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DIGITPORTS

DIGITal Twins applications for safer and greener Adriatic PORTS operations

Cross border benchmarking report on digitalization level of the Adriatic ports

(D.1.1.1)

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Sommario

1. Executive Summary

1.1 Objective

The purpose of this report is to provide a detailed analysis of the digitalization levels of Adriatic ports (as-is situation), benchmarking them against leading international practices, and propose actionable recommendations to address identified gaps. The report leverages a comprehensive methodology, combining primary data collection through surveys (questionnaires) and interviews, secondary research from academic and industry sources, and an evaluation of pilot actions outlined in the DIGITPORTS project. Key findings highlight the current state of digital adoption, operational inefficiencies, and alignment with sustainability goals. The recommendations focus on implementing advanced technologies, enhancing regional cooperation, and addressing policy and funding challenges.

1.2 Key Insights

The analysis reveals several critical gaps in digitalization across Adriatic ports. Many ports face fragmented adoption of digital tools, with limited integration of systems such as Port Community Systems, digital twins, and IoT technologies. Cybersecurity measures and data governance frameworks remain underdeveloped, exposing ports to risks in an increasingly digital ecosystem. Furthermore, alignment with sustainability goals, including carbon footprint reduction and energy efficiency, is inconsistent across the region.

Benchmarking against global leaders like the Port of Rotterdam, Singapore, and Shanghai highlights best practices in adopting digital twins, AI-driven logistics, and IoT-enabled automation. These ports demonstrate the transformative potential of advanced technologies, strong interoperability, and robust sustainability initiatives. The insights from these benchmarks provide a roadmap for Adriatic ports to elevate their operations to international standards.

Against this background situation, it is worth noticing that the governance models of Adriatic Italian and Croatian Ports compared to the Northern range ports (such as Rotterdam) and other mentioned international hubs (Singapore and Shanghai) must be carefully taken into consideration.

The formers have a landlord port structure while the latters have a public service port structure (public companies with shareholders), and the differences do impact on the range of digitalization processes that can be put in place.

Just to outline the main differences, the following structures are recalled:

Corporatized ports: almost entirely privatized, except that ownership remains public and often assumed as a majority shareholder. The port authority essentially behaves like a private enterprise. This management model is unique since it is the only one where ownership and control are separated, which lessens "public good" pressures landlord port authority faces and "shareholder value" pressures private ports face.

In the Rotterdam port areas, the landlord port authorities are public limited companies and consequently not government agencies any more (since 2004). These companies are highly commercialised entities, as public influence is only indirectly accomplished through the ownership interests that the Dutch state or municipal governments maintain in these public limited companies. Although legal title to the land in the port areas remains with the municipal government in most cases, the port authorities of Rotterdam have leased this land in perpetuity. These lease agreements with the relevant municipal governments therefore allocate the economic ownership of the port area to the port authorities. To date, the Dutch state has only acquired an ownership interest (29.2 per cent) in the Port of Rotterdam Authority in return for financial investments from the state

The Dutch Minister of Infrastructure and Environment and municipal government have delegated certain public powers to harbourmasters. The harbourmasters of the ports of Rotterdamm are employed by the privatised port authorities.

Landlord ports: Under the landlord model, a port authority is usually a separate legal entity with the capacity to conclude contracts (including concession agreements) and to enforce standards. Infrastructure, particularly terminals and quays, are leased to private operating companies with the port authority retaining ownership of the land (maritime real estate). The most common form of lease is a concession agreement where a private company is granted a long-term lease (20-35 years average) in exchange for rent that is commonly a function of the size of the facility as well as the investment required to build, renovate or expand the terminal. The private operator is also responsible for providing terminal equipment to maintain operating standards. The selection of the operators must undergo public procurement strict regulation on tranparency, best value-for-money and ROI principles and equal treatment.

Safety of navigation and harbourmaster duties and prerogatives are under the sole responsability of the Coastguard offices under the direct control of the Italian or Croatian Ministry of Transport, Sea and Infrastructures, respectively.

Main differences between port operating structures	Port Authority ows infrastructure	Port Authority own superstructure	Nautical safety rules	Port authority provides services directly
Corporatized Ports	Yes	Yes	Yes (directly employs Harbourmaster)	Yes
Landlord Ports	Yes	No	No (Maritime Authority - Coastguard)	No

The list of services of general interests such as nautical services (mooring, pilotage and towage), dredging, waste management are also treated differently (landlord model: concession vs Service ports: directly).

Althought the knowledge transfer is a valuable starting point for the Adriatic Ports to define a common baseline of digitalization requierements, these peculiar governance models must be kept in mind when trying to replicate digitalization processes and measuring them with metrics that address different ownerships and missions of port authorities.

1.3 Recommendations

The report underscores the need for a strategic, phased approach to digitalization. Key recommendations include the following:

- **Technology Implementation**: Initiate pilot projects for digital twins, IoT devices, and AI-powered analytics in operational areas like cargo handling (operated by private companies on a concessions scheme) and assets and resource management.
- **Regional Cooperation**: Establish cross-border data-sharing frameworks and foster collaborative projects to leverage shared resources and knowledge.
- **Capacity Building**: Conduct comprehensive staff training programs to bridge skill gaps and enhance technological readiness.
- **Policy Reforms**: Develop a unified digitalization strategy aligned with EU directives, streamline regulatory processes, and strengthen cybersecurity policies.
- **Sustainability Alignment**: Invest in renewable energy infrastructure and green technologies to reduce environmental impact and meet EU Green Deal objectives.

- **Funding and Investments**: Explore public-private partnerships and optimize access to EU funding mechanisms to address financial gaps.

By adopting these recommendations, Adriatic ports can address their current challenges, capitalize on their strategic geographical position, and emerge as competitive, sustainable hubs in the global maritime network.

2. Introduction

2.1 Background and Context

Adriatic ports play a critical role in regional and international trade, serving as key nodes in the European maritime network. In recent years, these ports have faced mounting challenges, including pressure to enhance operational efficiency, adapt to evolving global supply chains, meet sustainability goals, and address regulatory demands. Digitalization and automation have emerged as crucial solutions to address these challenges, offering the potential to improve port operations, reduce environmental impacts, and optimize resource utilization.

Despite progress, the pace of digital transformation in the Adriatic maritime sector has been slower than desired, hindered by factors such as high costs, an aging workforce, and the complexity of adapting legacy systems. This situation underscores the importance of a coordinated approach to digitalization, leveraging best practices and fostering cross-border cooperation to maximize efficiency and sustainability.

The DIGITPORTS project, funded under the Interreg VI-A Italy-Croatia programme, aims to address these challenges by introducing innovative digital twin applications to the Adriatic port ecosystem. This initiative is expected to enhance the digitalization, sustainability, and operational efficiency of these ports, enabling them to transition into modern, data-driven, and environmentally sustainable hubs.

2.2 Summary of the DIGITPORTS Project

DIGITPORTS aims to help solve a specific challenge in the maritime transport, i.e. how to exploit the technical opportunities of Digital Twins to upgrade the digitalization level of port authorities, public services of general interests and how to integrate better planning solutions at cross-border level.

The full digitalization of ports will leverage the Blue Economy growth of the Adriatic territories and beyond, being the port's authorities engine for growth in terms of works, services and global supply chain nodes connecting manufaturers and consumers of Southern Europe to ther rest of world.

DIGITPORTS partnership is geographily covering all the Adriatic Sea, and the Authorities have all technical and management capacities to carry out the pilot activities so to phisically produce the change at cross-border level, bringing together Core and Comprehensive European sea ports in the Adriatic area of Italy and Croatia:

Code	Organization	Acronym
LP1	North Adriatic Sea Port Authority (ports of Venice and Chioggia) - Lead Partner	NASPA
P02	Port Network Authority of the Eastern Adriatic Sea (ports of Trieste and Monfalcone)	PNAEAS
P03	Port of Ravenna Authority	ADSPMACS
P04	Port of Rijeka Authority	PRA
P05	Port of Ploče Authority	PPA
P06	Port of Zadar Authority	ZPA
P07	Port of Split Authority	SPA

In addition, Central Adriatic Sea Port Authority (representing the Ports of Ancona, Falconara, Pesaro, San Benedetto del Tronto, Pescara, Ortona and Vasto, hereafter CAPSA) is also taking part to the activities, to gain a more in-depth comprehension of the "As Is" situation of digitalization of the above listed ports, in comparison with other Italian and Croatian Adriatic ports, building on available knowledge and having a clearer picture of medium-long-term planning necessary to upgrade the ports' services using technology applications such as DT.

