How important is digitization to the port strategy? In your opinion, what are the most important areas of development, given the nine key technologies for digitization? What digital solutions are needed to be implemented in the port?

Using the AHP method, the overall priorities of the dimensions/sub-dimensions were determined for their prioritization. The AHP method was applied in two steps.

In the first stage, based on the judgments of the survey respondents, it was established which of the dimensions was more important in relation to the others, in order to determine their relative importance. The derivation of the priorities (weight) of the dimensions/subdimensions was made by comparing them in pairs, using Saaty's scale (Table 2):

Table 2. Saaty's scale for pairwise comparisons of the digital port dimensions and subdimensions

Intensity of importance	*Interpretation*
1	i and j have the same importance
3	i is slightly more important than j
5	i is more important than j
7	i is much more important than j
9	i is absolutely more important than j
2,4,6,8	intermediate judgments

Source: Saaty, 1987

The largest share is obtained by those dimensions/subdimensions considered by the respondent experts as the most important.

In the first step, the decision matrix is completed to establish the relative importance of the dimensions selected by the respondents.

The normalized matrix is deduced from the decision matrix in step two. In this matrix, each entry is calculated by dividing each entry in the decision matrix by the amount obtained on the corresponding column. The weight vector W for each of the compared elements is an N-dimensional column vector and it is obtained by calculating the average of the entries on each row in the normalized matrix. The local priorities obtained for the dimensions and sub-dimensions of the digital port were used in the second stage to calculate the global priorities of each sub-dimension, obtaining a hierarchy of them.

In the second stage, in order to determine the global priorities of the digital port sub-dimensions, the selected dimensions (operations, safety, security, energy, environment, and staff training) were used as criteria. These were calculated as the product between the priority of the port dimension of which they are part and the priority of each sub-dimension. Finally, the vector of the global priorities of the digital port sub-dimensions (*Wglobal priorities of sub-dimensions*) was obtained.

Checking the consistency of intuitive judgments of decision-makers (experts in the field) is done by calculating the CR consistency ratio, obtained by dividing the consistency index (CI) of the matrix containing decision-makers and the consistency index of a random matrix, denoted by RI. The randomly generated matrix, which contains randomly entered judgments, is provided by Saaty (1987). A CR≤ 0.1 ratio is considered normal for AHP analysis to be continued. The calculation formula for CI is as follows:

$$CI= (\lambda_{max}-N) / (N-1) \tag{2}$$

where: λ_{max} is the largest eigenvalue

The value of λ_{max} is obtained by considering the values obtained in decision matrix A, which are multiplied by the weight obtained by each dimension/sub-dimension of the digital port in the corresponding column. The sum of the values on each line is then calculated, resulting in the weighted sum vector. By dividing the weighted amounts by the weight of each dimension / sub-dimension of the digital port and calculating the average of these values, λ_{max} is determined.

$$A\bullet W= \lambda_{max}\bullet W \tag{3}$$

Consistency indices for the randomly generated matrix (Table 3), where N is considered the number of compared elements determined according to Saaty (1987), are presented below:

Table 3. Consistency indices from the randomly generated matrix

N	*3*	*4*	*5*	*6*	*7*	*8*
RI	0.58	0.9	1.12	1.24	1.32	1.41

Source: Saaty, 1987

The answers to the survey on the level of digitalization within river-sea ports compared to other ports in Romania and the importance of digitization for the strategy of each port are presented in Table 4.

Table 4. Distributions of the survey responses

Question (1-The lowest; 5-The best)	*1*	*2*	*3*	*4*	*5*
How interesting is your digitizing port?	0%	15%	25%	30%	30%
What is the level of digitization compared to other Romanian ports?	10%	25%	40%	25%	0%
How important is digitization to the port strategy?	0%	20%	30%	25%	25%

The answers, as shown in Table 4, show that the ports are interested in moving to digitization and that digitization is already a strategic option. When they were asked about the digital solutions implemented within the port, only three of the five ports answered. Most respondents referred to the traffic monitoring system and the digitalized management of port operations. The answers and statements provided revealed that the ports did not have a comprehensive status of the digital solutions used.

