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Study on Enabling Sustainable Management and Development of inland ports

D.3.2 Inventory of port cooperation and collaboration systems, digital tools and applications and assessing their effect on greening and economic sustainability objectives

Rotterdam, 17 November 2023

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Client: European Commission, DG MOVE

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Summary

Deliverable 3.2 elaborates on the work carried out within the framework of Sub-task 3.2 Inventory of port cooperation and collaboration systems, digital tools and applications and assessing their effect on greening and economic sustainability objectives.

The main objective of this sub-task is to provide an overview of the existing digital tools and technologies designed for use in inland ports and investigate their suitability to be used as effective and efficient tools for meeting the greening and economic efficiency objectives.

Chapter 1 introduces port digitalisation, defining it as the integration of digital technologies for optimal processes. It stresses IoT devices, sensors, data analytics, and automation for improved traffic management, cargo handling, logistics, security, and environmental monitoring. Automated cargo handling and real-time data sharing enhance efficiency and transparency. The goal is streamlined operations, cost reduction, and improved services across the supply chain. Successful digitalisation requires robust IT infrastructure, data-sharing, cybersecurity, standardised data formats, trained labour, collaboration, and a clear strategy. Inland port digitalisation is driven by efficiency, competitive advantage, global trade growth, supply chain optimisation, environmental footprint reduction, regulatory compliance, risk management, customer-centric approaches, technological developments, infrastructure optimisation, labour efficiency, and data-driven decision-making. Smart ports, resulting from rapid digitalisation and automation, use IoT, big data, machine learning, artificial intelligence, blockchain, and automation for enhanced operational and environmental performance. While more common in seaports, inland waterway ports recognise the importance of digitalisation for efficiency and sustainability in urban areas.

Chapter 2 explores how digital technologies can make inland ports more efficient and environmentally friendly. It underscores the role of strategically placed sensors and complex devices in real-time monitoring and efficient port management. Various sensor types contribute to the foundation of port digitalisation, emphasising advanced technologies like IoT, Blockchain, Big Data Analytics, Artificial Intelligence, and 5G networks. The chapter covers the potential of simulation software for traffic and cargo management, infrastructure planning, and environmental impact assessment, along with the applications of Virtual Reality and Augmented Reality in training, port design, and security. It introduces Digital Twins for real-time data analysis, citing examples from the Port of Trier and Port of Antwerp. Port Community Systems, Port Management Systems, Terminal Planning and Operating Systems, Land Traffic Management Systems, booking applications, gate operating systems, and Port Asset Management Systems and other tools are detailed as crucial digital tools for efficient port operations. Reporting tools are highlighted for data analysis and compliance. Further, the chapter emphasises the transformative shift brought by port automation and autonomation, distinguishing between digitalisation and automation. Automated and autonomous ports are discussed, showcasing their benefits and the distinctions in technology and human involvement. Inland ports are recognised as vital nodes in global supply chains, with digitalisation and automation offering multifaceted benefits despite challenges like high costs, skilled workforce needs, and cybersecurity concerns. The narrative concludes by highlighting the integration of airborne and waterborne drones, offering various benefits such as surveillance, security, and logistics optimisation in inland ports.

Chapter 3 elaborates on the cyber security aspects such as the threat taxonomy, potential impacts and mitigating measures.

Chapter 4 discusses the digitalisation of Environmental Management Tools (EMTs) in inland ports, emphasising its alignment with broader trends in digital transformation. EMTs, including ISO 14001, aim to manage and enhance environmental performance. Digitalising EMTs in inland ports offers efficiency gains, real-time monitoring, improved data accuracy, compliance support, sophisticated impact assessments, enhanced transparency, risk management, cost reduction, system integration, and adaptation to technological trends. Ultimately, this digital shift enables inland ports to efficiently meet environmental objectives, comply with regulations, and contribute to sustainable and responsible management. Further, this chapter explores the utilisation of digital tools for assessing and improving the environmental performance of ports. It delves into methodologies such as digitalised air quality monitoring, water quality monitoring, noise monitoring, energy consumption monitoring, Just-in-Time coordination, and waste management. For instance, digital air quality monitoring employs IoT devices and sensors to collect real-time data, enhancing accuracy and efficiency. Water quality monitoring uses smart sensors connected to an IoT network, enabling real-time data transmission, cloud-based analytics, and visualisation. Similarly, digitalised noise monitoring employs sensors and real-time data analytics to minimise disruptions and enhance overall environmental performance. The digitalisation of energy consumption monitoring involves smart meters, IoT integration, cloud-based monitoring, and visualisation, contributing to sustainability and cost reduction. Just-in-Time coordination leverages real-time tracking, data analytics, and collaborative platforms to optimize vessel arrivals, reducing fuel consumption and emissions. Digital waste management incorporates smart bins, IoT-based monitoring, waste sorting technology, and predictive analytics to enhance efficiency and sustainability. The methodologies discussed underscore the transformative impact of digital tools on port environmental performance, fostering sustainability and efficiency. This symbiotic relationship between digital tools and environmental management positions ports as key contributors to a more sustainable inland waterways ecosystem. Finally, the chapter highlights the profound environmental benefits of digital tools and technologies in transforming inland ports into sustainable and eco-friendly entities. As ports adopt digital innovation, they streamline processes through automation, optimising cargo handling, logistics, and infrastructure. This efficiency leads to reduced energy consumption and lower emissions, making port operations more environmentally friendly. The integration of IoT devices, blockchain, big data analytics, artificial intelligence, 5G networks, and other digital tools offers real-time monitoring and data-driven decision-making, contributing to environmental sustainability. Further elaboration provides details on the environmental benefits of various digital technologies and tools in inland ports, emphasising their role in achieving global sustainability goals. In essence, port digitalisation and automation contribute significantly to greening inland ports, aligning them with eco-conscious practices and positioning them as leaders in the sustainable transport and logistics sector.

Since no digital Environmental Management Tools (EMTs) specifically designed for the use in inland ports were identified during the study, Chapter 5 discusses selected digitalised EMTs designed primarily for seaports, but which could be adapted for the use in inland ports. The chapter particularly focuses on Pixel, GISGRO Green, and RightShip's Maritime Emissions Portal. Funded by the EU's Horizon 2020 program, Pixel is an IoT-based solution enhancing environmental sustainability in port ecosystems. The Port Environmental Index (PEI) is a central component, integrating diverse environmental impacts, utilizing IoT infrastructure, and providing a standardised metric for environmental assessments. PEI, while initially developed for seaports, could be adapted for inland ports with future modifications. GISGRO Green is a new-generation environmental management software for ports, aiding in achieving sustainability goals. The software uses manual or automated data sources and calculates vessel emissions based on port call data. It supports the Greenhouse Gas (GHG) protocol, providing visualisations for reporting emissions, fostering compliance, and enhancing communication of a port's sustainability practices. RightShip's Maritime Emissions Portal (MEP) combines AIS vessel movement data and RightShip's unique vessel insight data to assess environmental impact and reduce emissions. It provides an emissions inventory dataset, utilizing RightShip's emissions calculation method for vessels, and supports reporting for CO_2, SOx, NOx, PM10, PM2.5, and VOC. All these digital EMTs contribute to environmental sustainability in ports by providing comprehensive data, visualisation, and reporting tools. They empower port authorities to make informed decisions, adhere to regulations, and enhance environmental performance, ultimately supporting the green transformation of port operations.

Chapter 6 presents the results of a survey conducted among port authorities and operators in 2023, focusing on the digitalisation of inland ports. Key findings include a high awareness of digitalisation processes among inland ports, with over 60% having a digitalisation strategy. The most common digital tools used are Terminal Planning and Operating Systems, reporting applications, and port management systems. Digital tools for environmental management are less prevalent, with only 7.7% reported usage. The survey indicates a low level of digitalisation in measuring operational and environmental Key Performance Indicators (KPIs) in inland ports, with significant room for improvement. Communication between different stakeholders in inland ports, including Government-to-Government (G2G), Business-to-Government (B2G), and Business-to-Business (B2B), shows varying levels of digitalisation, with Port Community Systems being a common tool for such communications. The survey also explores the relationship between port size and digitalisation level, suggesting a general trend that larger ports tend to have more resources for digital initiatives, though the correlation is influenced by multiple factors such as resource availability, operational complexity, strategic vision, government policies, and collaboration. Overall, the results emphasise the importance of digitalisation strategies for inland ports to enhance efficiency, environmental sustainability, and competitiveness in a rapidly evolving industry.

List of abbreviations

AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIS	Automatic Identification System
B2B	Business to Business
B2G	Business to Government
CESNI	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure
CO	Customs Office
EA	Environmental Authority
EMS	Environmental Management System
EMT	Environmental Management Tools
EPM	Environmental Performance Measurement
FF	Freight Forwarder
G2G	Government to Government
GNSS	Global Navigation Satellite System
GOS	Gate Operating System
GPS	Global Positioning System
HMO	Harbour Master's Office
ID	Identification document
IoT	Internet of Things
IT	Information Technology
IWT	Inland Waterway Transport
LTC	Land Transport Companies
M2M	Machine to Machine
ML	Machine Learning
OCR	Optical Character Recognition
PA	Port Authority
PA	Port Authority
PAMS	Port Asset Management System
PAMS	Port Asset Management System
PP	Port Police
QC	Quay Crane
RFID	Radio Frequency Identification
RIS	River Information Services
RMG	Rail Mounted Gantry (Crane)
RTG	Rubber Tyred Gantry (Crane)
RTLS	Real-Time Location System
SA	Ship Agent
SC	Shipping Company
TO	Terminal Operator
TOS	Terminal Operating System, Terminal Planning and Operating System
VBS	Vehicle Booking System
VTMS	Vessel Traffic Management System
VTS	Vessel Traffic Services

1 Introduction

1.1 What is port digitalisation?

Port digitalisation is a process of applying and integrating available digital technologies into various port processes and activities in order to improve port operations and port management. Apart from digital technologies, the process involves the use and integration of data and automation. The overall process of port digitalisation includes using technologies such as Internet of Things (IoT) devices, various sensors that collect different information, data analytics, digital twins, predictive maintenance, and automation to optimize various aspects of port activities, including vessel traffic management, cargo handling, logistics, intra-port landside traffic management, security, and environmental monitoring.

Digitalisation of ports is of utmost importance for an enhancement of operational efficiency. Cargo handling equipment such as rubber tyred gantry (RTG) cranes, rail mounted gantry (RMG) cranes, quay cranes (QC), reach stackers, straddle carriers, wheel loaders, etc., can be automated and even interconnected, real-time data can be shared and analysed, while virtually all involved stakeholders can have relevant and timely information on the port activities of their concern. Automation as such reduces human operator related errors, increases handling speed, and improves the overall effectiveness. Moreover, multiple ports participating in a single or multiple supply chains can also be interconnected which contributes to the increased transparency between vessel operators, ports, cargo owners and other relevant stakeholders.

The overall goal of port digitalisation is to improve efficiency and effectiveness, automate and streamline operations, reduce risks and costs, and provide better overall services within the port industry and the entire supply chain. Last, but not least, port digitalisation can increase transparency by providing single source of information and relevant documentation for all stakeholders involved in port processes.

1.2 Preconditions for port digitalisation

The preconditions for port digitalisation encompass, inter alia, robust IT infrastructure, agreements on data sharing between relevant involved stakeholders, cybersecurity measures, standardised data formats, trained labour, stakeholder collaboration and a clear digitalisation strategy. These factors facilitate the efficient implementation of digitalisation in port management and operations.

1.2.1 Robust IT infrastructure

Robust IT infrastructure includes stable, reliable and high-speed internet connectivity, advanced networking systems, adequate server and data storing capacity, as well as modern hardware and software. These building blocks enable the seamless flow of data, efficient communication between systems, and the implementation of digital solutions to enhance various aspects of port management and operations, such as vessel scheduling, berth allocation, cargo tracking and overall supply chain management.

1.2.2 Data sharing

One of the most sensitive aspects of the port digitalisation is the aspect of data sharing. Port processes, such as cargo handling, vessel berthing, landside traffic, gate management, generate large amount of data which can be collected, processed, and used to improve these processes. In addition, the processing of the data generated by various processes can be used for learning about the ways to improve such processes. Thanks to the data availability and digitalisation of processes, various port stakeholders such as terminal operators, port authorities, cargo handling companies, land transport companies, and others can have real-time situational awareness of all activities going on in their field of interest.

The ownership of the data generated through port processes can be diverse. For example, vessel generated data such as vessel tonnage, installed power, number of crew members, amount of fuel or waste carried on board, typically belong to vessel owners or operators, while the quantity of cargo to be loaded/unloaded, and its destination typically belong to the cargo owner. In order to make use of data of various owners and enjoy the benefits of data and process digitalisation, various port actors must collaborate and share the data to a mutually agreed degree. Therefore, collaboration of port stakeholders is of crucial importance for the success of port digitalisation. One of the aspects of such collaboration are the data sharing agreements. Such agreements include establishing clear guidelines and protocols for data traffic and sharing between various stakeholders in the port community.