This will help to eventually scale the DT co-design model applied to DIGITPORTS partners, creating a network of digitalized cross-border ports, thus enhancing port's role as engine for growth in the cross-border ecosystem. The port of Ancona is interested in understanding how to potentially mirror the DT implemented in other ports which are destination routes, because it is the main Italian port for international passenger traffic by ferries. Their catchment area and main market is represented by Ro-Ro traffic, with intense traffic flows of trucks and Ro-Ro freight, with the Italian ports of Trieste, Venezia and Ravenna, with Greece (Igoumenitsa and Patras), Croatia (Split) and Albania (Durres). Finally, The Port of Ancona will add on capitalization involving the high training center for seafarers that has already benefitted from the pilot action carried out in INTESA project, e.g. the simulator for training presently used with training purposes.

n.	Associated Organization	Code
A01	Central Adriatic Port System Authority (ports of Ancona, Falconara, Pesaro, San Benedetto del Tronto, Pescara, Ortona and Vasto)	CAPSA

The project's overarching goal is to lead the digital transformation of Adriatic ports through the development and application of digital twin technologies, thus , first and foremost, to review the processes, optimizing the public assets valorization and efficacy of port operations. These tools will facilitate dynamic scheduling, predictive maintenance, real-time decision-making, and integration of administrative and operational processes. By aligning with international best practices, the DIGITPORTS initiative seeks to reduce operational costs, minimize carbon footprints, and improve resource allocation while fostering a sustainable and competitive port ecosystem.

2.3 Goal of the document

The purpose of this paper is to conduct a comprehensive analysis of the current ("as-is") digitalization level across the Adriatic ports and to give a preview of the future developments included in vision committements of each Port Authority ("to-be“). This includes identifying existing digital infrastructures, assessing gaps, and evaluating the challenges faced by these ports in their digital transformation journey in the middle and long-term timespan. The findings will be benchmarked against international best practices, focusing on leading ports such as Rotterdam, Singapore, and Hamburg, which have successfully implemented advanced digital solutions.

By providing actionable insights and recommendations, this report aims to support the DIGITPORTS project's objectives, offering a roadmap for enhancing digitalization efforts across Adriatic ports.

The ultimate goal is to foster a collaborative and data-driven approach to port management, ensuring that Adriatic ports remain competitive and environmentally sustainable in the global maritime landscape.

2.4 Background and Context

Digitalization is transforming the maritime and port sectors by streamlining operations, improving supply chain transparency, and enabling predictive analytics. Advanced technologies such as digital twins, IoT, and AI enhance decision-making, reduce costs, and support sustainability goals.

Adriatic ports are crucial gateways for trade between Europe, the Mediterranean, and beyond. They serve as transit points for goods, connecting major economic hubs and facilitating cross-border commerce. Their strategic location and capacity make them essential components of the European transport network.

The COVID-19 global pandemic revealed how dependent companies and countries are on resilient, efficient and fully visible supply chains in air, sea and road transportation. A lack of information can result in considerable delays that can compromise or, in the worst case, decrease or even obliterate the value of shipped goods.
As supply chains become increasingly complex and environmental standards and regulations are tightened, along with security in and around port areas, ports today face a host of challenges.
Ports have become service providers, energy hubs and an active nodes of the global supply chains. They deliver services to numerous stakeholders, including the coordination of port calls,

environmental management, ship-to-shore operations, as well as commercial and industrial property management.
In their traditional role, the size and capacity of ports were key to the success of this industry.
Nowadays, the supply chains are the ones competing at global level and the role of the ports must adapt quickly as efficiency takes precedence, and ports must become smarter so not to be *"the clay pot among the iron pots".*
This became apparent with the onset of the current COVID-19 pandemic, as many ports grappled with how to manage the impact of the economic crisis.
All in all, Adriatic Ports have experienced a wave of digitalization and automation initiatives in the last five years, due to multifaceted challenges such as : 1) the pressure on efficiency caused by competition, 2) post-pandemic effects on global supply chains resilience and cost structures, 3) scale expansion of container shipping and logistics; 4) increasing accountability of ports operations due to proximity of city centers, 5) greater demand for transparency and objective measurements of pollutants and port performance KPI's connected also to public procurement schemes of concessions procedures.
Italian and Croatian Port Authorities act as public body regulators of ports operations and strive for creating the baseline conditions for a safer, greener and more sustainable competitive port system. However, the pace of digital transformation in the maritime industry is still slow due to industry specific characteristics, such as high asset costs, high development costs, aging workforce and strict regulations, negatively impacting the ability to digitize effectively all kind of port operations. Also, due to the traditional set-up of the organizations, conventional players often lack the skills and agile processes for successful digital adoption.

Moreover, the outcomes of the DIGITPORTS are coherent with the European Commission statement that *"Europe must leverage the potential of digital transformation, which is a key enabler for reaching the Green Deal objectives".*
This idea is reinforced in the New Industrial Strategy for Europe, where it is underlined that the twin ecological and digital transitions will affect every part of our economy, society, and industry.
The Fit for 55 packages will drive the transition to achieve the 2030 goal of reducing carbon emissions by 55%.
Digital technology such as artificial intelligence, cloud computing, IoT and Digital Twins can enable the scale-up of EU's decarbonisation goals, especially in the maritime transport sector and in the ports, which are the crucial nodes of global supply chains.

DT testing ICT solutions and co-designing them at cross-border level, will benefit the replicability to other logistic nodes, also beyond the project's geographical scope (possibly EUSAIR Adriatic-Ionian area).

2.5 Objectives

This report seeks to assess the status of digitalization in Adriatic ports, identifying existing infrastructure, practices, and gaps. By comparing Adriatic ports with global leaders such as Rotterdam, Singapore, and Hamburg, the report aims to highlight actionable improvements and best practices.

2.6 Scope of the Study

The analysis concentrates on ports within the Adriatic region, covering both Italian and Croatian port authorities.

3. Port-Specific Assessments

3.1 North Adriatic Sea Port Authority (Venice and Chioggia) - NASPA

The ports of Venice and Chioggia are respctively Core and Comprehensive TENT Network multipurpose ports, embedded in the Venetian Lagoon, World Heritage Site protected by UNESCO, and are challenged by limited nautical accessibility, due to physical and environmental factors (shallow waters, fog) and by the effects of the operations of the Mo.SE. system that protects the city form high waters, with a permanent infrastructure at the inlets (automated submersed antiflooding gates), that imposes physical constraints on access to the Venice lagoon, making the Ports of Venice and Chioggia the only ones in Italy with regulated access, with locks will to regulate transit of ships even during the closure of the Mo.SE.

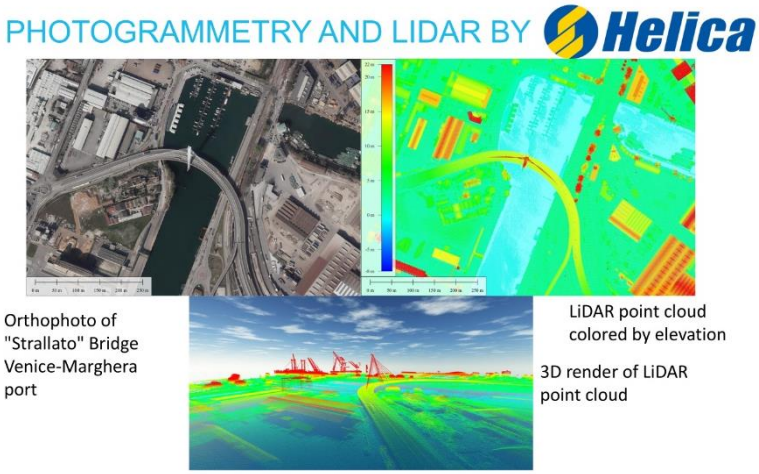
This has led NASPA to push towards DT replica of the scenario for testing operation times, locks and canals utilization rates and many other relevant indicators for becoming the first Italian port to be regulated by a lock and, at the same time, increase port operating time (24/7 goal) and capacity.

With the help of DIGITPORTS project, NASPA is trying to pursue the full digitalization concept to be applied oin all divisions of the Authority and to change the working culture into data-led decision making. Integrating sensor's networks of the lagoon , rules of navigation of Maritime Authorities, meteo databases and forecasts and charts (GIS system networks) will enable , via the pilot, the testing of the beta version of the DT scheduling tool that helps optimizing port operations also taking into consideration Mo.SE. effects. This Scheduling Tool is a decision support system based on an algorithm driven making software to support Maritime Administration to schedule entrance and exit of the vessels and guarantee port business continuity.