4. Results and discussions

This section has two parts. The first part presents the results obtained based on the survey, which made possible the ranking of the dimensions/subdimensions of the digital port in the case of the four river-sea ports analyzed. The second part presents the digital solutions needed to be implemented in these ports based on the interviews conducted.

Based on the responses of the fifty respondents to the survey, five main dimensions and sixteen sub-dimensions were selected, which were used in the AHP analysis to highlight which of them were a priority for the analyzed ports. These dimensions with the related sub-dimensions are *operations* (productivity (P), automatization (A), digital infrastructure inside the port (ID), logistic planification (PL)); *environment* (environmental management systems (SMM), emission and pollution control (CEP), waste management (GD), water management (MA)); *energy* (efficient energy consumption (CE), production and use of renewable energy sources (SER), energy management (ME)); *safety and security* (safety management systems (SMSig), security management systems (SMSec), integrated monitoring and optimization systems (SIMO), data security (SD)); *training staff* (TS) (training of the employees on how to manage a smart port and on acquiring skills and competencies for working with dedicated software).

The relative importance of the dimensions of the digital port was determined by the fifty respondents using the Likert scale from 1 to 5, where 5 is extremely important; 1 is extremely unimportant. The weighted arithmetic mean of the answers was obtained as follows: port operations (4.2); medium (3.84); energy (3.76); safety and security (3.82); staff training (3.74). Based on the weighted average, it turns out that in the opinion of the respondents the most important dimensions of the digital port are the port operations and the environment. The average importance of the main dimensions of the digital port is 3.87, which shows that the ranking method chosen in the study is appropriate.

Based on the judgments provided by the respondents, the decision matrix (in Excel) regarding the selected digital port dimensions was obtained (Table 5), with the largest share being given to the port operations (0.459).

Table 5. Decision matrix for digital port dimensions and consistency index

Dimensions	*Operations*	*Environment*	*Energy*	*Security and Safety*	*Staff Training*	*Priority of dimensions*
Operations	**1**	3	5	3	5	0.459
Environment	0.333	**1**	3	1	5	0.228
Energy	0.2	0.333	**1**	1	1	0.094
Security and Safety	0.333	1.000	1	**1**	1	0.131
Staff Training	0.200	0.200	1	1	**1**	0.089
CR=0.057						

Source: research data processing in Excel

Then, applying AHP, the pairwise comparisons of the port sub-dimensions were performed and the CR consistency indices were calculated (Table 6).

Table 6. Local priorities for sub-dimensions of the digital port

Dimensions of the digital port (criteria)	Local priorities for sub-dimensions
Operations (CR=0.06)	P-0.228; A-0.291; **ID-0.384**; PL-0.097
Environment CR= (0.043)	SMM-0.172; **CEP-0.559**; GD-0.192; MA-0.077
Energy (CR=0.033)	CE-0.260; **SER-0.633**; ME-0.106
Safety and security (CR=0.058)	SMSig-0.219; **SMSec-0.594**; SIMO-0.094; SD-0.094
Training staff (CR=0.057)	TS-0.089

Source: own research data processing in Excel

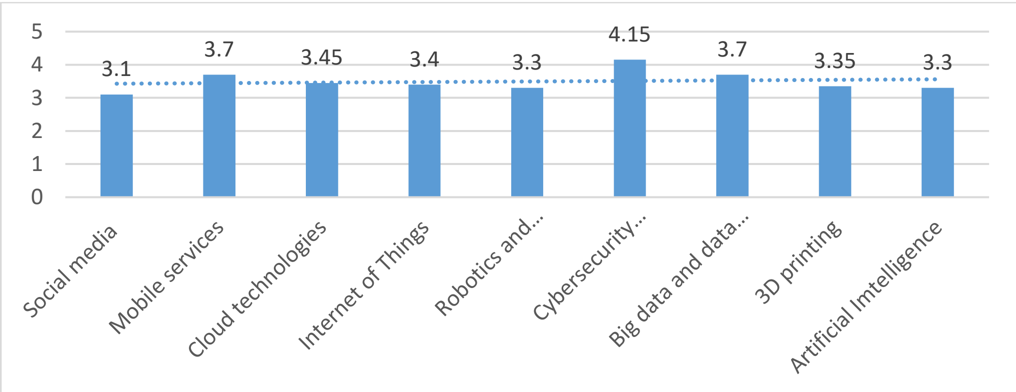
From the pairwise comparisons of the sub-dimensions considered using the selected dimensions as criteria (Table 5), it results that the largest shares are held by digital infrastructure (ID-0.384), emission and pollution control (CEP-0.559), renewable energy sources (SER-0.633) and the security management system (SMSec-0.594).