Data sharing agreements typically define what data can be shared (apart from the usual cargo documents such as cargo manifests or customs declarations), the way it will be shared, access rights and conditions. An exception here are the specific types of data that are required to be shared by law or practice in port operations, such as dangerous goods cargo, but even in this case not all data (apart from those required by the laws) are available for all participating stakeholders.Unfortunately, the benefits of compatible systems and data sharing are not always and immediately visible to port stakeholders, causing that the digitalisation process is sometimes rejected[1] or slowed on purpose. For this reason, the entire port community of port stakeholders require additional information and an ongoing educational effort on mutual benefits of port digitalisation and data sharing.[2]

1.2.3 Cybersecurity measures

Numerous port assets can be a target of a cyberattack. In this view, CESNI guidelines on cybersecurity in inland navigation[3] lists the main port assets that are susceptible to cyberattacks:

- Craft (vessel) reception and docking
- Security and safety
- Authorities and customs
- Passengers and tourist craft systems
- IT systems involved in traffic planning such at Vessel Traffic Services (VTS)
- Support services
- Mooring of the craft
- Automatic Identification System (AIS)
- Container storage and staying
- Energy service
- Distribution service
- Craft (vessel) communicating between the craft and the port or other land locations.

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[1] Brunilla et.al. (2021), Hindrances in port digitalisation? Identifying problems in adoption and implementation, *European Transport Research Review*, 13:62. Available at https://doi.org/10.1186/s12544-021-00523-0

[2] Kane et.al. (2015). *Strategy, not technology, drives digital transformation*. MIT Sloan Management Review. Deloitte University Press. Available at: https://www2.deloitte.com/content/dam/Deloitte/fr/Documents/strategy/dup_strategy-not-technology-drives-digital-transformation.pdf

[3] CESNI (2023), *Good practice guide – Cybersecurity in inland navigation. Especially for ports*, Strassbourg and Brussels. Available at: https://www.cesni.eu/wp-content/uploads/2023/05/Guide_cybersecurite_en.pdf

Categorisation of main port assets is convenient for determining the type of threats and cybersecurity attribute an asset must have. The basic attributes in cybersecurity are confidentiality, integrity, and availability, colloquially known as the "CIA triad".[4] Boyes, et.al.[5] introduced an additional attribute of possession to consider the context of ports and craft. Considering the type of cyberthreats and attributes of cybersecurity, measures for mitigating the risks of cyberthreats are typically organised into three sections:[6]

1. Organisation policies and procedures
2. Information technology / operational technology policies for ports
3. Technical security measures for ports.

More detailed information on cybersecurity aspects and measures is given in Chapter 3.

1.2.4 Standardised data formats

Standardised data formats for inland port digitalisation are often similar to those used in general logistics and supply chain management. Formats such as EDI (Electronic Data Interchange), XML (extensible Markup Language), JSON and UN/CEFACT[7] XML-based data standards like UNCEFACT XML and UN/EDIFACT can also be applied to inland port operations to facilitate seamless data exchange and interoperability.

1.2.5 Trained labour

To keep the pace with the emerging technologies, especially in port digitalisation, port authorities and port operators should train their workforce through specialised internal or external programmes. According to the International Association of Ports and Harbours (IAPH)[8], ports should cultivate both "cyber-aware" and "cyber-competent" workforce, meaning that all staff should be trained basic elements of IT technology applied in ports to maintain attentiveness and that ports' own IT and OT (Operational Technology) should receive more advanced training to sustain skills and develop new competencies. Developing the necessary digitalisation related skills of the port personnel is practically a life-long education process, mostly due to the speedy development of digital tools, port equipment and due to the dynamic needs of port users. In this view, continuous personnel training should be a part of the long-term digitalisation strategy. Training programmes should be tailored to specifically set goals, clearly identified port needs and trends in port digitalisation tools development. Such programmes could be designed together with local academic institutions.

1.2.6 Stakeholder collaboration

Successful harvesting of inland port digitalisation benefits is highly dependent on the collaboration of various port stakeholders involved in a myriad of port and port related activities in an outside of the port boundaries. This collaboration involves governmental organizations (customs, police, sanitary control, etc.), ministries, port authorities, port operators, logistic companies, land transport operators and various industry stakeholders involved in inland navigation trade and logistics. The most important "products" of stakeholders collaboration are the data sharing agreements, as

[4] Ibid

[5] Boyes et.al. (2021). *Good Practice Guide Cyber Security for Ports and Port Systems*, Institution of Engineering and Technology, London, United Kingdom. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/859925/cyber-security-for-ports-and-port-systems-code-of-practice.pdf

[6] CESNI (2023). *Good practice guide – Cybersecurity in inland navigation. Especially for ports*, Strassbourg and Brussels. Available at: https://www.cesni.eu/wp-content/uploads/2023/05/Guide_cybersecurite_en.pdf

[7] Iakymenkov, D., Roizina, G. (2022). How to develop real world electronic document equivalents using UN/CEFACT standards and reference data models, UNECE Project report. Available at: https://unttc.org/sites/unttc/files/2022-04/How%20to%20develop%20transport%20e-docs%20using%20UNCEFACT%20standards%20and%20MMT%20RDM.pdf

[8] IAPH (2021). *Cybersecurity Guidelines for Ports and Port Facilities*. Available at: https://sustainableworldports.org/wp-content/uploads/IAPH-Cybersecurity-Guidelines-version-1_0.pdf

indicated earlier. Apart from data sharing, stakeholders collaboration may include automation of processes, optimisation of supply chains, communication channels improvement between various stakeholders to achieve a streamlined and effective inland port digital ecosystem for the benefit of all users.

1.2.7 Clear digitalisation strategy

Clear digitalisation strategy is necessary to introduce a port into digital age and define the goals and scope of digitalisation efforts. Port digitalisation strategy refers to a comprehensive plan adopted by a port authority or similar organisation to leverage digital technologies and data driven solutions to improve port operations, enhance efficiency and improve overall performance. Port digitalisation strategies often include the integration of various technologies such as data analytics, digital twins, artificial intelligence, berth allocation, vessel scheduling, safety and security, environmental management, etc. The overall objective is to create a more connected, efficient, sustainable, and environmentally friendlier port ecosystem. It is very important to keep in mind that the process of port digitalisation should be seen as an enabler, not as the final goal.[9] Digitalisation processes should lead to the compliance with the strategic objectives set by port managers and oriented towards solving the most urgent sectoral challenges determined by the strategy.

1.3 Main drivers for inland port digitalisation

Several key drivers are propelling the digitalisation of inland ports:

1. **Efficiency and productivity**. Digitalisation of inland port activities streamlines port operations, enables process automation, enhances the operational efficiency, which, in turn, shortens the vessel turnaround times in ports and reduces waiting times, and improves cargo handling both on the quay side and in the handling yards and storages.
2. **Competitive advantage**. Inland ports that embark on the path of digitalisation can increase their competitiveness thanks to digitalisation-enabled faster and more reliable services to vessel operators and cargo shippers and receivers. This, in turn, often generates additional business and attracts further investments.
3. **Global trade growth**. Although inland ports are typically not on the frontline of major global trade routes like seaports, the increase of global trade exerts additional pressure on inland ports to handle more cargo too since many of the inland ports are directly connected with seaports by rail and/or inland waterways. Digitalisation of inland ports may help optimise their capacity without immediate need for the expansion of their physical infrastructure.
4. **Supply chain optimisation**. Since digitalisation is a process that is well advanced in other transport modes, leaving ports to lag behind[10], ports need to accelerate digitalisation in order to be better integrated into the overall supply chains which involve inland ports. Such integration brings more accurate cargo tracking, improves coordination, and reduces supply chain disruptions.
5. **Reduction of environmental footprint**. Digital tools can significantly enhance the environmental sustainability of inland ports by optimising energy use, reduction of emissions resulting from optimised movement of vessels and vehicles in ports and minimise waste through data-driven decision making.

[9] Gómez Díaz C., González-Cancelas, N., Camarero Orive, A.., Soler Flores, F. (2023). Digital Governance Approach to the Spanish Port System: Proposal for a Port. *Journal of Marine Science and Engineering*. 11(2):311. Available at: https://doi.org/10.3390/jmse11020311

[10] Vanelslander, T., Sys. C, Lee Lam JS, Ferrari C., Roumboutsos A., Acciaro M, Macário R., and Giuliano G. (2019). A serving innovation typology: mapping port-related innovations, *Transport Reviews*, 39:5, 611-629, Available at: 10.1080/01441647.2019.1587794

6. **Regulatory compliance**. Although not yet abundant, especially from the environmental reporting point of view, the domain of inland ports management and operation is being more regulated requiring accurate data collection and reporting. Digital tools help ports meet these regulatory requirements more efficiently.
7. **Risk management**. Digitalisation technology facilitates risk assessment and management in the domain of security, safety, and port operations. Predictive analytics can help prevent accidents and respond to emergencies effectively.
8. **Customer-centric approach**. Vessel operators and cargo owners favour regularly updated or even real-time information, operational transparency and efficiency. Digitalisation tools largely facilitate these customer demands.
9. **Technological developments**. Rapid development of Internet of Things (IoT) technologies, artificial intelligence (AI) and data analytics and their reasonable prices make it easier for ports to adopt them and thus benefit from digitalisation.
10. **Infrastructure optimisation**. Advanced digital tools such as digital twins and/or simulation tools can help ports to optimise infrastructure layouts and expansions more efficiently and with less risks.
11. **Labour efficiency**. Digitalisation is shaping a new framework for inland port labour, due to the increasing demand for new jobs focused on high-skilled personnel. In this perspective, the familiarization with data gathering, monitoring of activities, track & trace operations and automated systems appear to be fundamental for port labour[11]. Development of such skills greatly increases labour efficiency.
12. **Data-driven decision making**. Data-driven decision making is a process by which port stakeholders use data to make their decisions. Real-time data accessibility such as berth availability, storage space availability, more precise time of vessel arrival, more precise info on the cargo quantity, packaging and incoming/outgoing vehicles pre-hauling or on-hauling the cargo, can often be a gold mine for decision makers and transport planners in ports. Digitalisation facilitates the gathering, processing, and sharing of the necessary data, thus enabling better and more reliable decision-making.

In view of the impact of digitalisation on greening of ports, it is interesting to note the quantification of digitalisation impact in the Port of Barcelona, in absence of any similar study performed for inland waterways ports. The Port of Barcelona Impact of Digitalisation Study[12] assessed the effects of the port's digitalisation on decarbonisation of the Catalan economy. In direct effects, the Study demonstrated that digitalisation led to 13% reduction of the total emissions emitted by the port's activity. In the case of trucks, for example, the implementation of automatic doors or virtual gates has reduced access time by 37%. The automation of customs exits with the implementation of the Integrated Customs Control System (SICAD) reduces departure times by 15%. Both measures save €2.4 million in fuel, 23 tons of polluting emissions and 6,978 tons of CO2. With regards to vessel operations, the improvements introduced in the computerized management systems of all the operations in the container terminals (TOS) have reduced the berthing time by 2.2 million minutes, equivalent to 4.2 years, and savings of 40% in the emissions of each container.[13]

Having these significant benefits of port digitalisation in mind, it can be safely concluded that decarbonisation of port activities is one of the publicly most attractive drivers for inland port digitalisation.

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[11] Vaggelas, G.K., Leotta, C., (2019). Port labour in the era of port automation and digitalisation. What's next? *Impresa Progetto - Electronic Journal of Management*, n. 3. Available at: http://dx.doi.org/10.15167/1824-3576/IPEJM2019.3.1232

[12] Port de Barcelona (2023). *Economic impact of the commercial activity and digitalisation of the Port of Barcelona*, Summary Report. Available at: https://contentv5.portdebarcelona.cat/cntmng/gd/d/workspace/SpacesStore/806f91df-aae5-43a3-8835-531377ccb096/Summary_DI_ENG.pdf

[13] https://piernext.portdebarcelona.cat/en/technology/port-of-barcelona-impact-of-digitalisation-study/

1.4 Emergence of smart ports

Rapid advancement of port digitalisation and automation have significantly contributed to the emergence of the so called “smart ports”. There is no universally accepted definition of a smart port, but, in essence, a smart port is a digital port of a new generation, using digital tools for the enhancement of efficiency and sustainability. Smart ports use advance technologies such as Internet of Things, big data, machine learning, artificial intelligence, blockchain and automation to improve their operational and environmental performance. The smart port concept emerged as a logistic network where all land and waterborne segments were connected and integrated.[14] Smart port can also be seen as a system for visualizing and managing collected data that mobilizes technologies, computer architectures, and software for efficient and predictive decision making[15], which is then connected, automated, and controlled by artificial intelligence.[16]

In addition to port digitalisation, which can be seen as its precursor, port automation is one of the key features of smart ports allowing them to operate without (or with limited extent of) human intervention. All smart ports are also green ports, as one of their tasks is the reduction of their carbon footprint. In this view, smart ports often use renewable energy and other sustainable technologies to reduce their carbon footprint.

Smart ports are typically built with facilities enabling their connectivity with various actors in logistics and industry. The advanced technologies they use enable them to improve the cargo and information flows between vessels, terminals, land transport means and other participants in the supply chain.