Total tonnage	***IN***	***OUT***	***Total***	***notes***
Total tonnage	18.617.548	4.653.545	23.271.093	
Liquid Bulk (Ton)	6.207.373	447.112	6.654.485	
Dry Bulk (Ton)	6.745.594	131.572	6.877.166	
General cargo (Ton)	5.664.581	4.074.861	9.739.442	
N. of local and ferry passengers	80.531	73.813	154.344	
Cruise passengers			507.980	
N. Containers (TEU)	257.045	234.073	491.118	
Ro-Ro Units	49.887	53.622	103.509	
N. Private vehicles	16.364	14.849	31.213	
n. commercial vehicles	25.254	44.802	70.056	

Main past and current projects focusing on digitalization that are capitalized in DIGITPORTS include:

1. INTERREG ITHR – INTESA Improving Maritime Transport Efficiency and Safety in Adriatic (2019-2022): led by NASPA, the project established a network among the National Maritime Administrations of Italy and Croatia and main port authorities of the Adriatic Sea (Venice, Trieste, Ravenna, Ancona, Bari, Rijeka, Ploce and Split) with the scope of harmonizing and optimizing the procedures of the complete maritime transport process in order to make port and maritime transport system more efficient and safe. The project aimed at optimizing the port procedure from unload of the cargo from the ship to the forward by train or truck, at optimizing the procedure to enter and exit from the port; at increasing port performances in bad weather conditions safeguarding safety and security requirements; at designing and implementing integrated ICT tool for the management and broadcast of the information on Maritime Safe.
   The environmental and geographical peculiarities of the area (venetian lagoon) make the navigation of vessels more complex than in other national ports of call. The INTESA project gave solutions to assist navigation, thanks to innovative and highly technological solutions, e.g. navigational aids (on board devices, so called pilot portable unit – PPU), based on high-precision cartography specially produced and its integrated ortho-photo Database (LIDAR technology).
   Last but not least, INTESA project has enabled NASPA to further consolidate the cooperation that has been going on for many years with the General Command of Italian Coastguard, the Tide Forecasting and Reporting Centre of the Municipality of Venice and the Venice Lagoon Water Management Authority, for the collec-tion, ex-change and integration of systems and data for the definition of navigation aids. Indeed, the on-board display devices show not only the updated cartography, the exact position of the ship, but also all the marine weather data collected in real time and the navigability status of the channels, col-lected also from diverse DB available from the above mentioned public authorities.
   Further added value is the integration with real-time tidal height data that allow the display devices to update the status of bathymetry in real time based on the actual tidal height. Pilots now can count on a navigational aid that will provide them with all information relating to the progress of the ship, the position and status of the infrastructure as well as an exact indication of the draught in real time at the transit position.

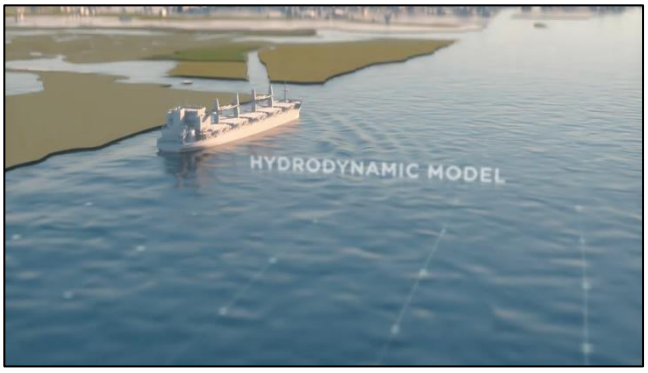


2. Connecting Europe Facility - GREEN C-PORTS (2020- 2023): the project, led by Fundacion Valencia Port (ES) provided port authorities with digital instruments and technologies to support the environmental sustainability of the efficiency of port operations (https://greencportsproject.eu/), including a suitable array of digitalisation tools and technologies to support port environmental sustainability and performance of port operations in the TEN-T Core Network, to reduce the negative impact of port operations on their cities, monitor emissions from ports and vessels, optimize the handling flows of cargo. For example, to address its nautical accessibility problems NASPA purchased and put in operation a sensor's network, crucial to have an optimized traffic schedule, based on the combination of navigation rules and weather conditions. Weather conditions need to be processed and made available in both real time but also on forecast modes, as to allow the most reliable model of planning entry/exit of ships through the main navigation channel (data from sensors). This pilot and others will be capitalized in the methodology and in data harvesting to feed DT developments of DIGITPORTS.

   GREEN C-PORTS Sensor Location: Sant'Elena Station (example of equipment)

3. Connecting Europe Facility „Channeling the Green Deal for Venice“ (2019-2024) – Thanks to this project, NASPA was able to identify solutions capable of improving navigability conditions along the Malamocco - Marghera channel in the Venice Lagoon, aiming to increase the operability of the canal in full compliance with the conditions of navigational safety and the mitigation of erosive processes affecting the lagoon shallows adjacent to the canal itself, mainly due to the passage of large ships.
   The access to the Commercial terminals of Porto Marghera is ensured via the main Malamocco-Marghera navigation channel, which extends for about 20 km, with a depth of -12 m, equal to the quota established by the current regulatory plan. The evolution basins have a diameter of 350 m. Along this access channel to the Marghera areas, one-way traffic is permitted (platooning of ships), alternating with ships up to 45 meters wide and 10.9 meters during the day.

The execution of the study was led by Danish Hydraulic Institute, CETENA and Force Technology, market leaders who have prepared a complex and articulated combination of hydrodynamic models, transport sedimentary and ship simulations. The continuous interaction between all the tools used allowed them to identify and optimize solutions, both operational/managerial and structural, that combined increased operability and navigational safety with the mitigation of the hydro-morphodynamic effects of the passage of ships along the channel (https://www.youtube.com/watch?v=90AS7w-9T9k).



3.2 Port Network Authority of the Eastern Adriatic Sea (PNAEAS)

The Port Network Authority of the Eastern Adriatic Sea oversees the ports of Trieste and Monfalcone in Italy.

Total tonnage (Trieste)	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk	*37.345.812*	*0*	***37.345.812***	
Dry Bulk	*422.614*	*21.197*	***443.811***	
General cargo	*9.582.614*	*8.252.688*	***17.835.302***	
N. of local and ferry passengers	*4.317*	*6.054*	***10.371***	
Cruise passengers	*16.244*	*16.261*	***468.599***	*Transits 143,549*
N. Containers (TEU)	*461.754*	*390.439*	***852.193***	
Ro-Ro Units	*147.465*	*151.105*	***29.857***	
N. Private vehicles	*43*	*1.044*	***1.087***	
n. commercial vehicles	*19.464*	*5.087*	***24.551***	

Figure 7: Port of Trieste

Total tonnage (Monfalcone)	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk	*0*	*0*	***0***	
Dry Bulk	*2.492.141*	*519.984*	***3.012.125***	
General cargo	*587.007*	*230.589*	***817.596***	
N. of local and ferry passengers	*5*	*32*	***37***	
Cruise passengers	*31.116*	*3.234*	***92.045***	*Transits 28,589*
N. Containers (TEU)	*231*	*190*	***421***	
Ro-Ro Units	*0*	*0*	***0***	
N. Private vehicles	*0*	*0*	***0***	
n. commercial vehicles	*44.687*	*645*	***109.187***	

Figure 8: Port of Monfalcone

This authority has been proactive in adopting digital technologies to enhance operational efficiency, sustainability, and integration within the European transport network. Notable initiatives include:

1. DIGSEA Project (DIGitalisation of Multimodal Transport in the Adriatic SEA)

PNA EAS leads the DIGSEA project, co-financed by the Interreg Italy-Croatia Cross-border Cooperation Programme 2014-2020. The project aims to consolidate technological knowledge from previous initiatives to create an integrated logistics chain covering the entire transport cycle. By capitalizing on prior developments, DIGSEA seeks to optimize multimodal traffic flows and enhance cooperation and efficiency across the logistics chain.

2. MERIDIAN Project

PNA EAS participates in the MERIDIAN project (Managing Europe's Busiest TEN-T Corridors Fostering Green, Digital, and Multimodal Services), co-funded by the Connecting Europe Facility (CEF) Programme. This project focuses on promoting the digitalization and decarbonization of transport

services along major European corridors, enhancing the efficiency and sustainability of port operations.

3. Port Community System (PCS) Implementation

Since 2014, the Port of Trieste has developed its own Port Community System to streamline communication and data exchange among port stakeholders. This system enhances operational efficiency by integrating various services and facilitating real-time information sharing, positioning Trieste as Italy's leading intermodal port with extensive rail connections to major European destinations.

4. 2030 ICT Strategy

PNA EAS has outlined a comprehensive ICT strategy aimed at integrating digital technologies into port operations by 2030. This strategy focuses on enhancing data management, improving communication systems, and adopting innovative solutions to maintain competitiveness and operational excellence.

3.3 Port of Ravenna Authority (ADSPMACS)

The Port of Ravenna Authority has been actively implementing digital technologies to enhance operational efficiency, safety, and sustainability.