The vector of the global priorities of these sub-dimensions ($W_{\text{global priorities of sub-dimensions}}$), which presents their hierarchy is shown below:

$W_{\text{global priorities of sub-dimensions}}$=[ID-0.176; A-0.133; CEP-0.127; P-0.104; TS-0.089; SMSec-0.08; SER-0.059; PL-0.044; GD-0.044; SMM-0.039; SMSig-0.028; CE-0.024; MA-0.017; SIMO-0.012; SD-0.012; ME-0.009]

The survey showed that the most important areas of development was Cybersecurity solutions Mobile services, and Big data and data analytics, while social media was of the least importance (Figure 2). Two of the four ports said that digitization was already a strategic choice, while the other two ports were making progress toward digitization through individual projects funded by the European Union. None of the four ports stands out from the others in terms of digitization (Table 4-option 5).

Figure 2. Key technologies for digitization in the vision of port authorities from the four ports analyzed



Ports must meet the growing demands of efficiency, economy, safety, and compatibility with the environment, which determines the need for digitization. Some of the most important issues reported by respondents in the survey and interviews were described in the form of digital solutions that needed to be implemented in these ports, presented in Table 7, which answers the research question.

Table 7. Digital solutions identified

Port dimensions	*Digital solutions identified to be implemented in the analyzed ports*
Operations	• introducing digital solutions such AI, IoT, 5G, etc. in order to increase the efficiency of port operations, but also to solve environmental problems and traffic congestion; • smart port procedures are needed to allow better use of available resources through more precise coordination of the port actors; • development of mobile applications that serve to inform port actors about port operations but also to report failures; • implementation of Big Data Analytics (BDA) to improve port operations, safety, and waterway management system. These would help the crews responsible for handling the ship; system operators providing navigation information to ships; pilots, who need accurate and timely information; port staff, who have to make decisions based on conditions and traffic in the area; • the remotely controlled digital infrastructure must ensure the automatic berthing of the ships and guidance of the traffic; • Automatic Identification System (AIS) provide data on the type of ship, the position of the ship, the speed of the ship, the type of voyage, and the estimated voyage time, and its implementation would allow ships to operate safely; • directing traffic and automatic berthing of ships by remote control of digital infrastructure; • optimizing systems to reduce machine downtime through intelligent simulation that uses real-time IoT data in a virtual model.
Environment	• the information provided by the local sensors could also be used to check the air quality before opening the cargo containers, due to the nature of the load and the long transport time, but also the dangerous gases; • reducing the number of emissions resulting from port traffic could be achieved by using emission control systems; • avoiding pollution can be achieved through the creation of the port area management centers that would ensure coordination in the region, as well as the implementation of environmental management systems.
Energy	• the use of renewable energy sources and state-of-the-art technologies would allow the protection of the environment.
Safety and security	• data security management system that can quickly adapt to the changes imposed by digital technologies; • the use of sensors and analysis of data flows could provide an improved level of assurance on the integrity of ship cargo; • the organization of the data flows transmitted to the navigation center, using the parameters of the 5G network. This could be done by transmitting data from different sensors (GPS, humidity, smoke, speed, etc.) to the navigation center, using wireless protocols over a private 5G network, which