In case of inland waterway ports, smart ports are not yet so common, although inland ports try hard to keep the pace with their seaside counterparts.[17] For their sheer size and volumes handled, seaports are in somewhat better position from the financial feasibility of digitalisation point of view. However, since many inland ports are located in urban areas, where greening is of high importance and where development space is usually very limited, hence digitalisation, as one of the tools for the improvement of efficiency and environmental sustainability, is very welcomed by port stakeholders. Moreover, inland ports are typically parts of wider intermodal supply chains, whereas digitalisation and automation in other transport modes and nodes are well ahead of such processes in inland ports. Consequently, inland ports are under pressure to speed up their digitalisation and automation processes[18] for the purposes of achieving seamless flow of goods and data along the entire supply chains.

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[14] Cimino, M. G., Palumbo, F., Vaglini, G., Ferro, E., Celandroni, N., & La Rosa, D. (2017). Evaluating the impact of smart technologies on harbor’s logistics via BPMN modeling and simulation. *Information Technology and Management, 18*(3), 223–239. Available at: https://doi.org/10.1007/s10799-016-0266-4

[15] Fernández, P., Santana, J. M., Ortega, S., Trujillo, A., Suárez, J. P., Santana, J. A., Domínguez, C. (2017). Web-based GIS through a big data open source computer architecture for real time monitoring sensors of a seaport. In *The Rise of Big Spatial Data* (pp. 41–53): Springer.

[16] Heuermann, A., Duin, H., Gorldt, C., & Thoben, K.D. (2017). Service ideation and design for process innovations in future seaports. In Paper presented at the 2017 International Conference on Engineering, Technology and Innovation.

[17] For example, see the project RPIS 4.0 – Smart Community System for Upper Rhine Ports.

[18] https://www.porttechnology.org/news/ctac-2021-digitalise-inland-terminals-to-boost-supply-chain-resiliency/

2 Port digitalisation technologies and platforms and their potential use in greening

2.1 Sensors and devices as basic building blocks of port digitalisation

2.1.1 Single sensors

Before stepping into more complex technologies enabling the port digitalisation, single sensors used in port digitalisation will be briefly presented in this sub-section.

Regardless of the type of port digitalisation technology (Internet of Things, artificial intelligence, big data, blockchain, digital twins, augmented reality, and virtual reality, etc.) applied, there is a number of devices designed to gather and transmit various data. These devices are commonly called smart sensors, or simply sensors. Smart sensors are designed to assist port authorities and operators to track, manage, operate, monitor and maintain the physical infrastructure, cargo handling equipment and cargo they manage and/or operate. Sensors can be attached, placed, or embedded in quay walls, warehouses, crane tracks, all sorts of cranes and other cargo handling equipment, port basins, lighting posts and other places of convenience. They can even be mobile – waterborne or airborne, attached to various types of drones. Sensors collect and transmit real-time data about operating conditions of berths, crane tracks, entry/exit gates and other types of infrastructure or superstructure. When used for inspecting and determining the physical condition of berths or cranes, for example, sensors can lower the number of necessary inspections and provide the necessary data so that the port authorities or operators can schedule preventive maintenance. Sensors used for structural health monitoring systems of quay walls or cranes, for example, are usually only a fraction of the cost of such structures, while the quick return of investment is just one of the benefits of such systems.

Sensors used to monitor the operations of cranes and other cargo handling equipment collect and transmit operational data enabling the operators to increase the operational efficiency, ensure proper and timely maintenance, increase cargo handling volumes, and improve productivity. Sensors of this type can be interconnected with other sensors mounted on different cargo handling equipment, giving the operator a full picture of the location of each piece of equipment, operational status and energy consumption, making it easier for the operator to identify bottlenecks and optimise operations accordingly.

Sensors can also be used to monitor various environmental parameters in ports, such as air quality, water quality, noise, waste accumulation, etc. These sensors are the basic elements of any environmental management tools applied in ports.

There are hundreds, if not thousands of different sensors and devices that are applied in port management and operations and detailed elaboration for all of them is beyond the scope of this study. However, the most typical sensors used in ports are briefly described in continuation:

- **Photoelectric short and long-distance sensors**. Short distance sensors are very useful in day-to-day operations in ports. For example, when containers are handled with trolley cranes at the quayside, it needs to be detected if containers are on the trolley platform or not. Distance sensors can be programmed to signal the operator when a container is properly positioned on a platform. Another example of their use is in straddle carriers where they assist the operator to measure the distance between the spreader and container and thus adapt the speed and position to avoid damage.[19] Long-distance sensors are used to maintain a minimum distance between vehicles operating along the same driveway, such as minimum distance between quay cranes, trucks, collision prevention for RTGs, or for protection from risk of collision between the crane boom and the ship deck.[20]

- **Pressure sensors**. These sensors measure the pressure wherever it may be needed, from the pressure in storage tanks for liquid cargo to the pressure of hydraulic systems in cargo handling equipment, or atmospheric pressure.
- **Level sensors**. Sensors of this type are used to measure the accurate level of liquid in tanks or levels of bulk cargo, such as grain in silos.
- **Temperature sensors**. Widest possible use. They can be used for measuring and transmitting the data on temperature of the pavement in handling yards, water and air temperature, temperature of oil and coolant liquids in cargo handling equipment, temperature in storages and tanks, temperature of cargo, etc.
- **Container tracking sensors**. These sensors monitor the location, status, and condition of containers, enabling real-time tracking and management.
- **Environmental sensors**. Sensors for atmospheric temperature, humidity, air quality (iNose for example), and other environmental factors help ensure optimal conditions for cargo and personnel.
- **GPS and location sensors**. Global Positioning System sensors provide accurate location data for vessels, containers, and vehicles within the port area.
- **Radio-frequency identification (RFID) tags**. Radio-frequency identification tags are attached to containers, equipment, and vehicles for automated identification and tracking. Data collected by RFID systems is integrated in the IT platform that handles the traffic management in the terminals.
- **Weight sensors**. These sensors measure the weight of containers and cargo, ensuring compliance with safety regulations.
- **Motion sensors**. Detect movements in machinery, vehicles, and equipment to optimize operations and maintenance scheduling.
- **Camera Systems**. Surveillance cameras and image recognition technology enhance security, safety, and monitoring of port activities. Cameras can be equipped with night and thermal visioning systems.
- **Light Detection and Ranging (LiDAR) sensors**. LiDAR sensors are used for accurate measurement and mapping of port areas, aiding in planning and navigation. These sensors can be used for the widest possible applications in ports. For example, LiDAR sensor is installed on the trolley to help position the spreader on the quay crane. The trolley position and the laser scanner distance measurements are combined to create a dynamic 2D profile of the current cargo load on each ship. This data is then used together with control software to assist the crane operator in handling containers smoothly and efficiently. Furthermore, LiDAR sensors can be used for environment perception of terminal tractors. Intelligent driver assistance systems for collision awareness with geofencing functionality contribute to an increase in efficiency of the transport process and reduce the risk of unplanned machine downtimes and accidents. Modularly designed systems offer an environment perception capability of up to 360° for terminal tractors and their trailers. Equipped with dynamically adjusted scan fields and geofencing functionality for specific yard areas, the system provides maximum convenience and optimal warnings - acoustically and/or visually.[21]

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[19] IFM (2020). Sensors and systems for port automation. Brochure. Available at: https://www.ifm.com/ifmweb/downcont.nsf/files/ifm-brochure-port-automation-2020-gb/$file/ifm-brochure-port-automation-2020-gb.pdf

[20] SICK AG (2007). *Sensors and solutions for ports. Higher efficiency and greater safety*. Industry guide. Available at: https://www.sick.com/media/pdf/8/98/098/IM0015098.pdf

[21] SICK AG (2020). Port Sensor Solutions for Container Terminals. Industry overview. Available at: https://cdn.sick.com/media/docs/9/09/909/industry_overview_port_sensor_solutions_for_container_terminals_en_im0094909.pdf

- **Vibration sensors**. These sensors detect vibrations in cargo handling equipment or infrastructure assets, helping to predict, prevent or mitigate mechanical and structural failures.
- **Gas sensors**. Monitor the presence of hazardous gases and chemicals in the port environment for worker safety.
- **Air quality sensors**. These sensors are designed to monitor the predetermined indicators of air quality, including the presence of selected pollutants.
- **Noise sensors**. Used to monitor noise levels and detect unusual sounds that may indicate equipment malfunction.
- **Wind and weather sensors**. Provide real-time data on wind speed, direction, and weather conditions for safe navigation and operations.
- **Power monitoring sensors**. These sensors track energy consumption to optimize resource usage and identify opportunities for energy efficiency.
- **Water quality sensors**. The main purpose of these sensors is to monitor the pollutants in the water in port areas. Sensor tracks the levels of various pollutants in the water and alert the operators when certain pollutants breach the maximum allowed levels.

2.1.2 Complex devices and systems

Apart from single sensors, port digitalisation technologies encompass various devices and systems that combine different sensors that are used for specific purposes. Examples include the following applications:[22]

- **Volume measurement of bulk materials**. This system automatically detects the load and the upper edge of the loading ramp of a passing dump truck and determines the volume difference in seconds. The evaluation software integrated into the system generates a 3D model of the load based on the measurement data. This enables the volume and thus, for example, the dry weight of the load to be calculated simply and easily. The system can also detect whether a dump truck is empty before being loaded in the port. It uses LiDAR sensors, HD cameras, appropriate software.
- **Access monitoring of rail facilities**. The video monitoring of rail operations in ports can be significantly improved through intelligent access control with real-time alerts. The LiDAR sensor-based object detection system automatically detects unauthorized persons and notifies the responsible personnel.
- **Vehicle hotspot detection systems**. Vehicles operating in ports are constantly at risk which could lead to fires caused by, for example, overheated brakes or engines, scorching damage, or technical defects. Early detection of overheated spots on vehicles enables port personnel to take necessary action.
- **System for protection of vessel loaders**. Numerous areas on vessels and in ports must be monitored for vessels to be loaded and unloaded safely. Locations such as hatches, deck structures, vessel loader booms, and mobile machines are all potentially hazardous areas. Object detection systems designed for vessel loader protection minimize the risk of collision and maximize productivity.
- **Conveyor hotspot detection systems**. In bulk terminals, conveyor belts transport materials such as coal or grains. Disruptions in the facility, caused, for example, by fire ignited by hot bulk materials, can lead to significant operational delays, high costs and environmental pollution. The conveyor hotspot detection systems automatically and continuously measure the temperature of the conveyed materials using a thermal image camera. Overheated material is detected fully automatically, and an alert is triggered. This enables the responsible personnel to take early prevention measures.

[22] SICK AG (2023). Port Sensor Solutions for Bulk Terminals. Industry overview. Available at: https://cdn.sick.com/media/docs/4/74/774/industry_overview_ports_sensor_solutions_for_bulk_terminals_en_im0104774.pdf

- **Real-time location systems (RTLS)**.[23] These systems, similar to RFID tags, are becoming a useful tool in the management of ports and container terminals. Digitalisation processes in ports require better visibility and tracking of assets in real-time, improving operational efficiency and labour safety. These systems typically consist of three main components: tags, sensors, and software. Tags are attached to assets, such as vehicles, equipment, inventory, or even people, and emit a signal that is picked up by sensors. Sensors are strategically placed throughout an area to capture the signals emitted by the tags. The data collected by the sensors is then processed by software to determine the location of the tags in real-time. The software component of RTLS systems is responsible for processing the data collected by the sensors and determining the location of the tags in real-time. The software can be customized to meet the needs of specific applications, such as worker safety or asset tracking. Benefits of RTLS include, but are not limited to, the following:
  - **Vehicle tracking.** Vehicles entering ports are given RTLS tags and sensors, enabling real-time monitoring of their actual condition, location and movement over time. This is very useful in combination with Digital Twins of ports, where an entire port is digitally replicated and visualised on appropriate large size monitors and screens. Operation managers can track the location and status of different vehicles and set various alert triggers, if, for example, vehicles or containers are queued in unusually long queues or loaded/unloaded in wrong places, or if maintenance of a vehicle is needed. More importantly, such oversight of vehicles enables optimised routing and scheduling of vehicles, avoiding or reducing waiting times, queues, and congestion. This, in turn, will reduce fuel consumption and reduce emissions of pollutants.
  - **Collision avoidance.** The larger the port, the larger the risk of collision between various types of vehicles moving in a port. Depending on the traffic situation in the port, certain port areas can be designated as critical areas, where, for example, vehicle speed can be significantly limited to avoid collisions, damage or accidents. A number of alert triggers can be set to identify vehicles not respecting the rules and take corrective actions accordingly. In combination with, for example, proximity sensors, a safety area can be established around every vehicle, and alerts could be set whenever a vehicle distance from other vehicles, persons, or fixed objects is shorter than the radius of the safety area.
  - **Container storage.** Tracking of containers in real time can optimise storage and reduce waiting times for container movements, and it can assist operators of cargo handling equipment to load/unload containers to/from appropriate locations in the container yard. In addition, RTLS can be used to monitor the physical condition of containers, allowing for their storage in appropriate environments and their proper maintenance.
  - **Labour safety.** Apart from equipping equipment and vehicles with RTLS, port workers can also be tracked through RTLS. This allows to couple the movement of personnel with vehicles in real time, ensuring that they are not at risk of injuries or accidents. Moreover, RTLS for port workers can alert operators of potential hazards, safety concerns, unauthorised access to restricted areas or even dangerous weather conditions.