Total tonnage	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk	4.165.692	436.670	4.602.362	
Dry Bulk	9.682.711	384.828	10.067.539	
General cargo	8.260.085	2.573.145	10.833.230	
N. of local and ferry passengers	223	163	386	
Cruise passengers	141.032	140.410	330.952	
N. Containers (TEU)	109.894	107.087	216.981	
Ro-Ro Units	37.518	40.780	78.298	
N. Private vehicles	142	2.592	2.734	
n. commercial vehicles	4.906	10.648	15.554	

Notable initiatives include:

1. Digital Twin Project

The Port of Ravenna is developing a comprehensive Digital Twin in collaboration with CNT Technologies. This virtual replica of the port's infrastructure and operations assists in asset management, project planning, maintenance, and supports major canal dredging programs. The Digital Twin integrates data from various sources, providing real-time information to optimize port activities and decision-making processes.

2. Port Community System (PCS) Implementation

The Port of Ravenna has implemented a Port Community System to streamline communication and data exchange among port stakeholders. This digital platform enhances operational efficiency by integrating various services and facilitating real-time information sharing, positioning Ravenna as a competitive intermodal port with extensive connections to major European destinations.

3. PASSport Project

As a participant in the PASSport (Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS high Accuracy and Authentication to improve Security & Safety in port areas) project, the Port of Ravenna is enhancing situational awareness to improve safety and security within the port area. The project involves deploying a fleet of drones equipped with high-accuracy GNSS receivers to monitor pollution, support e-navigation, protect critical infrastructure, and detect underwater threats.

4. CRESPORT Project

The Port of Ravenna is leading the CRESPORT (Improving the Cyber Resilience and Security of Adriatic Ports) project, aiming to enhance cybersecurity in Adriatic ports. Recognizing the risks associated with digitalization, CRESPORT seeks to strengthen cyber resilience through a collaborative approach, adopting a common strategy in compliance with international cybersecurity frameworks.

5. Digital Integration with Rail Transport

In collaboration with Mercitalia Logistics, the Port of Ravenna is promoting digital integration between their technological systems to improve the quality and efficiency of rail transport services. This initiative facilitates better planning and management of operations, such as loading and unloading maneuvers and the management of waybills, thereby increasing the competitiveness of rail and intermodal transport.

3.4 Port of Rijeka Authority (PRA).

The Port of Rijeka has been actively involved in several digitalization projects aimed at enhancing its operational efficiency, sustainability, and integration within the European transport network.

Total tonnage	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk	*6.327.461*	*232.055*	*6.559.516*	
Dry Bulk	*726.685*	*586.290*	*1.312.975*	
General cargo	*40.344*	*510.524*	*550.868*	
N. of local and ferry passengers	*72.708*	*73.405*	*146.113*	
Cruise passengers	*0*	*0*	*37.693*	
N. Containers (TEU)	*2.241.634*	*1.632.339*	*3.873.973*	*20” + 40”*
Ro-Ro Units	*0*	*0*	*0*	
N. Private vehicles	*656*	*0*	*656*	
n. commercial vehicles	*0*	*0*	*0*	

Figure 3: Port of Rijeka

Notable initiatives include:

1. DigLogs Project (Digitalising Logistics Processes)

The DigLogs project focuses on developing advanced digitized logistics processes for multimodal freight and passenger transport. As a partner, the Port of Rijeka has implemented pilot activities to improve supervision, monitoring, and safe handling of goods and passenger flows. These activities aim to increase transport network efficiency by enhancing synchronization between logistics users, operators, and control bodies, thereby reducing traffic congestion and pollution.

2. PROMARES Project (Promoting Maritime and Multimodal Freight Transport in the Adriatic Sea)

The PROMARES project aims to enhance maritime and multimodal freight transport by addressing challenges related to accessibility and network efficiency from ports to hinterlands. The Port of Rijeka Authority participated in pilot actions testing ICT solutions to simplify freight transport and create intermodal logistics hubs, thereby improving coordination among stakeholders.

3. Port Community System (PCS) Implementation

The Port of Rijeka is developing an ICT solution for a Port Community System (PCS) to modernize port operations through the use of ICT systems and new management methods. This system aims to standardize and centralize protocols and messages shared among port community members, enhancing communication and operational efficiency.

3.5 Port of Ploče Authority (PPA)

The Port of Ploče is actively pursuing digital transformation to enhance operational efficiency, safety, and sustainability.

Main traffic figures year 2023	***IN***	***OUT***	***Total***	***notes***
Total tonnage				
Liquid Bulk (Ton)	1.162.392	54.546	1.216.938	
Dry Bulk (Ton)	2.528.729	566.883	3.095.612	
General cargo (Ton)			468.148	
N. of local and ferry passengers				

Cruise passengers				
N. Containers (TEU)			32.058	
Ro-Ro Units				
N. Private vehicles				
n. commercial vehicles				

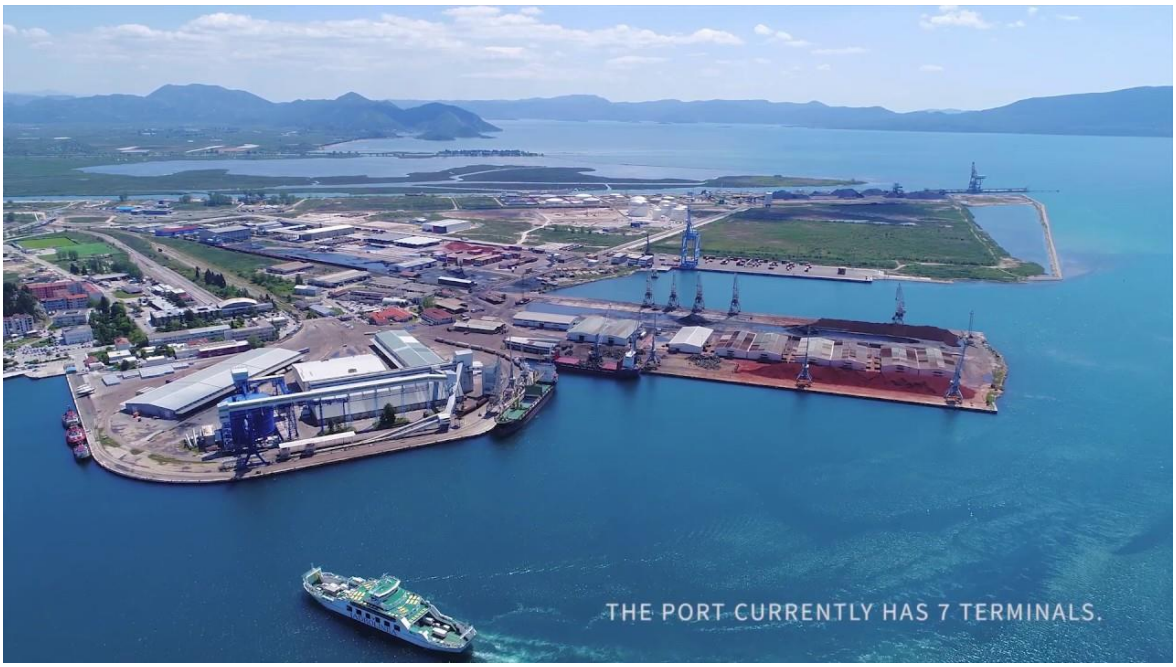


Figure 4: Port of Ploče

Notable initiatives include:

1. SmartPortPloče Project

The Port Authority of Ploče, in collaboration with Markoja d.o.o., is implementing the SmartPortPloče project, aiming to become Croatia's first smart port connected via a private 5G standalone (SA) network. Co-financed by the European Commission with €958,125, the project focuses on process automation and sensor integration to improve competitiveness and reduce the port's carbon footprint.

Key components include:

- **Real-Time Locating System (RTLS):** Enables precise tracking of vehicles within the port, enhancing operational efficiency

- **Cargo Surveillance:** Utilizes smart cameras and video analytics for monitoring cargo handling and storage, improving security and record-keeping
- **Incident Prevention and Management:** Employs sensors and drones to detect fires and localized sea pollution, facilitating prompt responses to emergencies

2. Port Community System (PCS) Implementation

The Port of Ploče is developing a Port Community System to digitize information exchange among stakeholders, aiming to enhance communication, streamline operations, and improve overall efficiency.

3. TRANSPONEXT Project

As part of the TRANSPONEXT initiative, the Port of Ploče is digitalizing railway processes and procedures to improve the quality, safety, efficiency, and environmental sustainability of transport services. This involves modernizing ICT tools and implementing innovative solutions to enhance cross-border transport operations.

3.6 Port of Zadar Authority (PZA)

The Port of Zadar is actively engaging in digitalization initiatives to enhance operational efficiency, sustainability, and integration within the Adriatic maritime network.