Port dimensions	*Digital solutions identified to be implemented in the analyzed ports*
	would allow the extension of the Internet connectivity of the system, detection for use by specific applications (ie. collision avoidance navigation, etc.); • information exchange based on blockchain would allow data protection, improving transparency between stakeholders; • cybersecurity involving full automation of controls and processes; • real-time data collection through the implementation of Big Data Analytics could provide information appropriate for port safety and security, at the required time, and for the people involved.
Training staff	• training staff on the use of dedicated software, which is necessary for the acquisition of IT/IS knowledge and which combined with detailed knowledge of port operations would allow an adequate redesign of processes and networks;

The authors present three potential scenarios (case studies) starting from the research carried out in the case of the four Romanian river-sea ports:

Scenario 1 is a scenario that presents the automation of ship-based logistics transport. It refers to the application of 5G technology in a smart port context using a ship in one of the analyzed ports, equipped with additional 5G connectivity to support real-time data flows of sensors from other ships to the command center and real-time steering commands to a remote ship. The benefits are remote control by a single operator for several ships, optimization of navigation speed, real-time route planning to optimize port operations, and avoiding unnecessary berthing times based on data provided by port authorities.

Scenario 2 refers to a combination of 5G technology and assisted navigation using IoT sensors and video cameras. This scenario consists of the implementation of a data-assisted navigation application using an IoT detection system and video cameras installed in the port and on the ships. The installation of the sensors on the ships that monitor the ship's operating parameters allows the provision of information on the speed and direction of the ship, speed of the water and wind, depth of the water, etc. to the local ship monitoring equipment, enabling those on board to make appropriate decisions. This type of application allows a safer port operation and increased security of navigation based on data provided by sensors and video cameras, even in severe weather conditions.

Scenario 3 envisages the implementation of travel communication and monitoring technologies. They help a better communication between ships and ports of operation with the effect of reducing transport with empty units and avoiding downtime due to navigation errors, through real-time connectivity of the navigation equipment. The benefits are a low number of navigation events such as ship collisions, blockade of ships due to shallow waters, and low logistical costs due to decisions based on diagnosis and monitoring on board, the impact of the human factor on potentially wrong decisions being limited.

Similar results were observed by other authors, as follows:

- for sustainable development of ports, the implementation of digital solutions would lead to the improvement of operations and their management, even if the level of digitization is much lower in the case of small and medium-sized ports, compared to large ports (Paulauskas et al., 2021a);

- the use of innovative technologies, such as IoT and Big Data, would support decision-making, which would limit the impact of wrong decisions of the human factor, with benefits for the development of sustainable, safe, and connected ships (Sullivan et al., 2019);

- modern technologies for identification and location and video cameras can contribute to safer and faster handling operations. Also, safety conditions are improved using robust wireless networks and Internet connectivity, smart sensing, and IoT technologies (Yang et al., 2018);

implications on the level of digitization. The digitization of port activities and their management is essential for stimulating activities and increasing the possibilities of port services, thus contributing to improving the competitive position on the maritime transport services market (Paulauskas et al., 2021b).

based on the coordinated actions of the automated and remotely piloted boats and a ground station to ensure the delivery process from port to ship to reduce the time and cost of the delivery process, improving safety and reliability in transport (Bilal et al., 2018).

Ports differ in size, organization, and connections to the hinterlands. That is why the recommendations for port management vary from one port to another, even if they have a number of common features. The analyzed ports are not looking for a standard for a management model, but solutions that contribute to the optimization of port management and operations in the context of sustainable development. Based on the study, some of these recommendations could be staff training on acquiring skills to work with dedicated software, ICT solutions, increasing security of information systems, port development plans, network solutions between port actors, increasing public investment in port infrastructure, and testing the most appropriate digital technologies.

Conclusions

The study is useful for the business and academic environment by highlighting the most important dimensions and sub-dimensions of the digital port and how they can be ranked to provide an overview of priority digital solutions for Romanian river-sea ports which want to respect the principles of sustainability, as well as improve operational efficiency.

Digital port activities make possible the intelligent integration of sustainable solutions and renewable energy sources with an effect on reducing pollution.

To become competitive in the long run, ports need a number of major changes: redesigning processes, creating inter-organizational networks, revitalizing port areas, expanding services to obtain cost advantages, improving productivity and efficiency, and aspects that can be made easier by the digital transformation of the ports. Data security and safety is an area to which the port authorities pay particular attention, which involves the introduction of data security and confidentiality management systems in ports, in parallel with the training and monitoring of the employees.