2.2 Advanced port digitalisation technologies

2.2.1 Internet of Things (IoT)

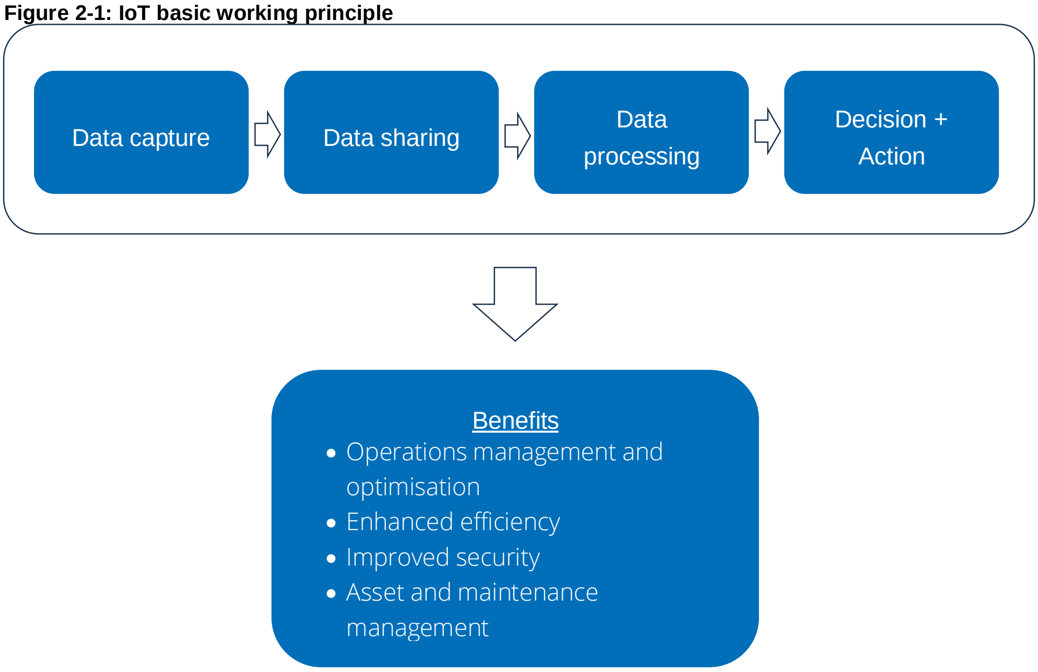
Internet of Things (IoT), as defined by the Institute of Electrical and Electronics Engineers (IEEE), is a network of devices such as sensors and embedded systems connected to the Internet, thus enabling physical objects to collect and exchange data[24]. Various sensors are of utmost importance as they measure the physical characteristics of objects and transform them into numerical values,

[23] https://ubisense.com/smart-port-rtls/

[24] Jayavardhana, G., Rajkumar, B., M. Slaven, M., and P. Marimuthu, P. (2013) Internet of things (IoT): a vision, architectural elements, and future directions, *Future Generation Computer Systems*, 29(7), pp. 1645-1660, 2013.

which can be read by another device (in machine to machine - M2M communication via Internet) or by the user, in real-time providing multiple support features such as identification, location information, object tracking, object monitoring and process management. In this way, users can perform remote control over objects of interest. As elaborated in previous section, cargo handling equipment and other devices and assets can be equipped with necessary sensors and transmitters enabling shipment tracking, temperature measurements of the cargo or vehicles, tracking vehicle accumulation and queuing, congestion monitoring and other benefits that can enhance the operational efficiency and environmental performance, and that can reduce operational costs. Combination of various sensors with positioning devices enables situational awareness between various port stakeholders in the port area, allowing, for example, traffic management, control of vehicles and handling equipment moving in the port area or prediction of arrival times.

Figure 2-1: IoT basic working principle



Source: Consortium

2.2.2 Blockchain technology

Blockchain or chain of blocks is a read-only distributed peer to peer ledger that contains encrypted information that is structured in blocks.[25] In other words, blockchain is a database for storing transactions that is shared among all the parties in a network. It serves as an encrypted ledger for information. The peer-to-peer network uses a consensus mechanism, which ensures that the transaction is valid before it is recorded to the ledger.[26] A participating stakeholder must validate a transaction by providing the same hash[27] as the other stakeholders in the network. This hash is a specific and unique code that describes a message with information. When a new transaction (for example, the cargo is loaded onto a vessel) is made, a hash is created, and all stakeholders in the network check to make sure the hash matches what it should be, ensuring the transaction is valid. Once everyone agrees, the transaction is added to the blockchain – meaning that the information in the hash is validated. The hash helps keep everything secure and makes it easy to verify that the

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[25] https://piernext.portdebarcelona.cat/en/technology/blockchain-logistics-and-ports-present-and-future/

[26] Oude Weernink, M., van den Engh, W., Francisconi, M., Thorborg, F. (2017) The Blockchain Potentials for Port Logistics, Research Paper, Smart Port NL and Port of Rotterdam. Available at: https://smartport.nl/wp-content/uploads/2017/10/White-Paper-Blockchain.pdf

[27] The "hash" refers to a specific and unique code generated by a cryptographic algorithm that describes the content of a message with information. It is created from the transaction data, meaning that it is unique to the data it represents, so even a small change in the data will produce a completely different hash.

information was not compromised or misused in any way. The validated information is recorded on a block. A block can be compared to a container whereas everyone can see it from the outside, but only those with permission, a private key, can access the content.

Blocks are interlinked between each other in an orderly fashion creating a temporary and immutable line that guarantees the integrity of the information within each block.

Such feature makes blockchain technology a secure and transparent system, allowing the processing of transactions in a decentralized way and validated by the network, generating trust among users. Any attempt to modify or alter the data is automatically detected, meaning that no information can be used without the knowledge of the information owner.

Blockchain technology can benefit ports in numerous ways. Some of them are briefly elaborated in continuation:[28]

- **Trust**. Since any usage of the information stored in a blockchain can be granted only on the basis of shared consensus of participating stakeholders, hence the information is considered reliable. In such way, trust is being built up among participating stakeholders. Blockchain technology is therefore considered to be very convenient for ports where the sharing of information between various stakeholders is difficult due to the initial lack of trust.
- **Security**. All data stored in a blockchain is encrypted. This provides a solution for the complex process of writing information to and validating information on the ledger. The complex mechanism not only ensures the validity of the information, but also prevents any fraudulent activities. In practice, after several blocks have been added onto each other, changing the information stored on the block becomes highly unlikely. Furthermore, a blockchain-based identity management system can be used to verify the identities of people and vehicles entering and exiting the port, trying to prevent unauthorized access and improve the overall security of the port.
- **Effectiveness**. The financing of international trade can be a complex and time-consuming process that requires the involvement of multiple parties. The use of blockchain technology can streamline and automate the trade finance processes in a port. For instance, a smart contract can be used to automatically trigger payment once the conditions of the trade finance agreement have been met. This can reduce the time and costs involved in trade finance transactions.[29]
- **Visibility**. Introduction of the blockchain technology in ports increases the visibility in the supply chain since it enables tracking and tracing of various cargoes or containers. Increased visibility facilitates the exchange of information between various actors along the supply chain. The real-time knowledge of whereabouts of cargo and the flow of information in real-time can increase both payments and movements of cargo. For example, the delivery of a container to a receiver or importer can take place only when the invoice of the container is paid, and a delivery/payment notice is sent out. Without the blockchain technology the processes of loading/unloading, stuffing/stripping of containers, endorsement of Bills of Lading, payment of the freight, etc. are not immediately connected between different parties along the supply chain, and in many cases such transactions require manual intervention. Blockchain technology, on the other hand, allows for the data sharing as soon as the container is unloaded from a vessel. In this way, payments can be significantly accelerated and be realised in a matter of minutes, instead of days.
- **Network expansion**. Being fully compatible with other digital technologies applied in ports, such as port community systems, Internet of Things, Digital Twins, etc., blockchain technology

[28] Ibid.
[29] https://www.shipfinex.com/blog/blockchain-technology-in-port-operations

can contribute to the expansion of the network of port users by allowing them to connect to the network not only through a centralised party, but also individually, in a decentralised way. This option is possible only through a public and open blockchain solutions. Furthermore, different blockchain networks around the world can also be interconnected, allowing ports and stakeholders to exchange information in a unique way.

- **Integration of supply chain flows**. Blockchain technology can enable a better integration of supply chain flows (physical, financial and information flows). To move the physical flow of goods through the port, for example when unloading a container of its cargo, it is necessary for the various parties involved to share certain information. Some examples here are trade finance, information required by Customs and every piece of information required by a party to perform consecutive tasks. Integrating these flows could give the port a new competitive advantage in the continuously changing supply chain environment. Moreover, new long-term contracts could be established with customers.

2.2.3 Big data analytics

Big data is a term that describes the large volume of data – both structured and unstructured – generated during day-to-day port operations. Big data can be analysed for insights that lead to better decisions and strategic business moves.[30] Data generated in ports are of the widest possible scope, such as number and features of vessels and barges currently served in ports, type of cargo stored in storages and warehoused, current productivity of cranes, handling yard equipment, individual workers or entire dockers' gangs, traffic density of land means of transport arriving to the port, circulating in the port area or leaving it, estimated times of arrival (ETA), payment and billing information, demurrage and laytime, contract related information, trade data, structural loads of quay walls or quayside cranes, etc. All this data and information can be stored in databases as they constitute "big data", and they can be used for various purposes leading to the improvement of performance indicators, overall port efficiency and management of various port assets.

Data collection is performed through various IoT sensors and devices, RFID sensors and tags, and GPS systems which facilitate real-time data collection, enabling accurate insights into port operations. Examples of major areas where big data analytics can assist ports are the following:

- **Operational efficiency**. Big data analytics facilitates streamlining of operations by port/terminal operators. By analysing past data, ports can predict vessel arrival times more accurately, allowing them to optimise berth allocations and reduce congestion. This results in shorter turnaround time for vessels, increase utilisation of port capacities and enhancement of overall operational efficiency. Since the operational efficiency of equipment and workers can also depend on weather and atmospheric conditions operations managers can use the general weather related data, temperature, fog occurrence, precipitation predictions,
- **Cargo handling and inventory management**. Efficient cargo handling is of utmost importance for a port's success. Big data analytics enable the monitoring and optimisation of cargo movements. Through predictive analytics, ports can anticipate cargo flows and allocate resources accordingly, preventing bottlenecks and optimizing workforce management. Additionally, data-driven insights facilitate better inventory management, ensuring that the right cargo is in the right place at the right time.
- **Maintenance and safety**. A lot of due attention is given to the issues of safety in port operations. Using big data analytics, ports can employ predictive maintenance strategies and plans. Collected data, such as crane performance and equipment health, allow ports to anticipate potential breakdowns and schedule maintenance before actual failures occur. Such

[30] https://www.sas.com/en_us/insights/analytics/big-data-analytics.html

approach reduces downtime, improves safety and extends the lifetime of equipment and machinery.

- **Port layout planning**. Using the data on weights, loads, traffic intensity, waiting times, types of equipment and vehicles being used in certain areas, port/terminal planners can see which part of a port/terminal have the highest workload. Having this data at hand and in real-time enables port planner to adjust and optimise port/terminal layout or, if necessary, plan the port expansion.
- **Environmental impact**. It is known that ports have a significant impact on the environment due to emissions, noise and other factors originating from vessels, cargo handling equipment, land transport means, etc. Big data analytics related to vessel and vehicle emissions, energy consumption, and traffic patterns allow ports to develop strategies to minimise their environmental impacts, such as adopting cleaner energy sources, providing shore-side electricity supply for vessels, and charging stations for electricity driven vehicles and cargo handling equipment, and implementing sustainable practices.