Total tonnage	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk	-	-	190.362	
Dry Bulk			36.307	
General cargo			100.648	
N. of local and ferry passengers			2.567.021	
Cruise passengers			170.807	
N. Containers (TEU)			0	
Ro-Ro Units			0	
N. Private vehicles			636.287	Private and commercial
n. commercial vehicles			0	see above

Figure 5: Port of Zadar

Notable projects include:

1. ADRIJOROUTES Project

As a partner in the ADRIJOROUTES project, the Port of Zadar is involved in promoting sustainable solutions for maritime cultural tourism. The project focuses on developing innovative and inclusive tourist experiences in Adriatic ports, utilizing digital tools to enhance cultural heritage and improve the integration of ports with local communities.

2. Port Community System (PCS) Implementation

The Port of Zadar is working towards implementing a Port Community System to streamline communication and information exchange among port stakeholders. This digital platform aims to improve operational efficiency, reduce administrative burdens, and enhance the overall competitiveness of the port.

3.7 Port of Split Authority (PSA)

The Port of Split is actively engaging in digitalization initiatives to enhance operational efficiency, sustainability, and integration within the Adriatic maritime network.

Total tonnage	***IN***	***OUT***	***Total***	***notes***
Liquid Bulk (Ton)			594.138	
Dry Bulk (Ton)			1.885.045	
General cargo (Ton)			1.184.327	
N. of local and ferry passengers			4.910.625	*Local ferry, catamaran, excursion boats, international ferry*
Cruise passengers			388.204	
Ro-Ro Units			214.720	*Number of trailer + truck*
N. Private vehicles			755.122	*Total number of vehicles excluding truck/trailer*

Figure 6: Port of Split

Notable projects include:

1. AIMPRESS Project

The Port of Split Authority (PSA) is a key partner in the AIMPRESS project, which focuses on implementing digital tracking and data management systems to improve operational efficiency and sustainability. Initiatives under this project include the acquisition of RFID systems for advanced tracking, portable devices for on-the-go operational management, and comprehensive data management software to streamline workflows and reduce manual intervention. Additionally, PSA is implementing an AI-powered energy management system to optimize energy usage throughout port operations, utilizing predictive analytics for demand forecasting and real-time monitoring capabilities.

2. SUSPORT Project

The Port of Split Authority (PSA) is a key partner in the SUSPORT project, an EU initiative focused on enhancing environmental sustainability and energy efficiency in Italian and Croatian ports through increased cross-border cooperation and coordinated management. Key activities for the Port of Split under SUSPORT include modernization of Public Lighting and procurement of a Hybrid Vehicle.

The SUSPORT project facilitates the exchange of best practices and the development of common methodologies for environmental sustainability, tested through pilot activities. It aims to strengthen institutional capacities for greener maritime transport.

More information about Port of Split role in SUSPORT: https://portsplit.hr/eu-projekti/susport/

3. Port Community System (PCS) Feasibility Analysis

A feasibility analysis has been conducted for implementing a Port Community System in the Port of Split. The study evaluates potential costs, savings from digitalizing business processes related to cargo processing, and the impact on port users. The analysis suggests that adopting a PCS could lead to significant financial savings, process optimization, and increased competitiveness for the port.

3.8 Central Adriatic Port System Autority (CAPSA)

Central Adriatic Sea Port Authority (Ports of Ancona, Falconara, Pesaro, San Benedetto del Tronto, Pescara, Ortona and Vasto, herafter CAPSA) is an independent public body with landlord port model, that plans and promotes infrastructures and state-owned property, coordinates and controls port operations, carried out by private companies on concessions basis, guaranteeing and leveraging the

common playing field in the multipurpose port system, spreading across a wide territory across Marche and Abruzzo regions).

Total tonnage	*IN*	*OUT*	*Total*	*notes*
Liquid Bulk (Ton)	3.047.103	696.373	3.743.476	
Dry Bulk (Ton)	367.333	10.479	377.812	
General cargo (Ton)	2.617.917	2.747.762	5.365.679	container + ro/ro
N. of local and ferry passengers	427.911	432.719	860.630	
Cruise passengers	44.137	43.690	87.827	
N. Containers (TEU)	88.037	85.115	173.152	
Ro-Ro Units	67.004	67.929	134.933	tir + trailer
N. Private vehicles	111.098	123.427	234.525	
n. commercial vehicles			0	

Figure 7: Port of Ancona

Notable initiatives include:

1. CRESPORT Project

The Port of Ancona is partner of the CRESPORT project (Improving the Cyber Resilience and Security of Adriatic Ports), aiming to enhance cybersecurity in Adriatic ports. Recognizing the risks associated with digitalization, CRESPORT seeks to strengthen cyber resilience through a collaborative approach, adopting a common strategy in compliance with international cybersecurity frameworks.

2. INTERREG ITHR – INTESA Improving Maritime Transport Efficiency and Safety in Adriatic (2019-2022): the project established a network among the National Maritime Administrations of Italy and Croatia and main port authorities of the Adriatic Sea (Venice, Trieste, Ravenna, Ancona, Bari, Rijeka, Ploce and Split) with the scope of harmonizing and optimizing the procedures of the complete maritime transport process in order to make port and maritime transport system more efficient and safe.

3. DIGSEA Project (DIGitalisation of Multimodal Transport in the Adriatic SEA)

CASPA is partner of the DIGSEA project, co-financed by the Interreg Italy-Croatia Cross-border Cooperation Programme 2014-2020. The project aims to consolidate technological knowledge from previous initiatives to create an integrated logistics chain covering the entire transport cycle. By capitalizing on prior developments, DIGSEA seeks to optimize multimodal traffic flows and enhance cooperation and efficiency across the logistics chain.

4. Digitalization Level in Adriatic Ports („As-Is“ Scenario)

4.1 The questionnaire

Data are collected through a questionnaire sent to 8 port authorities, the seven partner authorities of the DIGITPORTS project plus the associate organization.

The questions arose from the analysis of international best practices in the field of digital twin and port management, aimed at establishing the technological "confidence" of the various port authorities in the field of GIS and Digital Twin as well as the initiatives already undertaken individually. Questions have been selected to collect general information on the port authorities involved in the project as well as some specific insights aimed at understanding the current level of digitalization in some specific areas.
An attempt was made to assess the perception of security and cybersecurity in the port sector and to understand the level of cultural maturity required for the change that the path toward the Digital Twin demands.

The questionnaire is organized into eight sessions:

- General Port Information;
- Digital Infrastrusture;
- Digital applications;
- Digitalization strategy;
- Environmental and climate monitoring;
- Safety and security practices (including cybersecurity);
- Digital Twin;
- Best practices and Benchmarking.

Here are some considerations regarding the selection of the questionnaire questions:

- It is very useful to know the level of digital implementation of port authorities, as well as any digitalization strategies implemented, as the entire concept of digital twin is based on this type of infrastructure. Without an adequate digital infrastructure, the digital twin cannot be implemented effectively, compromising the benefits it could offer to the port in terms of efficiency, sustainability and safety.
- Security and cybersecurity are increasingly important issues in digital infrastructures in general, and therefore also in the port sector.

- The concept of Digital Twin is not always clear and defined, this section of the questionnaire is aimed at understanding how the various port authorities interpret it and if and how actions in this direction have already been implemented.

All the questionnaires were returned completed, 7 of which were from DIGITPORTS project partners and one from the associated organization.

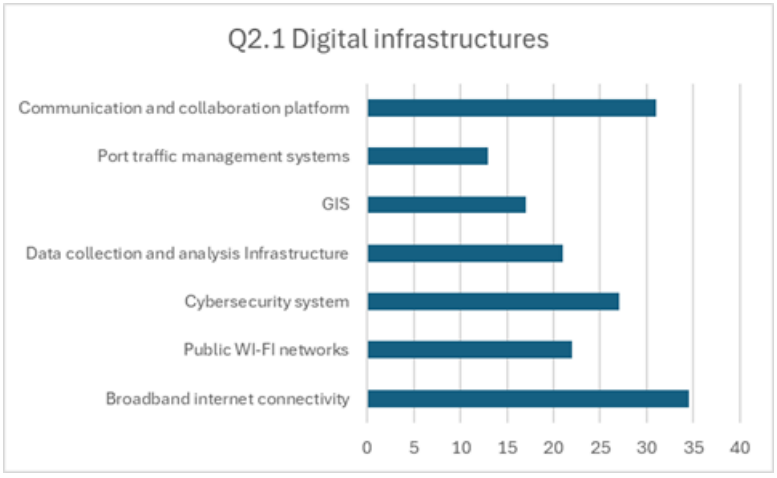
4.2 Section 1: General Ports Information

In section one of the questionnaire, responses were quite heterogeneous, and the diversity of responses does not allow for aggregations. However, all ports responded fully to the "main traffic figures 2023," from which the vocations of individual ports more or less emerge.

From an organizational point of view, as expected, considerable differences emerge in terms of staffing. While not all ports stated the number of employees, among the responses we find values in the range 25-120 employees, with an average of 66.6, off wich ICT departments have an average of 5.4 peoples.