Identifying the digital solutions to be implemented in the Romanian river-maritime ports, starting from the ranking of the dimensions/sub-dimensions of the port, showed that decision-makers give the greatest importance to the port operations (0.459), through its sub-dimensions “digital infrastructure” (0.384), “automation” (0.291), and “productivity” (0.228). The reason is that the four ports analyzed are integrated into the river, sea, road, and rail transport routes, the volume of transactions is increasing, and digitalization of operations would lead to savings in terms of time and money. Within the environmental dimension (0.228), priority was given to “emission and pollution control” (0.559) and “waste management” (0.192), because discharges of hazardous substances and waste onboard ships are due to both poor onboard management practices, and those from the shore, as a result of the absence of adequate facilities in the port for receiving waste from ships. Among the sub-dimensions regarding energy management (0.094), the use of “renewable energy sources” (0.663) and “energy consumption” (0.260) were found as priorities.

Improving energy performance requires state-of-the-art technological solutions, identifying high energy consumption areas and port operations, operational improvements, exploiting renewable energy sources (wind energy, wave energy, electricity, solar energy, biomass energy), and installing smart grids for better energy management, etc. Regarding port security and safety (0.131), a dimension that requires special attention, the share is held by “security management systems” (0.594), and this is due to the fact that port information systems contain sensitive data, whose confidentiality is crucial, and therefore security management becomes a concern of the port administrators. The need for proper training of port staff (0.089) on the acquisition of skills to work with dedicated software is a dimension the experts in the field prioritized.

The digitization process in the Romanian river-sea ports is quite slow, and from the statements of the respondents, it resulted that they have an observer role regarding this process for the time being, and in the near future the necessary steps will be taken in this direction.

The survey and interviews conducted in the analyzed ports aimed to identify the perspectives on the potential digital solutions needed in these ports. Based on the answers obtained in the survey, the nine key technologies for digitization (Digital Transformation Scoreboard, 2018), which were designated for other sectors of the industry, proved to be applicable for ports as well. The respondents consider that implementing the presented solutions in the four river-sea ports in Romania could open the way to digitalization. A future research concern is making comparisons between fluvial and maritime ports from the perspective of digitalization and proposing a methodology for evaluating the level of digitalization of these ports.

A limitation of this research refers to the fact that the concept of the smart port is new and developing, and the perceptions and experiences of the respondents in the field of the smart port are relatively subjective. However, the results obtained in this study can be used by port operators in the process of the digital transformation of the ports. Another limitation of this study is the evaluation of the current levels of digitization of the analyzed ports, which would allow clearer information on the areas of activity that require further improvements. The accuracy of the assessment of the current levels of digitalization of ports is influenced by the differences between the answers given by the respondents, but also by other factors such as the available funds and the economic environment of the port, factors that can influence both the level of digitalization and the volume of investments in digitalization.

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References

Acciaro, M., Ghiara, H. and Cusano, M., 2014. Energy management in sea ports: A new role for port authorities. *Energy Policy*, 71, pp.4-12.

Alves de Moura, D. and Goulart de Andrade, D., 2018. Concepts of Green Port Operations – One Kind of Self Diagnosis Method to the Port of Santos – Brazil, *Independent Journal of Management & Production*, 9(3), pp.785-809.

Bergqvist, R. and Zandén, N., 2012. Green port dues - The case of hinterland transport. *Research in Transportation Business & Management*, 5, pp.85-91.

Bilal, M., Kumar, A., Cianca, E. and Lindgren, P., 2018. Improving Port Operations through the Application of Robotics and Automation within the Framework of Shipping 4.0. *In International Symposium on Wireless Personal Multimedia Communications (WPMC)*, [online] Available at: <https://ieeexplore.ieee.org/document/8712998> [Accessed on 1 September 2021].

Buck, W., Gardeitchik, J. and van der Deijl, A., 2017. Move Forward: Step by step towards a digital port (Whitepaper). PortForward—Digital solutions by Port of Rotterdam, Rotterdam, [online], Available at: <https://www.britishports.org.uk/system/files/documents/smart_port_papers.pdf> [Accessed on 4 September 2021].