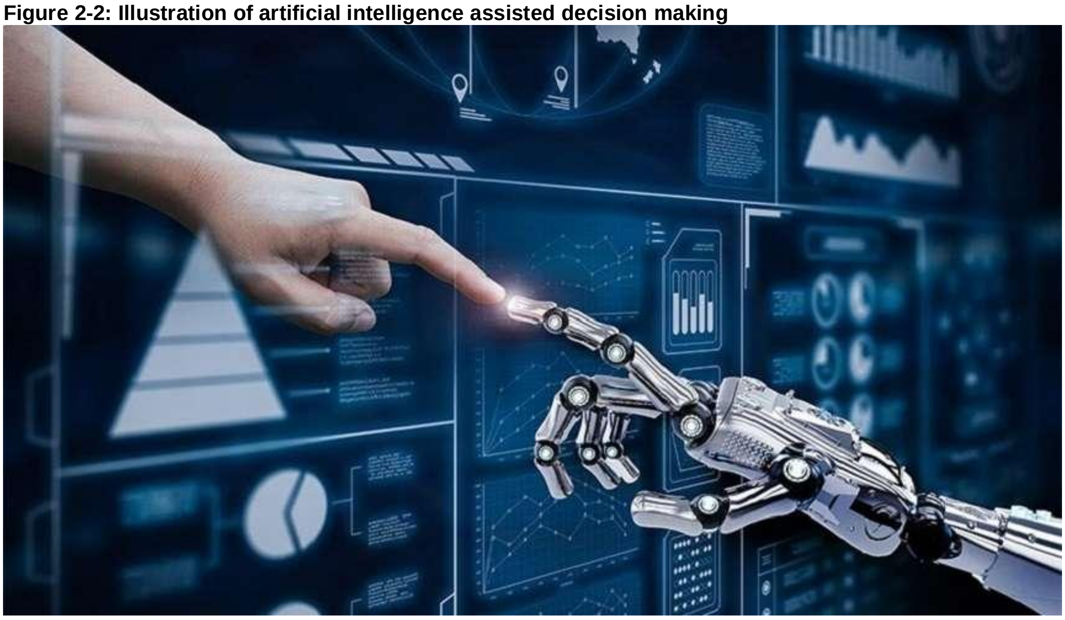
While the benefits are promising, the implementation of big data analytics in ports also presents challenges. Security concerns arise due to the sensitive nature of port data. Ensuring data privacy and cybersecurity is essential to prevent unauthorized access and data breaches. Additionally, the upfront costs of implementing data analytics infrastructure and training personnel can be significant hurdles for port authorities.

The use of big data analytics in ports marks a paradigm shift in the maritime industry. Ports that embrace this technology stand to gain improved operational efficiency, enhanced cargo handling, and better decision-making capabilities. The ability to harness insights from vast amounts of data enables ports to address challenges proactively and make informed choices for sustainable growth. While challenges exist, the potential benefits make the integration of big data analytics an indispensable tool for modern port management. As technology continues to advance, the role of big data analytics in reshaping ports is set to expand further, ushering in a new era of efficiency and innovation.

2.2.4 Artificial intelligence

Artificial intelligence (AI), in a nutshell, refers to the simulation of human intelligence in machines (hardware and software), allowing them to execute tasks that would otherwise require human intelligence. Examples of such tasks, in general, include the following: problem-solving, learning, reasoning, recognising patterns, understanding human language, and making decisions.

Figure 2-2: Illustration of artificial intelligence assisted decision making



Source: https://datascienceforu.com/machine-learning/

AI uses all previously explained technologies for the tasks it is programmed to do. Smart ports could not exist if there was no AI. Since smart ports development is gaining momentum all over the world, it is safe to state that AI is a real game changer in transportation in general, and especially in ports which are the nodes in which many complex operations need to be performed to enable seamless and reliable supply chains. Data collected by various sensors, shared by Internet of Things and processed by appropriate software is used in complex algorithms to mimic the thinking process in humans. Artificial intelligence has already been applied in shipping and ports automation, and the development of AI applications in port automation is in full force through current projects, e.g., project SEAMLESS.[31]

Thanks to its features, AI can have a significant influence on port operations.[32] Basically, ports can use the features of AI technologies in the following aspects of their operations:

- **Cargo management**. Systems of artificial intelligence can optimise cargo handling by predicting arrival times, identifying priority shipments and suggesting optimal storage and loading strategies. This leads to the avoidance or reduction of congestion and faster turnaround times of both vessels and land vehicles.
- **Predictive maintenance**. AI sensors can monitor the condition of port infrastructure, superstructure and equipment in real-time, enabling predictive maintenance to prevent breakdowns and accidents and reduce downtime. Predictive maintenance reduces operational costs, making ports more economically sustainable.
- **Traffic management**. AI algorithms analyse vessel and vehicle movements to optimise traffic flows within port areas, thus minimising congestion and emissions and at the same time maximising efficiency.
- **Security**. AI-driven surveillance systems can detect anomalies and potential security threats, enhancing port security and ensuring the safety of assets, goods, services and personnel.
- **Environmental monitoring**. AI can assist ports to comply with environmental regulations by monitoring emissions and suggesting environmentally friendly practices and strategies. In this way, AI directly assists in the reduction of the environmental footprint of ports.

31 https://www.seamless-project.eu

32 Ghazaleh, M. (2023). Smartening up Ports Digitalisation with Artificial Intelligence (AI): A Study of Artificial Intelligence Business Drivers of Smart Port Digitalisation. *Management and Economics Review*, 8(1). Available at: DOI:10.24818/mer/2023.02-06

Artificial intelligence systems are not without challenges. Like other novel systems, some of the concerns include data privacy, high investment costs in infrastructure and technology, skills gaps and regulatory compliance. For these reasons, ports should have a clear set of goals of digitalisation set and, if possible, should have a detailed and convincing business plan on how to introduce AI systems in daily operations and management and at what level. Despite challenges, it is safe to claim that the rapid development of AI will introduce such systems more and more into ports, especially in those ports with high level of automation. Integration of AI and IoT will further enhance real-time monitoring and decision-making capabilities. Ports will therefore become smarter, more efficient, and environmentally sustainable nodes for international supply chains.

2.2.5 5G networks

5G, short for “fifth generation” is the latest generation of wireless technology for mobile and broadband communication. Compared to the previous generations, it offers significant advantages, such as high data transfer speed, increased capacity, enhanced reliability, improved coverage, energy efficiency and significantly reduced latency. Latency is very important when it comes to port automation. Latency refers to the time it takes for a signal to travel from a device to the network and back again. Sometimes called ping time, it is a critical component for anyone using real-time communication services like video calls or remote operating equipment.

With the low latency offered by 5G networks, remote operations of port and terminal equipment, from terminal tractors and other cargo handling equipment to cranes, becomes one step closer to a widespread reality. 5G enables low-latency machine-to-machine communications, which is critical in some automated and autonomous applications.[33] Here are some key aspects of how 5G is applied in port digitalisation and automation:

- **High-speed data transmission**. 5G offers very fast data transmission compared to any previous wireless technology. This allows ports to transmit large volumes of data quickly, enabling real-time communication and data exchange between various devices and systems.
- **Low latency**. As already mentioned, 5G networks have very low latency, meaning that there is minimal delay in data transmission. This is very important for port applications, since low latency is essential for safety and efficiency when operating with autonomous vehicles and remote-controlled machinery.
- **IoT connectivity**. Thanks to their high capacity, 5G networks can connect a vast number of IoT sensors and devices, allowing port authorities and operators to monitor and manage various aspects of port operations, such as container (pallet, parcel, etc.) tracking, equipment maintenance and security systems.
- **Remote control and automation**. 5G enables more efficient and safer remote control of machinery and equipment within the port. This refers to remotely operated cranes, trucks, terminal tractors, straddle carriers, drones, etc., improving operational efficiency and reducing the need for human intervention in hazardous environments.
- **Enhanced security**. With 5G, ports can deploy advanced security systems such as high-res video surveillance, facial recognition, and access control, to enhance security and safety measures.
- **Data analytics**. Speed and connectivity provided by 5G networks enable ports to collect and analyse huge amounts of data. This data can then be used for predictive maintenance, optimising logistics and improve informed decision making to improve the overall port performance.

[33] Ramakrishnan, V. (2022) Digitalising Port Operations with 5G Connectivity. *Port Technology*, 117. Available at: https://www.porttechnology.org/technical-papers/digitalising-port-operations-with-5g-connectivity/

- **Environmental monitoring**. Ports can use 5G to deploy sensors and monitoring systems for environmental purposes, such as monitoring air quality, water (in the port basin) quality, noise levels, emissions from vessels and all vehicle and cargo handling equipment circulating in the port, etc. Such data collection and processing can help ports comply with environmental regulations or set a good practice example of environmental sustainability.

Port authorities and operators all over the world have quickly recognised the importance and benefits of deployment of 5G networks in port management and operations. For example, 5G networks will be the backbone of an intelligent logistics platform that connects small and medium sized inland ports as part of China's digital silk road.[34] In Europe, the Port of Duisburg was using the 5G network to trial semi-automated control of cranes at the port.[35]

2.2.6 Data analytics and business intelligence tools

Data analytics refers to the collection, transformation, and organisation of data to extract meaningful conclusions, make predictions and forecasts, and drive informed decision making.

Data analytics is often confused with *data analysis*. While these are related terms, they are not exactly the same.[36] In fact, data analysis is a subcategory of data analytics that deals specifically with extracting meaning from data. Data analytics includes processes beyond analysis, including data science (using data to theorise and forecast) and data engineering (building data systems). In this view, data analytics is a multidisciplinary field that employs a wide range of analysis techniques, including math, statistics, and computer science, to draw insights from data sets. Data analytics is a broad term that includes everything from simply analysing data to theorising ways of collecting data and creating the frameworks needed to store it.

There are four basic types of data analytics[37], as demonstrated in Figure 2-3.

- **Descriptive analytics**. The simplest analytics[38], describing what has happened in an analysed case, event, or situation. All other types of data analytics are built upon it. It uses the raw gathered data to explain what has happened or what is currently happening in an environment under analysis. For example, it can identify a sudden drop in port throughput in a given time period. Here, data visualisation is very convenient for descriptive analysis since graphs and charts can clearly show trends and anomalies in data.
- **Diagnostic analytics**. A step forward in analysing the causes of anomalous event, it reveals a reason or a cause of why such event has occurred. It can determine if there is a correlation between different performance parameters and even causal relationships where possible. For example, by comparing the throughput with the productivity of the quay cranes or the waiting time of cargo handling equipment at the handling yards or at the storage areas, the diagnostic analytics can reveal that the sudden drop in throughput can be caused by lower productivity of a quay crane which, in turn, may be caused by mechanical issues, inexperienced new operator, failures in remote or automatic operation of a crane, or it may be caused by a congestion at the handling yard or storage area. This gives a port operator the right information on what corrective actions may be taken to avoid the unwanted chain of events.

[34] Wheeler, A. (2020). Will 5G change logistics and ports? *Splash 247*, Available at: https://splash247.com/will-5g-change-logistics-and-ports/

[35] European 5G Observatory (2022). The German mobile operator has begun construction of a private 5G network at the Port of Duisburg. Available at: https://5gobservatory.eu/deutsche-telekom-launches-5g-test-site-at-german-port/

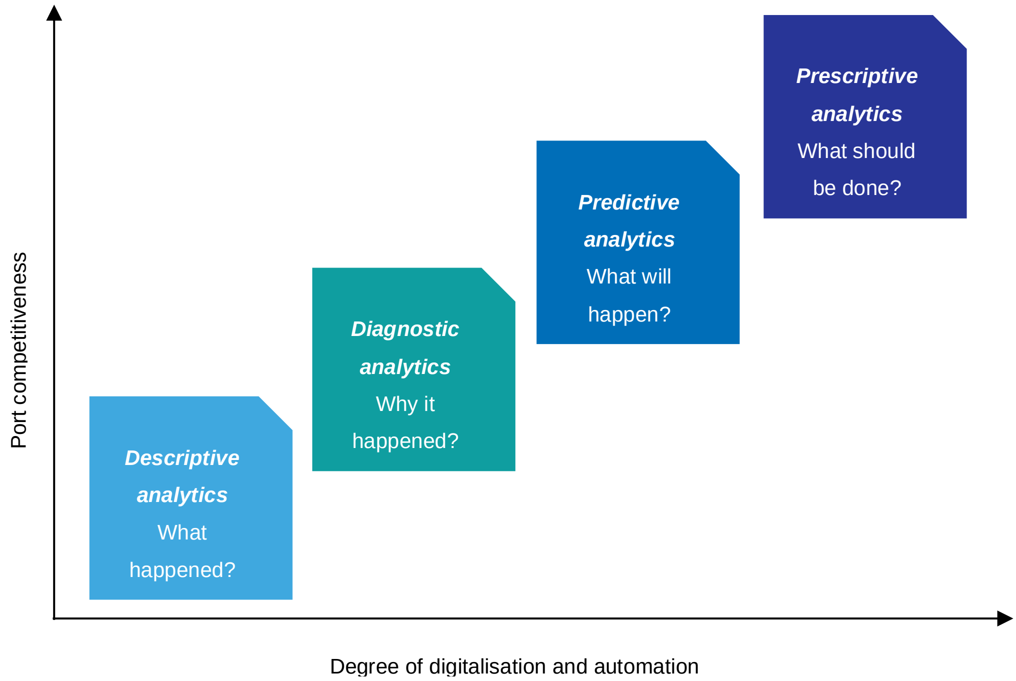
[36] Coursera, (2023). Data Analytics: Definition, Uses, Examples, and More. Available at: https://www.coursera.org/articles/data-analytics

[37] Harvard Business Review (2018). *HBR Guide to Data Analytics Basics for Managers*. Harvard Business Review Press

[38] https://online.hbs.edu/blog/post/types-of-data-analysis

- **Predictive analytics**. This type of analytics uses historical data to make forecasts about future events. In inland ports it can be applied to the arrival rates of barges, predict cargo volumes, demand fluctuations and even maintenance needs. As another example, the predictive analytics can use past trends to predict the shares of unpropelled barges and self-propelled vessels arriving to port and thus help the operators to adjust the array of services offered to one or the other type of vessels. This allows port operators to plan in advance, allocate resources more efficiently and optimise inventory levels.
- **Prescriptive analytics**. Goes beyond prediction and recommends strategies and actions to optimise outcomes. For instance, in inland ports it can suggest best routes of land transport means within the port area or the best routes of cargo handling equipment in the handling or storage area, scheduling and resource allocation strategies to minimise operational costs or maximise throughput. For example, prescriptive analytics considers various factors such as cargo volume forecasts, equipment availability and workforce schedules to recommend the most efficient way to allocate cargo handling equipment and labour resources, thus minimising bottlenecks and improving throughput. Last but not least, prescriptive analytics can take into account sustainability goals and environmental regulations when making recommendations. It can help port operators find ways to reduce emissions and energy consumption through equipment scheduling or infrastructure improvements.