4.3 Section 2: Digital Infrastructure

The responses to the questions in this section show a rather heterogeneous level of digital infrastructure implementation. However, the aggregation of the responses shown in the figure below provides an overview that offers some insights.



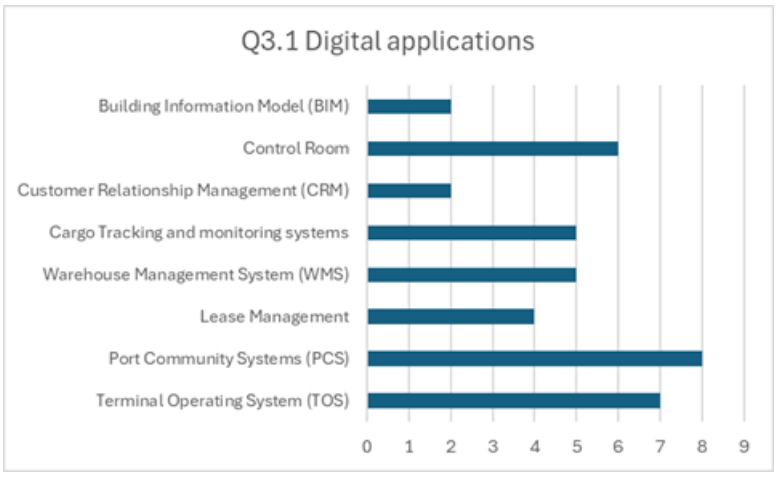
First of all, the highest score is obtained by broadband connectivity, which is nevertheless one of the fundamental building blocks of modern digital infrastructure.

A high aggregate score is also achieved by cybersecurity practices, which seems to be guided by precise operational procedures in almost all ports, indicating a good level of awareness. However, as will be highlighted in Section 6 of the questionnaire, analysis of the port-specific responses shows that not all ports adopt sufficiently structured cybersecurity measures.

The area where implementation appears to be the least advanced is undoubtedly GIS. Considering the aggregated level, this technology is therefore in an early adoption phase. Data collection, one of the pillars of digital twins, also shows significant room for improvement.

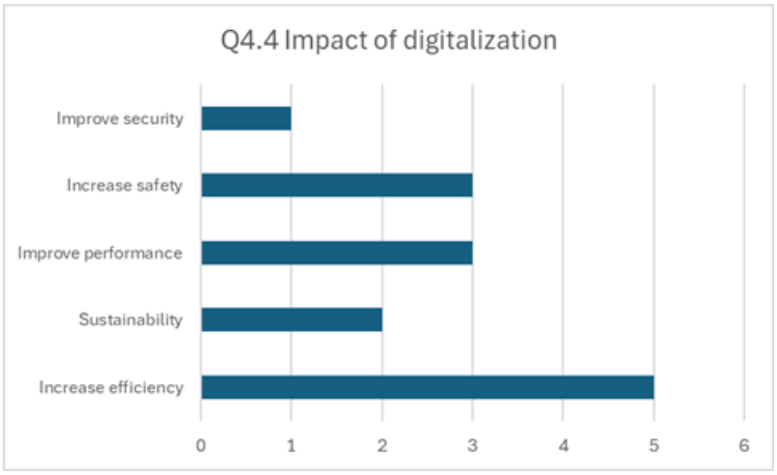
4.4 Section 3: Digital Applications

In the area of digital applications, all ports state that they currently use a Port Community Systems, while for the other options proposed in the questionnaire, the use of digital applications varied. Obviously the ones most in use are those that relate more to specific port activities, such as Terminal Operating Systems and Cargo Tracking and Monitoring Systems. Curiously, on the other hand, CRMs are in use in only two out of seven ports, while quite expected is the low level of adoption of Building Information Modeling, a technology with a guaranteed future but still struggling to enter the culture of ports and organizations in general.



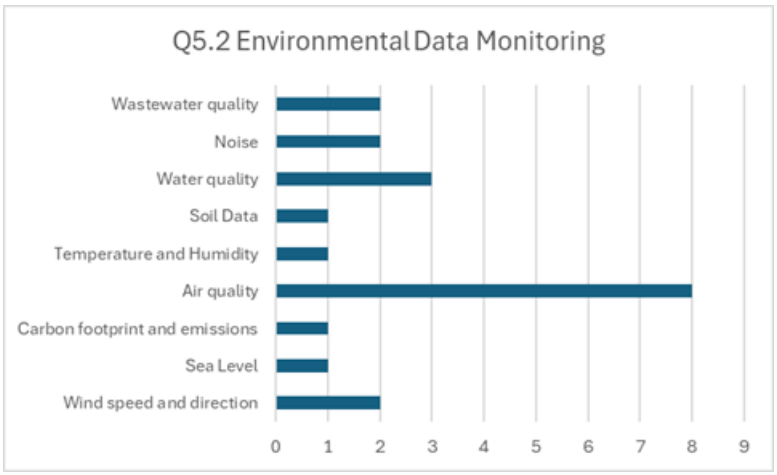
4.5 Section 4: Digitalization Strategy

Regarding digitization strategy, almost all ports state that they have one. Almost all ports state that they have resources dedicated to digitization. When asked about the expected benefits of digitization, the ports brought different answers, with greater emphasis on increasing efficiency and secondarily performance and safety, as ilustrated in the figure below.



4.6 Section 5: Environmental and Climate Monitoring

The ports have implemented various environmental monitoring systems. The answers to the questions in this section are particularly mixed, but an aggregate view shows that environmental and climate monitoring is almost only limited to air quality analysis (present at all ports) and to a lesser extent water quality analysis.



Only one port claims to also monitor some other climate data such as temperature, humidity, soil data, sea level, carbon footprint and emissions.

Sensitivity in the use of environmental monitoring data is diverse, although mainly directed toward keeping track of environmental changes, but only one port reported that the data collected play a critical role in managing and planning port activities.

4.7 Section 6: Safety and Security (including cybersecurity)

Physical security measures appear to be well established across all port authorities, albeit with some variations. However, when it comes to cybersecurity measures, detailed data reveals contradictions compared to the aggregate data obtained in section 2. The declared cybersecurity measures range from 'basic protection of personal computers' to structured and proceduralized measures that seem to adequately address the issue. This highlights a significant gap between different ports in terms of the cybersecurity measures applied.

4.8 Section 7: Digital Twin

Almost all port authorities are planning to implement a Digital Twin, while one has already started a pilot on the topic. Each port briefly described the vision in terms of a Digital Twin and directed the pilot actions of the DIGITPORTS project to cover some aspects of the envisioned Digital Twin.

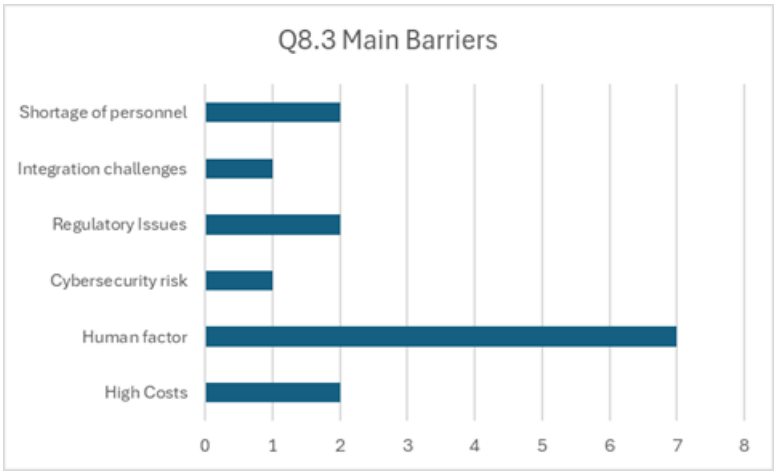
The challenges in implementing the digital twin capture various aspects, but certainly a common factor is the stated need to have a lot of digital data available, both in terms of port phisical representation, and from IoT sensors, that are reliable and can be organized in an integrated model.

The opportunities seen in implementing a digital Twin, on the other hand, are very practical: improved efficiency and security.

4.9 Section 8: Best practices and benchmarking

The port of Rotterdam is unanimously considered a reference in terms of digitization. Other ports are mentioned, but only a few of them got more than one mention: Singapore, Hamburg, and Los Angeles.

Best practices to be followed/implemented include the need for different stakeholders to better collaborate and to better integrate the data, procedures, and systems that make up the port ecosystem.



The barrier of greatest concern to port authorities is undoubtedly the "human factor," declined in several of its forms: mainly lack of digital skills and resistance to change but also shortage of personnel. Other barriers mentioned are the high initial costs required and regulatory issues.

5. Benchmarking Against International Best Practices

In Section 8 of the questionnaire, the Port of Rotterdam is unanimously regarded as the benchmark in terms of digitalization. Other ports are also mentioned, and among those receiving more than one mention are Singapore, Hamburg, and Los Angeles.