Buiza, G., Cepolina, S., Dobrijevic, A., del Mar Cerbán, M., Djordjevic, O. and González, C., 2015. Current Situation of the Mediterranean Container Ports Regarding the Operational, Energy and Environment Areas. *International Conference on Industrial Engineering and Systems Management* (IESM), Seville. [online] Available at: <https://www.researchgate.net/publication/287595786_Current_situation_of_the_Mediterranean_container_ports_regarding_the_operational_energy_and_environment_areas> [Accessed on 25 June 2021].

Buiza-Camacho, G., del Mar Cerban-Jimenez, M. and Gonzalez-Gaya, C., 2016. Assessment of the Factors Influencing on a Smart Port with an Analytic Hierarchy Process. *Revista DYNA,* 91, pp.498–501.

Chen, J., Huang, T., Xie, X., Lee, P.T.W. and Hua, C., 2019. Constructing governance framework of a green and smart port, *Journal of Marine Science and Engineering,* 7(4), 83, pp.1-17

Chiu, R.H., Lin, L.H. and Ting, S.C., 2014. Evaluation of Green Port Factors and Performance: A Fuzzy AHP Analysis. *Hindawi Publishing Corporation. Mathematical problems in Engineering*, 2014, pp.1-12. [online] Available at: <https://www.hindawi.com/journals/mpe/2014/802976/> [Accessed on 12 July 2021].

Chou, C.C., 2010. AHP Model for the container port choice in the multiple-ports region. *Journal of Marine Science and Technology*, 18(2), pp.221-232.

Czachorowski, K., Solesvik, M. and Kondratenko, Y., 2019. *The Application of Blockchain Technology in the Maritime Industry*. In book: Green IT Engineering: Social, Business and Industrial Applications, Springer International Publishing, Part of the Studies in Systems, Decision and Control book series (SSDC, volume 171). [online] Available at: <https://link.springer.com/chapter/10.1007/978-3-030-00253-4_24> [Accessed on 12 July 2021].

ECMAR (European Council for maritime Applied R&D), 2017. *Maritime Technology Challenges 2030 New Technologies and Opportunities, Brussels, Belgium*. [online] Available at: <https://www.ecmar.eu/media/1813/ecmar-brochure-maritme-technology-challenges-2030.pdf> [Accessed on 4 September 2021].

European Commission, 2018. *Digital Transformation Scoreboard*. [online] Available at: <https://op.europa.eu/ro/publication-detail/-/publication/683fe365-408b-11e9-8d04-01aa75ed71a1> [Accessed on 5 January 2020].

Fernández, P., Santana, J. M., Ortega, S., Trujillo, A., Suárez, J. P., Domínguez, C., Santana, J., and Sánchez, A., 2016. Smartport: A Platform for Sensor Data Monitoring in a Seaport Based on FIWARE. *Sensors*, 16(3), 417, pp.1-24. https://doi.org/10.3390/s16030417

Gurumurthy, A., and Bharthur, D., 2019. Impact of Digitalisation in the Ports Sector. *Artificial Intelligence In India*, 5, pp.1-27. Available at: <https://ssrn.com/abstract=3873179> [Accessed on 07/07/2020

Heilig, L., Lalla-Ruiz, E. and Voß, S., 2017a. Digital Transformation in Maritime Ports: Analysis and A Game Theoretic Framework. *Netnomics,* 18, pp.227–254.

Heilig, L., Schwarze, S. and Voß, S., 2017b. An Analysis of Digital Transformation in The History and Future of Modern Ports. Proceedings of the 50th Hawaii International Conference on System Sciences (HICSS). [online] Available at:https://scholarspace.manoa.hawaii.edu/bitstream/10125/41313/paper0164.pdf [Accessed 15 May 2020].

Inkinen, T., Helminen, R. and Saarikoski, J., 2019. Port Digitalization with Open Data: Challenges, Opportunities, and Integrations**.** *J. Open Innov. Technol. Mark. Complex*, 5(30), pp.1-16.