Figure 2-3: Four types of data analytics

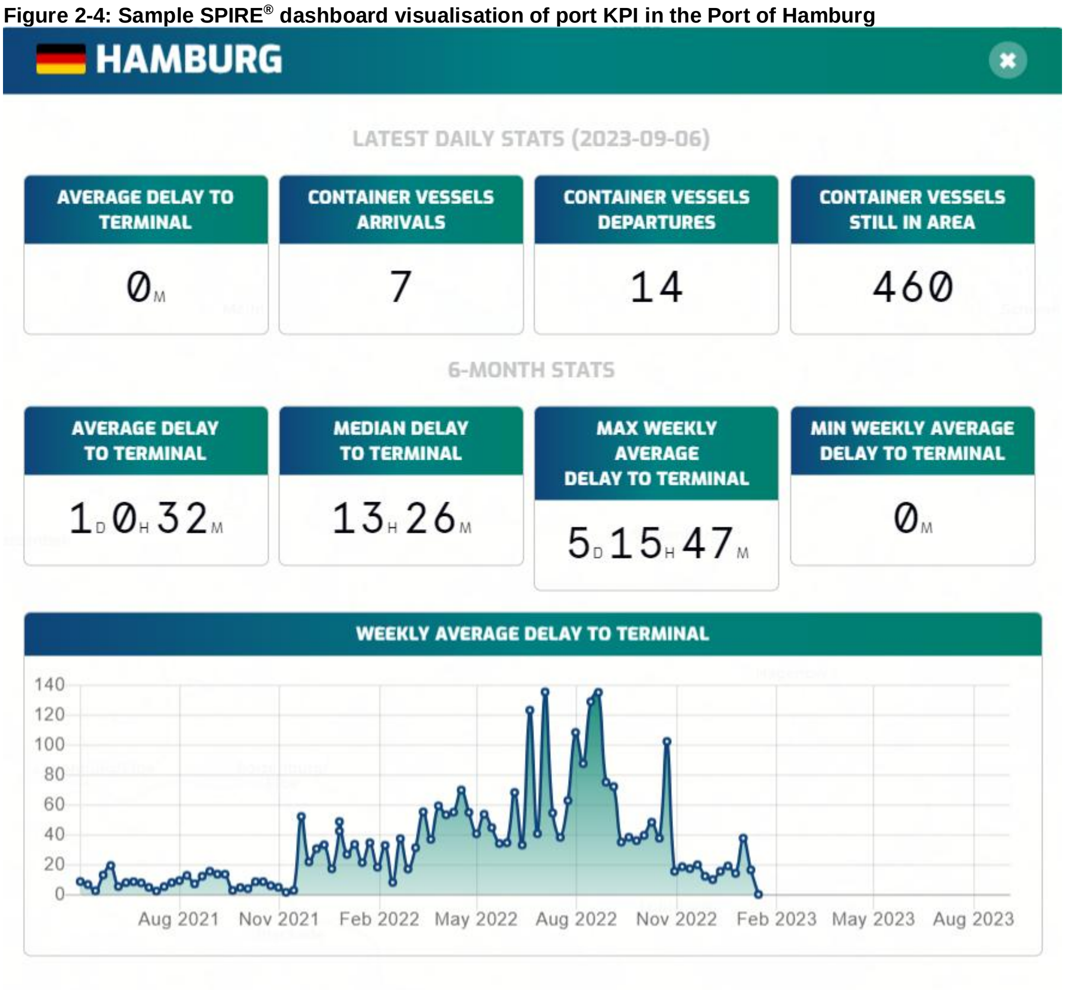


(Source: Consortium)

From the features of each type of data analytics used in ports, it can be concluded that the more sophisticated data analytics type is applied, the more competitive port can be. Ports using a combination of these analytics can streamline operations, reduce costs, enhance service quality and adapt to dynamic market conditions more effectively. As a result, they can attract more customers, vessel operators, cargo owners and logistic partners, ultimately gaining a competitive edge in the industry. Additionally, the more sophisticated data analytics in a port are, the higher is the digitalisation and automation level in that port. This is due to the fact that handling the large amounts of data, processing it and use it for predictive and prescriptive models requires various digital tools and devices, plus automated equipment which can best use the results of the sophisticated data analytics.

Business Intelligence (BI) is different from data analytics, although they are closely related. BI involves sophisticated techniques of data analysis and solutions that are helping port managers to analyse huge amount of data and make their own informed decisions aimed at improving of the overall port efficiency. While the BI focuses on reporting, querying and *data visualisation* to provide past, current, and sometimes predictive views of port operations, data analytics examines data to discover meaningful patterns, insights and trends which can then be used in predictive and prescriptive analytics aimed at making data-driven decisions. The following figure demonstrates the data visualisation of the statistical parameters within the business intelligence tool SPIRE ® used by the Port of Hamburg.

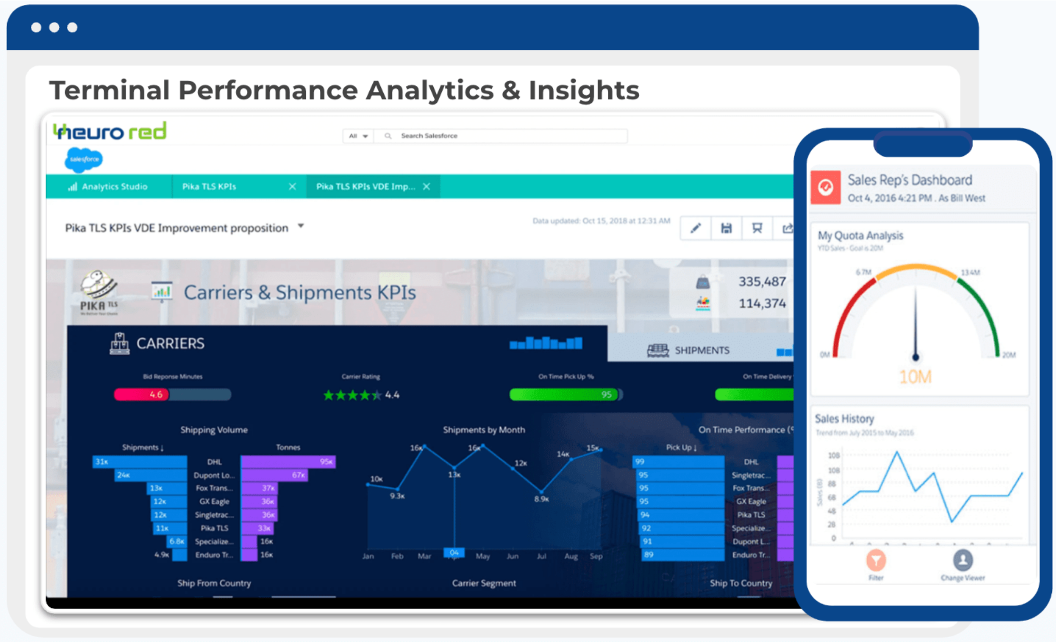
Figure 2-4: Sample SPIRE® dashboard visualisation of port KPI in the Port of Hamburg



(Source: www.spire.com)

In addition, the figure below shows the analytical part of terminal performance and insights within the Neurored ® business intelligence tool.

Figure 2-5: Illustration of the analytical aspects of the BI tool by Neurored.



Source: https://www.neurored.com/port-terminal-management-software/

BI in inland ports refers to the use of data and technology to collect, analyse, and present information that can be used to make informed decisions and improve operations within the port area. In a general case, the BI is applied in inland ports as follows:

- **Data collection**. Inland ports collect data from various sources, including sensors, IoT devices, cargo tracking systems, traffic management systems, River Information Services, security cameras and others. This data contains various information, such as that on cargo movements, vehicle traffic, cargo handling equipment traffic and their utilisation rates, security issues, etc.
- **Data integration**. BI systems integrate data from different sources, creating a unified visualisation of port operations, allowing BI system users to access a holistic picture of what is currently happening in the port.
- **Data analysis**. BI tools[39] and techniques analyse the integrated data. The results of this analysis are presented in various ways, such as reports, dashboards, and visualisations so that the trends and patterns can be identified easier.
- **Decision-making support**. The insights gained from data analysis help port authorities and operators make informed decisions in traffic management, resource allocation, berth planning, maintenance schedules, railway movement, quay cranes movement, shift production, etc.
- **Performance monitoring**. BI tools can help in performance monitoring in such way that key performance indicators (KPI) changes are visualised and managed over time. This allows port managers to keep track on KPI targets and thresholds, identify areas for improvement and take proactive or corrective measures to tackle various issues.
- **Forecasting**. BI tools can use predictive analytics to forecast future trends and demand, which can help in capacity planning, ensuring that the port is well prepared for dynamic changes on the volatile markets.
- **Customer service**. BI systems can be used to improve customer service in inland ports by providing real-time information to land transport operators, logistic companies, cargo owners, and other port stakeholders. This can improve coordination, reduce waiting times, and make various stakeholders more open to digitalisation and data sharing.

[39] For example: [Tableau](https://www.tableau.com/resource/business-intelligence) (https://www.tableau.com/resource/business-intelligence) , [Power BI](https://powerbi.microsoft.com/en-us/) (https://powerbi.microsoft.com/en-us/) and [QlikView](https://www.qlik.com/us/products/qlikview) (https://www.qlik.com/us/products/qlikview)

- **Environmental compliance and reporting**. BI tools can assist in ensuring that the port authorities and operators comply with regulatory and reporting requirements. These tools can automatically generate compliance reports and send them to the relevant authorities.

Overall, business intelligence in inland ports empowers decision-makers with data-driven insights, enabling them to optimize operations, enhance efficiency, and better serve the needs of their customers and partners in the supply chain.

2.3 Simulation technologies, virtual and augmented reality

2.3.1 Port and terminal simulation software

Simulation software plays a vital role in optimizing and improving the operations of inland ports. Inland ports are key components of the transportation and logistics network, and they face various challenges related to traffic management, cargo handling, and overall efficiency. Simulation software can be used in inland ports for the following activities:

- **Traffic management and planning**
  - *Traffic flow analysis*: Simulation software can model the movement of trucks, trains, and other vehicles within the port. It helps identify potential bottlenecks and congestion points, allowing port authorities to optimize traffic flow.
  - *Resource allocation*: By simulating various scenarios, port operators can determine the optimal allocation of resources, such as cranes, forklifts, and storage space, to minimize waiting times and increase throughput.
  - *Capacity planning*: Simulation enables inland ports to assess their capacity and plan for future growth or expansion based on projected traffic volumes.
- **Cargo handling and logistics**
  - *Loading and unloading optimisation*: By simulating cargo handling processes, ports can identify ways to optimize loading and unloading procedures, reducing turnaround times for vessels, vehicles and trains.
  - *Scheduling and planning*: Port operators can use simulation to develop efficient schedules for vessel arrivals and departures, rail services, and truck movements.
- **Infrastructure planning and maintenance**
  - *Infrastructure simulation*: Inland ports can model their infrastructure, including roads, rail tracks, storage areas, and cranes, to assess their capacity and identify areas in need of maintenance or repair.
  - *Emergency response planning*: Simulation can be used to develop emergency response plans and assess their effectiveness in various scenarios, such as accidents, natural disasters, or security incidents.
- **Environmental impact assessment**
  - *Environmental simulation*: Simulation software can help assess the environmental impact of port operations, including emissions, noise pollution, and habitat disruption.
- **Training and education**:
  - *Training simulators*: Inland port personnel can use simulation software for training purposes. Simulators can replicate real-world scenarios, helping operators and staff practice emergency response, equipment operation, and logistics procedures in a risk-free environment.
- **Cost reduction and efficiency improvement**
  - *Scenario analysis*: Ports can use simulation to assess the impact of different operational changes or investments. This helps in making informed decisions to reduce operational costs and increase efficiency.

- **Data analysis and reporting**
  - *Data visualization*: Simulation software provides visual representations of operations, making it easier to analyse data and identify trends or areas for improvement.
  - *Performance metrics*: Inland ports can use simulation to establish key performance indicators (KPIs) and measure their performance against these metrics.