Anyway, as clearly stated in Chapter 1.2, the ports of the Adriatic have very different operational characteristics compared to the northern ports. Reference is made to that chapter without reiterating it here.

5.1 Case Studies

Leading ports such as Rotterdam, Singapore, and Hamburg serve as exemplary benchmarks for digital transformation in the maritime sector. The Port of Rotterdam has established itself as a global leader in smart port development, employing digital twin technology to model and simulate port operations in real-time, thereby enhancing predictive maintenance, optimizing resource allocation, and improving safety. Additionally, the port has implemented the Internet of Things (IoT) across its operations, connecting sensors to monitor infrastructure conditions, cargo movements, and environmental factors in real time. The port's collaboration with IBM to develop a centralized digital dashboard enables port operators to access and analyze data seamlessly, further enhancing decision-making processes.

The Port of Singapore is at the forefront of AI-powered logistics, utilizing machine learning algorithms to optimize vessel scheduling, cargo routing, and resource allocation. Through its Next Generation Port project, Singapore has incorporated autonomous vehicles and automated cranes to improve efficiency and reduce reliance on manual labor. Furthermore, its Maritime Single Window system consolidates shipping documentation, significantly reducing processing times and enhancing the overall user experience for stakeholders.

The Port of Hamburg has adopted a comprehensive smart port ecosystem that leverages big data analytics, IoT, and blockchain technology to enhance operational efficiency and sustainability. One of its flagship initiatives, the SmartPORT Logistics platform, facilitates real-time communication between stakeholders, enabling dynamic traffic management and efficient cargo handling. Moreover, the port has implemented green energy solutions, including shore power facilities and energy-efficient lighting systems, to reduce its environmental footprint. These initiatives position Hamburg as a global leader in sustainable port operations, demonstrating the critical role of technology in achieving environmental goals.

In the USA, the Port of Los Angeles has set benchmarks with its Port Optimizer, a cloud-based platform that digitizes and integrates data from various stakeholders, providing end-to-end supply chain visibility. This initiative has significantly improved cargo flow and reduced bottlenecks. Additionally, the port has implemented AI-based predictive analytics to manage container dwell times and reduce congestion. The Port of Long Beach, its neighbor, has adopted similar approaches, including autonomous vehicle trials and the development of green terminals powered by renewable energy.

These examples highlight the transformative potential of advanced technologies when strategically implemented, emphasizing interoperability, sustainability, and innovation. They provide valuable insights and best practices for Adriatic ports striving to enhance their competitive edge and align with global standards.

These examples illustrate the transformative potential of advanced technologies when strategically implemented. They highlight the importance of interoperability, data integration, and sustainability in driving digitalization efforts, offering valuable insights for the Adriatic ports as they seek to enhance their competitive edge and align with global standards.

5.2 Key Learnings

From these examples, several critical insights emerge for Adriatic ports aiming to enhance their digital transformation:

1. Data Governance Models: Effective data management frameworks, such as those implemented in Rotterdam and Singapore, ensure seamless data integration across stakeholders. Establishing centralized dashboards and leveraging IoT devices for real-time data collection can enable Adriatic ports to enhance decision-making and operational transparency.
2. Investments in Emerging Technologies: Ports like Shanghai and Hamburg have demonstrated the transformative potential of emerging technologies, including AI, blockchain, and IoT. Strategic investments in these technologies can optimize workflows, enhance predictive maintenance, and improve safety standards.
3. Integration with Regional and Global Supply Chains: Successful ports, such as those in Long Beach and Shenzhen, highlight the importance of aligning port operations with broader supply chain networks. This includes adopting interoperable systems, such as Port Community Systems and Maritime Single Windows, to facilitate seamless communication and coordination among stakeholders.

These lessons underscore the importance of a strategic approach to digitalization, emphasizing interoperability, collaboration, and a strong focus on sustainability to ensure long-term resilience and competitiveness.

6. Strenghts, Weaknesses and Opportunities of Adriatic Ports

6.1 Strengths

1. **Strategic Geographical Location**: Adriatic ports serve as critical gateways connecting Central and Eastern Europe with the Mediterranean and beyond, enabling robust trade linkages and facilitating multimodal transport networks.
2. **Emerging Digital Initiatives**: Several ports, have implemented Port Community Systems and are experimenting with digital twin technologies, showcasing a growing commitment to modernization.
3. **Focus on Sustainability**: Some past and ongoing projects highlight efforts to align operations with environmental goals.
4. **Collaborative Frameworks**: The DIGITPORTS project fosters cross-border collaboration, aiming to unify digital strategies across Adriatic ports, which can amplify their collective impact.
5. **Integration with EU Funding Mechanisms**: Access to Interreg and Horizon Europe funds provides financial backing for innovative projects and technological upgrades.

6.2 Weaknesses

1. **Fragmented Digital Adoption**: While some ports have advanced digital systems, the overall adoption remains inconsistent, with gaps in interoperability and scalability across the region.
2. **Lag in Technology Implementation**: Compared to global benchmarks like Rotterdam and Singapore, Adriatic ports are slower in adopting cutting-edge technologies such as AI-driven logistics, blockchain, and IoT integration.
3. **Limited Data Governance**: The absence of centralized data governance frameworks leads to inefficiencies and challenges in real-time decision-making.
4. **Insufficient Investment in Automation**: Many Adriatic ports rely heavily on manual operations, limiting their ability to compete with fully automated global leaders like Shanghai and Hamburg.
5. **Alignment with Sustainability Goals**: While some initiatives focus on green technologies, a comprehensive, standardized approach to sustainability across all Adriatic ports is lacking.
6. **Cybersecurity Risks**: Digital systems are often not adequately secured, leaving ports vulnerable to cyber threats, as highlighted by limited collaborative frameworks like CRESPORT.

This analysis underscores the need for Adriatic ports to address weaknesses by leveraging their geographical advantages, embracing standardized digital frameworks, and investing in advanced technologies to align with international benchmarks.

6.3 Opportunities for Improvement

Adriatic ports have significant opportunities to enhance their digital transformation journey through both short-term and long-term strategies. In the short term, ports can focus on standardizing digital tools to ensure seamless communication and data exchange. Small-scale digital twin projects targeting specific operational areas like predictive maintenance and cargo tracking could demonstrate immediate value and pave the way for broader adoption. Enhancing cybersecurity protocols to protect emerging digital infrastructure is a pressing need, as is investing in workforce development through training programs that familiarize staff with modern digital tools. Additionally, centralized dashboards for real-time operational monitoring could greatly enhance decision-making and resource allocation.

Long-term strategies involve more ambitious transformations. Ports can gradually transition to full-scale automation, incorporating autonomous cranes, vehicles, and cargo handling systems to increase operational efficiency and reduce reliance on manual labor. Integrating AI and machine learning into port operations will enable advanced analytics for traffic predictions, logistics optimization, and improved energy management. Investment in green technologies, such as shore power facilities and electrified equipment, will align operations with EU Green Deal objectives while reducing environmental impact. Blockchain technology offers a promising avenue for enhancing supply chain transparency and security, and fostering regional collaboration through a digitalization alliance can encourage knowledge sharing, joint projects, and coordinated funding applications.

Addressing policy and funding gaps is equally essential. A cohesive digitalization strategy is currently lacking, resulting in fragmented efforts and inefficiencies. Inconsistent regulations across jurisdictions hinder the implementation of standardized tools and cross-border projects, while insufficient policies on cybersecurity expose ports to significant risks. On the funding side, limited investment in research and development constrains innovation, and reliance on public funds slows the pace of transformation. Many ports also underutilize available EU funding programs due to administrative complexities and insufficient expertise in preparing grant applications.

To overcome these challenges, Adriatic ports must prioritize the development of a unified digitalization policy in collaboration with EU and national bodies. Simplifying grant processes and providing technical support can help ports access available funding more effectively. Public-private partnerships (PPPs) could be promoted to attract private investment, demonstrating the long-term benefits of digital infrastructure. Regional cooperation will further enhance these efforts by streamlining cross-border projects and leveraging shared resources. By addressing these gaps and implementing targeted strategies, Adriatic ports can align themselves with global best practices and establish a competitive, sustainable, and technologically advanced maritime ecosystem.

7. Recommendations

7.1 Strategic Recommendations

To position Adriatic ports as leaders in maritime digitalization and sustainability, strategic initiatives must focus on upgrading digital infrastructure and fostering cross-border cooperation and data-sharing frameworks.

Digital Infrastructure Upgrades

Upgrading a port authority's digital infrastructure can act as a facilitator by improving operational efficiency, safety, and sustainability. The adoption of digital platforms and IoT sensors optimizes vessel and cargo traffic management, reducing waiting times and congestion. Digital Twins integration enables advanced simulations for more accurate planning. Enhanced cybersecurity systems protect sensitive data and critical infrastructure. The use of blockchain ensures traceability and transparency in logistics operations. In addition, AI and Big Data solutions foster strategic decisions based on predictive analytics. A modern infrastructure attracts investment, improves competitiveness and supports the green transition with smart grids and optimized energy management.