Kapkaeva, N., Gurzhiy, A., Maydanova, S. and Levina, A., 2021. Digital Platform for Maritime Port Ecosystem: Port of Hamburg Case. Transportation *Research Procedia*, 54, pp.909–917.

Karli, H., Öztaş Karli, R.G. and Çelikyay, S., 2021. Fuzzy AHP Approach to the Determinatıon of Smart Port Dimensions: A Case Study on Filyos Port. *Düzce University Journal of Science & Technology*, 9, pp. 322-336.

Kenyon, G.N., Goldsmith, M., Neureuther, B.D. and Zhou, D., 2018. Improving the return on investment in ports: opportunities in data management, *Maritime Economics & Logistics*, 20 (4), pp.514-530.

Lam, J.S.L. and Notteboom, T., 2014. The Greening of Ports: A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe. *Transport Reviews*, 34(2), pp.169–189.

Liao, M.S., Ding, J.F., Liang, G.S. and Lee, K.L., 2016. Key Criteria for Evaluating the Green Performance of Ports. *Journal of Testing and Evaluation*, 44(4), pp.1791-1801.

Molavi, A., Lim, Gino J. and Race, B., 2019. A Framework for Building a Smart Port and Smart Port Index. *International Journal of Sustainable Transportation*, 14 (9), pp. 686-700. https://doi.org/10.1080/15568318.2019.1610919.

National Institute of Statistics, 2015-2021.Data base.[online] Available at: <https://insse.ro/cms/ro/tags/transportul-portuar-de-marfuri-si-pasageri> [Accessed on October 2022].

Pak, J.Y., Yeo, G.T., Oh, S.W., and Yang, Z., 2015. Port Safety Evaluation from a Captain's Perspective: The Korean Experience. *Safety Science*, 72, pp.172–181.

Paulauskas, V., Philipp, R., Henesey, L., Paulauskas, D., Sutnikas, A., Meyer, C., Gerlitz, L., Heine, N., Kozyczkowski, K. Zigus, A. and Silonosov A., 2021a. Smart Ports' Influence on Coastal Sustainability. *Proceedings of 25th International Scientific Conference. Transport Means,* [online] Available at: <https://www.researchgate.net/publication/356749788_Smart_Ports'_Influence_on_Coastal_Sustainability> [Accessed 1January 2022].

Paulauskas, V., Filina-Dawidowicz, L. and Paulauskas, D., 2021b. Ports Digitalization Level Evaluation. *Sensors*, 21(6134), pp.1-22.

Pavlic, B., Cepak, F., Sucic, B., Peckaj, M. and Kandus, B., 2014. Sustainable Port Infrastructure, Practical Implementation of the Green Port Concept. *Thermal Science*, 18(3), pp.935-948.

Saaty, T.L., 1987. The Analytic Hierarchy Process-What It Is And How It Is Used. *Mathl Modelling*, 9(3-5), pp.161-176.

Sullivana, B.P., Desaib, S., Solec, J., Rossia, M., Ramundoa, l. and Terzi, S., 2019. Maritime 4.0 – Opportunities in Digitalization and Advanced Manufacturing for Vessel Development. *Procedia Manufacturing*, 42, pp.246-253.

Turcanu (Marcu), A.L., 2022. *Factors with impact on the management of goods transport on the Danube.* PhD thesis, Dunarea de Jos University, Galati.

Yang, Y., Zhong, M., Yao, H., Yu, F., Fu, X. and Postolache, O., 2018. Internet of Things for Smart Ports: Technologies and Challenges. *IEEE Instrumentation & Measurement Magazine,* 21(1), pp.34-43.

Yuen, C.I.A., Zhang, A. and Cheung, W., 2012. Port competitiveness from the users' perspective: An analysis of major container ports in China and its neighboring countries. *Research in Transportation Economics*, 35(1), pp.34-40.

Zhou, C., Su, F., Pei, T., Zhang, A., Du, Y., Luo, B. and Song, C., 2020. COVID-19: Challenges to GIS with Big Data. *Geography and Sustainability*, 1, pp.77-87.