The use of simulation software in inland ports is highly customizable, allowing each port to tailor its simulations to its specific needs and challenges. By utilizing simulation technology, inland ports can enhance their operational efficiency, reduce costs, improve safety, and better plan for future growth and changes in demand.

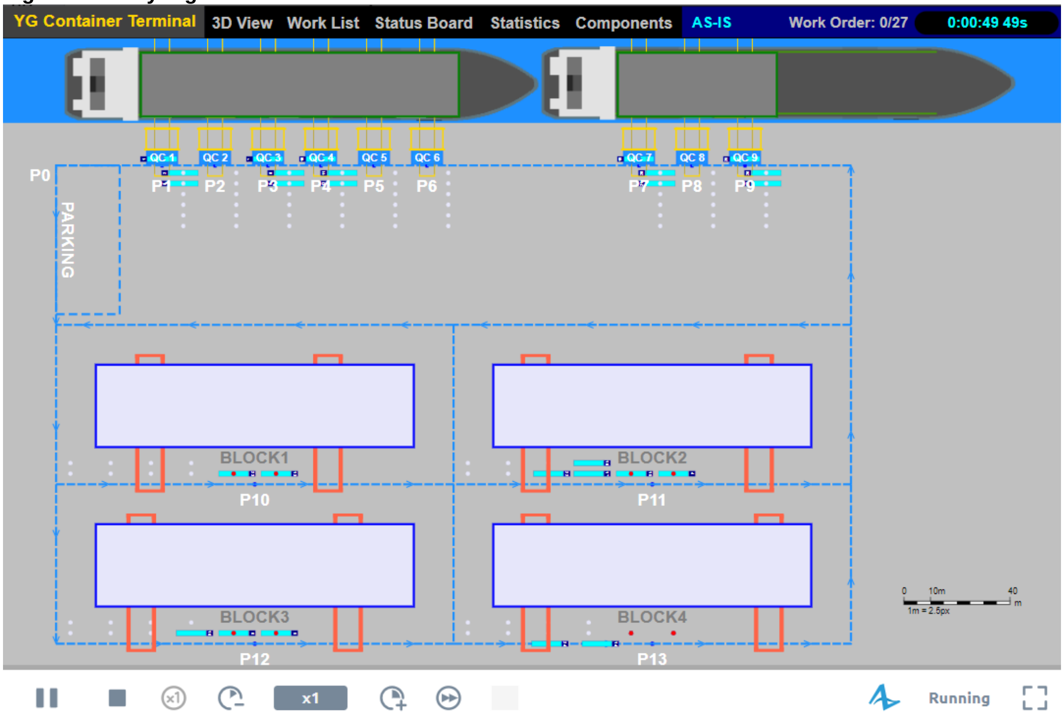
There is a vast amount of port simulation software available on the market. Some of the most popular ones are the following:

- **AnyLogic.** This is a widely used simulation tool. Apart from ports, it is used in logistics, supply chain, manufacturing industry, GIS information, emergency management, etc. It is the only commercial software that can support hybrid state machines, which can effectively describe discrete and continuous events[40]. AnyLogic is a powerful tool for cutting costs and increasing throughput at ports and container terminals. It enables deep insight and provides a risk-free environment to develop plans. Port and terminal simulation can be used for detailed internal logistics analysis, decision support, risk mitigation, and disruption response. Significant losses can be incurred through idle time and demurrage and minimizing them requires insight across all operational interactions in a port or terminal. The multimethod approach of simulation modelling with AnyLogic helps capture the true characteristics of facilities such as container terminals, including berthing, transfer, storage, multimodal transport, and staffing. Furthermore, the22ctionns of port authorities also affect environmental factors as well, including noise, gas emissions, and particulates. Capturing all such variables in a simulation model allows you to understand their relationships and answer questions such as:
  - Are straddle carrier operations causing a bottleneck?
  - What impact will increasing the number of berths have?
  - Can tank storage changes reduce transfer times?
  - How to optimize bridge crane algorithms.

  Simulation modelling helps answer questions with verifiable statistics and visual feedback. AnyLogic can capture the dynamics of business processes without compromise, including internal logistics of ports and terminals. Specific libraries cover the components of container ports, bulk cargo ports, and oil and LNG terminals, while multimodal transportation is naturally supported with the rail and road libraries. AnyLogic enables port throughput to be increased and costs to be cut, ensuring a maximum return on investments. "What-if" questions can be asked, it can develop strategies for the ongoing optimal operation of port and terminal resources. Simulation modelling with AnyLogic is an invaluable tool for container terminal and bulk port analysis and management. Using port simulation software is key to the detailed analysis and optimal operation of port facilities.

[40] Wang, W. and Peng, Y. (2022). *Port Planning and Management Simulation*. Elsevier Publishing.

Figure 2-6: AnyLogic screenshot of the container terminal model



Source: AnyLogic web page[41]

- **Arena**.[42] Arena simulation tool improves routes and timing to reduce waiting costs on vessels and trucks. Its features are the following:
  - *Streamlined port and terminal process modelling.*
    - Arena employs a modelling approach that simplifies the creation of process flows for ports and terminals, making it fast, intuitive, and easy to grasp.
    - It allows the user to swiftly construct simulations and visualize outcomes using Arena's drag-and-drop elements and structures. These features are complemented by captivating 2D and 3D animations, all achieved without the need for programming assistance.
  - *Optimisation dashboards for ports and terminals.*
    - Arena's dynamic dashboards, integrated into the system, offer essential model analyses to support the optimisation of ports and terminals.
    - Within the Arena platform, users have the flexibility to craft customized displays of model information, enhancing the overall comprehension of network operations.
  - *Common functionalities:*
    - Assess loading and unloading techniques,
    - Identify operational bottlenecks,
    - Determine facility size prerequisites,
    - Calculate warehouse capacity needs,
    - Evaluate labour force requirements.
- **FlexTerm**.[43] FlexTerm, formerly recognised as FlexSim CT, is a software solution developed and distributed by FlexSim Simulation Software Company. It stands as a pioneering commercial simulation tool meticulously tailored for container terminals. One of its standout features is the user-friendly drag-and-drop modelling approach, simplifying and expediting model creation. Within FlexTerm's rich 3D object library lies an assortment of port-specific 3D machinery, equipment, and objects. These elements can be easily integrated into 3D models,

[41] https://cloud.anylogic.com/models
[42] https://www.rockwellautomation.com/en-gb/products/software/arena-simulation/discrete-event-modeling/port-terminal.html
[43] Wang, W. and Peng, Y. (2022). *Port Planning and Management Simulation*. Elsevier Publishing.

encompassing assets such as quay cranes, RTGs, trailers, container vessels and barges, rails, straddle carriers, and more. FlexTerm's simulation model extends its capabilities to optimize every component of container terminal operations, including but not limited to:

- Enhancing throughput
- Exploring new port planning strategies
- Improving equipment utilization
- Reducing waiting times and queue lengths
- Achieving workload balance through efficient resource allocation
- Investigating alternative investment scenarios
- Examining cost reduction initiatives
- Demonstrating the implementation of new equipment

Furthermore, FlexTerm serves as a potent tool for scrutinizing container yard stacking strategies, yard layouts, gate configurations and capacities, quay crane allocations, and berth assignments. Notably, FlexTerm offers adaptable, real-time statistical data collection. It encompasses KPIs such as berth throughput, vessel queueing and waiting times, quay crane utilization rates, truck queueing and waiting times, and yard equipment utilization rates, among others.

- **Simio**.[44] Simio equips users with a comprehensive set of features and tools for the analysis of data gathered from port operations. This data encompasses critical aspects such as berthing frequency, cargo and container handling durations, and throughput. The robust 3D visualization capabilities of Simio bring port-related processes to life, allowing for the vivid representation of statistical feedback derived from simulated models. Simio empowers users to conduct intricate analytics, addressing pivotal questions related to strategy development, operational optimisation, stress test planning, and downtime reduction within ports and terminals. By applying discrete event simulation to analyse activities associated with cargo loading and unloading, Simio yields insights that are instrumental in creating optimised schedules aimed at minimizing downtime and demurrage fees, along with their unwanted consequences. Simulation modelling plays a pivotal role in capturing the complex dynamics inherent to ports that oversee multiple entities utilizing and managing their terminals. By incorporating behavioural patterns and environmental factors as variables within a simulation model, Simio facilitates an in-depth comprehension of ongoing dynamic interactions, thereby streamlining the decision-making process. Simio offers seamless support for the integration of complex variables, facilitating the creation of precise simulation models for port and terminal operations. This software streamlines the modelling procedure through its extensive library, while also enhancing analytical accuracy by enabling the integration of real-time data and historical variables. Simio's port simulation models can then be leveraged to address key management inquiries, such as:
  - Identifying bottlenecks arising from specific operations, such as straddle carrier activities.
  - Assessing the potential impact of expanding berthing infrastructure on overall port operations.
  - Evaluating how optimizing the loading and unloading processes can influence throughput, revenue, and customer satisfaction.

According to the results of the survey conducted in the summer of 2023, none of the participating ports were using simulation software for their operations and management.

2.3.2 Virtual Reality technology

Virtual reality is the term used to describe a three-dimensional, computer-generated environment which can be explored and interacted with by a person. That person becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or

[44] https://www.simio.com/applications/port-simulation-software/

perform a series of actions.[45] Virtual reality is one of the basic building blocks for the Digital Twins technologies. Inland ports can use virtual reality (VR) tools in various ways to enhance their operations, training, and decision-making processes, some of which are the following:

- **Training and simulation**. VR simulators can provide realistic training environments for operators of various cargo handling equipment.[46] Additionally, VR can be used to simulate emergency scenarios, such as fires, spills, or accidents, allowing port personnel to undergo realistic emergency response training in a safe virtual environment.
- **Port design, planning and operation**. VR can assist in the design and layout planning of port facilities. Decision-makers can visually explore different configurations and assess the efficiency and functionality of various designs before construction begins. During the operational use of the port VR simulations can model and analyse traffic flow within the port, helping to identify potential bottlenecks, congestion points, and optimal traffic management strategies. Moreover, using VR headsets and cameras, maintenance personnel can conduct remote inspections of equipment and infrastructure within the port. This allows for quick visual assessments without the need for physical presence. VR can also provide maintenance workers with virtual, step-by-step guides for equipment maintenance and repair procedures.
- **Port security and surveillance**. Port security personnel can use VR for training exercises that simulate security threats and practice response procedures. VR can enhance surveillance systems by providing a 360-degree view of critical areas within the port. Security personnel can monitor the port in real-time from a central location using VR.

Incorporating VR tools into inland port operations requires investment in hardware and software, as well as training for personnel. However, the benefits in terms of improved training, planning, safety, and decision-making can make VR a valuable asset for modernizing and optimizing inland port operations. VR tools generally do not capture real-time data or support extensive data analysis. They are more focused on creating engaging experiences. As VR technology continues to advance, its applications in the logistics and transportation industry are expected to expand further.

2.3.3 Augmented Reality technologies

Augmented reality (AR) is the integration of digital information with the user's environment in real time. Unlike virtual reality (VR), which creates a totally artificial environment, AR users experience a real-world environment with generated perceptual information overlaid on top of it.[47]

Augmented Reality overlays digital information, such as graphics, text, or 3D models, onto the physical world, typically viewed through a smartphone, tablet, head-up-displays (HUD), smart glasses, or other AR-enabled devices. Applications of AR in inland ports include, inter alia, the following activities:

- **Asset maintenance and repair**. Maintenance personnel can use AR applications to access real-time data and maintenance instructions while inspecting equipment and infrastructure within the port. AR overlays relevant information onto the physical equipment, helping technicians identify issues and perform repairs efficiently.
- **Training and assistance to starters**. AR can be used for training new employees and help them in their first tasks in port operations. Trainees and fresh starters can wear AR glasses or use mobile AR apps to receive real-time guidance and instructions as they perform tasks within the port.

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45 https://www.vrs.org.uk/virtual-reality/what-is-virtual-reality.html
46 https://flint.systems/2022/training-simulators-for-the-port-sector-why-vr/
47 https://www.techtarget.com/whatis/definition/augmented-reality-AR

- **Navigation and pathfinding**. AR can provide port workers and visitors with navigation assistance. It can display routes, points of interest, and safety information overlaid onto the real-world environment, helping individuals find their way within the port's vast and complex layout.
- **Cargo handling**. AR can assist cargo handlers by providing visual signs and instructions for loading and unloading cargo from vessels and trucks. It can improve accuracy and efficiency by guiding workers in positioning cargo containers correctly.
- **Safety training and drills**. AR can facilitate safety training and emergency response drills. Port personnel can participate in immersive AR simulations that mimic emergency scenarios, helping them practice safety procedures and responses.
- **Inventory management**. AR can aid in inventory management within the port. By scanning QR codes or using AR apps, workers can access real-time information about container contents, storage locations, and handling instructions.
- **Remote assistance**. AR enables remote experts to provide guidance and support to on-site personnel. Through AR-enabled devices, remote experts can see what on-site workers see and provide real-time assistance, troubleshooting, or advice.
- **Documentation and inspection**. AR can streamline documentation processes. Workers can use AR to access digital documentation, inspection checklists, and historical data by scanning equipment or containers, reducing the need for physical paperwork.
- **Environmental monitoring**. AR can provide real-time environmental data, such as air quality, noise levels, and weather conditions, taken over from sensors and control centres, overlaid onto the port environment. This information is valuable for monitoring and ensuring compliance with environmental regulations.