Cross-Border Cooperation and Data-Sharing Frameworks

Collaborative frameworks for cross-border cooperation and data sharing are essential to creating a unified and efficient Adriatic port network. Establishing a regional digital alliance will facilitate knowledge exchange and enable joint projects that maximize resource utilization. A standardized data-sharing framework supported by robust cybersecurity protocols will ensure secure and seamless integration of information across ports, enhancing interoperability and decision-making. Cooperation with international partners can also accelerate the adoption of best practices and foster innovation, while alignment with EU regulations and funding mechanisms will provide financial and technical support for these initiatives. By strengthening regional cooperation and leveraging shared resources, Adriatic ports can achieve a more cohesive and competitive maritime ecosystem, ensuring long-term resilience and sustainability.

7.2 Tactical Recommendations

To achieve immediate and tangible progress in digital transformation, Adriatic ports should implement targeted tactical measures, including pilot projects for emerging technologies and comprehensive staff training initiatives.

Pilot Projects for Emerging Technologies

Pilot projects serve as an effective approach to testing and demonstrating the potential of emerging technologies on a smaller scale before wider adoption. Adriatic ports should focus on implementing digital twin technology in specific operational areas, such as equipment maintenance, cargo tracking, and environmental monitoring. These projects will provide actionable insights into how such innovations can optimize workflows and improve decision-making processes. Similarly, deploying IoT sensors for real-time monitoring of port operations, coupled with AI-powered analytics, can enhance resource allocation and operational efficiency. Testing automation technologies, such as autonomous cranes and vehicles, in selected terminals can further showcase the potential to reduce operational bottlenecks and improve safety. Pilot initiatives should be aligned with sustainability goals by incorporating green technologies, such as electrified equipment and renewable energy systems, to demonstrate their dual impact on efficiency and environmental performance.

Staff Training and Capacity Building

The success of digital transformation efforts heavily depends on the ability of port personnel to adapt to and effectively utilize new technologies. Comprehensive training programs are essential to bridge the gap between existing skill sets and the requirements of modernized port operations. Ports should offer targeted workshops and on-the-job training sessions to familiarize staff with digital tools, such as Port Community Systems, data visualization dashboards, and automated equipment. Collaboration with universities and training institutions can help establish certification programs focused on maritime digitalization. Additionally, leadership training for managers will ensure that strategic decisions align with technological advancements and operational goals. Capacity building efforts should also emphasize fostering a culture of innovation and adaptability, empowering staff to embrace changes and contribute to the ports' long-term digitalization strategies.
By implementing pilot projects and investing in staff training, Adriatic ports can build a solid foundation for their digital transformation journey, ensuring both technological and human readiness to meet the challenges and opportunities of the modern maritime landscape.

8. Conclusion

The analysis of the digitalization landscape of Adriatic ports highlights both progress and challenges. While individual ports have made notable strides in implementing technologies like Port Community Systems, digital twins, and renewable energy solutions, the overall adoption of advanced digital tools remains inconsistent across the region. Compared to international benchmarks such as Rotterdam, Singapore, and Shanghai, Adriatic ports lag in areas like automation, AI integration, and comprehensive data governance. Key gaps in interoperability, cybersecurity, and alignment with sustainability goals underscore the need for a more unified and strategic approach.

The findings emphasize the importance of leveraging the DIGITPORTS initiative as a catalyst for transformative change. Pilot projects focusing on digital twins and other emerging technologies can serve as practical demonstrations of innovation, providing valuable insights and building confidence among stakeholders. Investments in staff training, regional cooperation, and standardized frameworks for data sharing are critical to ensuring the success of digital transformation efforts. Addressing policy and funding gaps will further enable Adriatic ports to scale their digital initiatives and align with global best practices.

To realize these goals, stakeholders—port authorities, private operators, policymakers, and funding bodies—must collaborate closely. Port authorities should commit to the gradual rollout of advanced technologies while fostering a culture of innovation and adaptability. Policymakers need to create enabling environments through cohesive digitalization strategies and streamlined regulations. Funding bodies, including EU programs and private investors, should provide targeted support to bridge financial gaps and accelerate technological adoption.

The future of Adriatic ports lies in their ability to embrace innovation, integrate with regional and global supply chains, and prioritize sustainability. By taking decisive action now, stakeholders can ensure that these ports remain competitive, resilient, and environmentally responsible, securing their position as key players in the global maritime ecosystem.

9. Appendices

9.1 Enabling Technologies

In modern port operations, several advanced technologies are employed to enhance efficiency, safety, and sustainability. Here's an overview of key technologies:

5G Technology:

The fifth-generation wireless communication technology that offers high-speed, low-latency connectivity, facilitating advanced applications such as real-time data exchange and automation in port operations.

Internet of Things (IoT)

IoT involves interconnected devices that collect and exchange data. In ports, IoT devices such as sensors and RFID tags monitor cargo conditions, track equipment status, and manage energy consumption. This connectivity facilitates real-time decision-making and enhances operational transparency. For example, IoT sensors can provide live cargo updates, ensuring transparency and minimizing bottlenecks in logistics.

Geographic Information Systems (GIS)

GIS technology manages and analyzes spatial data, providing detailed insights into port layouts, traffic patterns, and environmental factors. By integrating GIS, ports can optimize navigation routes, manage land use effectively, and monitor environmental impacts, contributing to more efficient and sustainable operations.

The integration of these technologies enables ports to transition into smart ports, characterized by enhanced operational efficiency, improved safety measures, and a reduced environmental footprint. Adopting such advanced tools is essential for ports aiming to remain competitive in the evolving maritime industry.

Building Information Modeling (BIM)

Building Information Modeling (BIM) is a digital management model in the field of design, construction, and management of a building or infrastructure project. It is not merely the three-dimensional representation of buildings, but an innovative approach consisting of collaborative and interconnected processes and tools through the integration of digital models of civil or building products, from design to the entire lifecycle of the building.

As is well known, the BIM methodology can cover programming, heuristic and conceptual design, detailed and executive design, site planning, organization and control of construction costs and timelines, site management, delivery, as-built documentation, operation and maintenance, demolition, and replacement.

Digital Twins

A digital twin is a virtual replica of a physical asset, system, or process that enables real-time monitoring, simulation, and analysis. In port operations, digital twins can model infrastructure such as terminals, cranes, and transport networks, allowing for optimized resource allocation and predictive maintenance. For instance, the Port of Livorno utilizes a digital twin to enhance logistics tasks by capturing real-time data through 5G connectivity, improving operational efficiency.

Artificial Intelligence (AI)

AI technologies analyze vast amounts of data to identify patterns, optimize processes, and predict outcomes. In port settings, AI can be applied to automate berth allocation, enhance cargo handling efficiency, and improve safety protocols. Additionally, AI-driven predictive maintenance can forecast equipment failures, allowing for timely interventions that minimize downtime. For instance, AI models can simulate various allocation scenarios to find optimal solutions, reducing ship wait times.

9.2 Glossary of Terms

Adriatic Ports: Ports located along the Adriatic Sea, serving as critical nodes for regional and international trade, connecting Central and Eastern Europe with the Mediterranean.

Blockchain: A decentralized, secure digital ledger technology used to record transactions transparently, ensuring data integrity and trust across port logistics and supply chains.

Carbon Footprint: The total amount of greenhouse gases emitted directly or indirectly during port operations, measured in units of carbon dioxide equivalent.

Cybersecurity: Measures and practices designed to protect digital systems, data, and infrastructure in ports from cyberattacks and unauthorized access.

Interoperability: The ability of different systems, devices, and organizations to work together seamlessly, enabling efficient communication and data exchange in port operations.

Maritime Single Window: A digital platform that consolidates shipping documentation and regulatory compliance processes, reducing administrative burdens and enhancing efficiency.

Port Community System (PCS): A centralized digital platform used by ports to streamline communication and data exchange between stakeholders, such as port authorities, shipping companies, and logistics providers.

Predictive Maintenance: A data-driven approach to equipment maintenance that uses real-time monitoring and analytics to predict and address potential failures before they occur.

Public-Private Partnership (PPP): A collaborative arrangement between public sector entities and private companies to fund, develop, and implement projects, such as port digitalization initiatives.

Sustainability Goals: Objectives aimed at minimizing environmental impacts, improving energy efficiency, and reducing carbon emissions in port operations.

Supply Chain Integration: The coordination and alignment of processes and systems across different stakeholders to create a seamless flow of goods, information, and resources.

Renewable Energy Systems: Infrastructure that utilizes sustainable energy sources, such as solar or wind power, to reduce reliance on fossil fuels and lower the environmental impact of port activities.

9.3 List of References and Sources

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