The survey of inland ports, carried out in summer of 2023, did not reveal any inland port using this technology in its day-to-day operations. However, the desk research revealed one interesting project, carried out from October 2018 to September 2021 in Germany. The project was titled Innovative applications for Augmented Reality in inland ports and seaports – InnoPortAR.[48] The project's goal was to support and optimize the work processes in inland and seaports with the help of computer-based augmented reality (AR) enhancements. The project's objectives were to test different use cases in practice, such as showing the employees in ports the additional information about their environment in the field of vision of a pair of data glasses and thus enable them to receive support for carrying out their activities.

InnoPortAR provided initial insights into the potential of AR solutions within port environments, showcasing several practical applications.[49] These AR solutions demonstrated notable benefits, including reduced error rates, time savings, elimination of media disruptions, improved documentation, and decreased mental and physical strain on employees. Additionally, they proved effective for training and instructing new or inexperienced personnel.

However, the full-scale implementation of AR solutions in ports remains limited due to ongoing hardware development and the need for adaptation to dynamic port conditions. Certain AR devices face challenges stemming from external environmental factors, space constraints, and safety regulations, making their usage difficult.

When comparing Assisted Reality and Mixed Reality solutions, it becomes evident that Mixed Reality solutions possess restricted applicability in operational settings. Concerns such as ergonomics, safety, and battery life need to be addressed. Head-mounted displays essential for

[48] https://www.cml.fraunhofer.de/en/research-projects/InnoPortAR.html

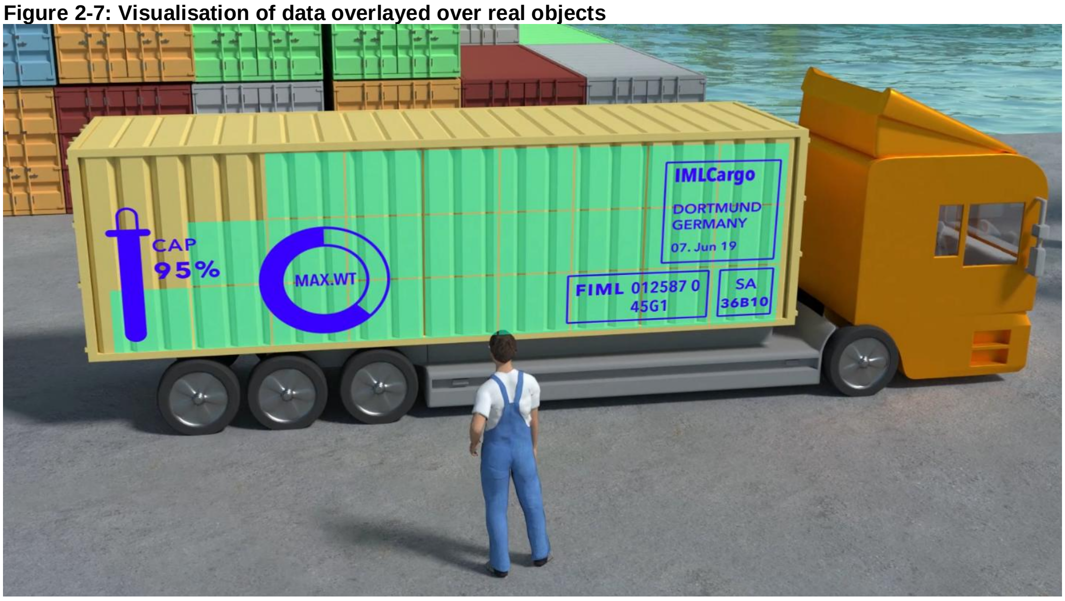
[49] Schulte-Hobein, N., Lück, I., Stweing, F.J., Klukas, A. And Lorenz, M. (2023). InnoPortAR - Innovative applications for Augmented Reality in inland ports and seaports, *IPIC 2023 9th International Physical Internet Conference*, Athens, Greece. Available at: https://repository.gatech.edu/server/api/core/bitstreams/a0086dd8-ab95-4609-9295-b2d9b42fa920/content

Mixed Reality solutions often have limited usage due to their weight and battery constraints. Furthermore, field-of-vision limitations and helmet requirements pose additional hurdles for AR solutions employing head-mounted displays. In contrast, Assisted Reality solutions find smoother implementation within port environments. The necessary hardware is often more cost-effective, and the head-mounted devices facilitating Assisted Reality experiences tend to be lighter, enabling extended usage without ergonomic concerns.

Regarding software solutions, the project revealed challenges in complex component object recognition. This difficulty stemmed from the need for algorithm optimisation and the limited computing power of AR devices at the time. In summary, software development is more straightforward when applied to standardized use cases with existing processes and documentation. Cost-effective AR solutions are most feasible when deployed to a large user base, as single-use applications tend to be prohibitively expensive. However, as AR software development and artificial intelligence advance, development costs are expected to decrease in the coming years.

In light of the positive outcomes in supporting employees, AR solutions hold promise for specific use cases within ports in the future, contingent on continued technological advancements and cost efficiencies.

Figure 2-7: Visualisation of data overlayed over real objects



Source: video still from the project clip on CML Fraunhofer web page[50]

2.3.4 Digital Twins

Defined in the widest possible sense, Digital Twin (in general) is a virtual representation of a physical facility, created thanks to the data and input from sensors, IoT devices, cameras, physical plans and drawings, and other sources. Nowadays, Digital Twin technology finds applications across numerous sectors and a wide range of products. Examples include aviation, general manufacturing, industrial design, construction, retail, energy and utilities, and healthcare, among others. The difference between the Digital Twins and Virtual Reality tools is mainly in the fact that Digital twins are not primarily focused on creating immersive experiences but rather on capturing and analysing real-time data and simulating the behaviour of the physical port, while VR tools create immersive, interactive, and often three-dimensional simulated environments. They are

[50] https://www.cml.fraunhofer.de/en/research-projects/InnoPortAR.html

primarily used for training, visualisation, and experimental purposes. VR tools allow users to step into a digital environment and interact with it, providing a realistic but simulated experience.

By integrating the realms of the virtual and the physical within the given operational environments, digital twins enable users to conduct in-depth data analysis and employ monitoring systems to proactively address issues before they manifest. Through the utilization of real-time data, simulations, and machine learning, Digital Twins empower businesses and organizations to optimize efficiencies, unearth novel prospects, and construct comprehensive simulations. In essence, Digital Twins are revolutionizing the entire process of data capture, analysis, and interpretation within organizations, resulting in more efficient and impactful decision-making.

These principles can also be extended to the realm of port operations, involving the real-time monitoring of vessels and port cranes, or even the entire port, for the purpose of optimizing overall performance. Ports across the globe have demonstrated significant enthusiasm for the idea of a Digital Twin and its potential to enhance efficiencies and boost port productivity.[51] From the point of view of its building blocks, a digital twin is not a solitary product or technology; instead, it represents the integration of various technologies, all strategically designed to assist a port in monitoring its existing assets. It can contain technologies such as sensors, Internet of Things and related devices, simulation, virtual and augmented reality, 5G networks, blockchain, machine learning, data analytics, drones, etc. For inland ports, this means capturing data from various sources, such as cargo handling equipment, vessels, vehicles, and environmental sensors, and integrating it into a comprehensive digital model.

In their daily work, inland ports face a myriad of challenges, ranging from operational efficiency to environmental sustainability. Digital Twin technology is emerging as a game-changing solution for the inland port industry, offering transformative capabilities to enhance operations, improve decision-making, and bolster competitiveness.

One of the primary benefits of Digital Twins for inland ports is the potential for significant improvements in operational efficiency. By creating a virtual replica of the port's infrastructure and operations, port authorities and operators gain unprecedented insights into how the port functions. This includes real-time tracking of cargo movements, equipment utilization, and traffic flow within the port.

Digital Twins enable the optimisation of key operational aspects:

- **Resource allocation**. Port operators can use the digital model to allocate resources more efficiently, reducing congestion, and minimising wait times for vessels and trucks.
- **Cargo handling**. Real-time tracking of cargo and container movements allows for optimised loading and unloading processes, reducing turnaround times for ships and trucks.
- **Maintenance**. Predictive maintenance can be employed to minimise downtime and extend the lifespan of critical equipment, such as cranes and conveyors.
- **Traffic management**. Simulations within the Digital Twin can help identify and alleviate traffic bottlenecks, enhancing the flow of goods in and out of the port.

Inland ports have increasingly been under scrutiny for their environmental impact. Digital Twins offer a valuable tool for addressing these concerns. Environmental sensors integrated into the digital model can monitor air and water quality, noise levels, and emissions. This data can be used to:

[51] Bills, T. (2023). The Promise and Peril of Digital Twins for Ports, Technical paper, *Port Technology International*, Edition 131. Available at: https://wpassets.porttechnology.org/wp-content/uploads/2023/05/10162532/PTI131_Esri_13-16.pdf

- **Reduce environmental footprint.** Port's overall emissions can be reduced by identifying sources of pollution and inefficiency, port operators can implement measures to reduce emissions, conserve energy, and minimize environmental impact.
- **Compliance**. Constant monitoring and reporting of environmental parameters can ensure compliance with environmental regulations and standards.

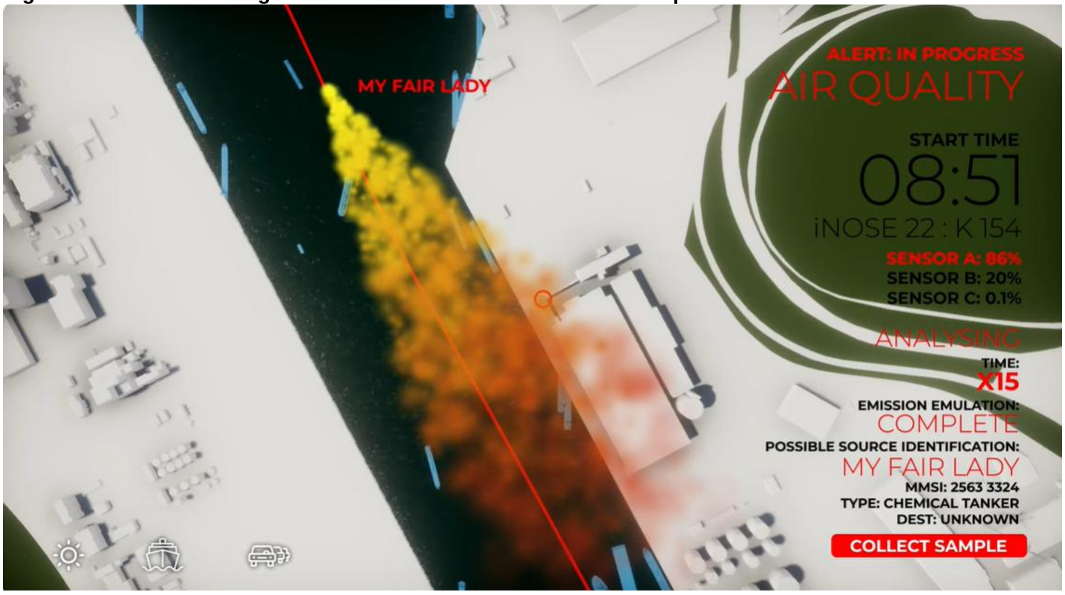
During the survey of inland ports carried out in summer of 2023, only one inland port (of those which responded to the questionnaire) reported to use the Digital Twin technology – the port of Trier in Germany.[52] With the Digital Twin technology", the Trier port company wants to take a further step towards digitalized logistics processes, benefiting from the cooperation within the "Tolkien" project.[53] The Tolkien project is based on a cooperation between the Port of Duisburg, Nautilus Log, the Fraunhofer Institute and the Port of Trier, which has received federal funding of 216,000 euros for this purpose. The Port of Trier was already involved in nationwide digitization measures with the Sinlog project. Sinlog was about completely digitising freight documents and making them available to all stakeholders in real time. The Tolkien project is about increasing the transparency of processes in inland ports by digitally mapping and modelling business processes by creating a uniform database. In the long term, logistics chains can be planned better and more effectively through digital traffic recording of rail and inland waterway vessels to accelerate a noticeable CO_2 reduction. The project phase started on 1 July and is expected to be completed by 30 June 2025. "Tolkien" is initiated as part of the funding program for innovative port technologies (IHATEC), with which the Federal Ministry for Digitalisation and Transport (Bundesministerium für Digitales und Verkehr (BMDV)) supports research and development projects that contribute to the development or adaptation of innovative technologies in German sea and inland ports.

One of the fully functional Digital Twins for ports is the one used in the Port of Antwerp, for both sea and inland parts of the port. The system used is called APICA, which stands for Antwerp Port Information & Control Assistant. This virtual assistant connects the inputs from smart cameras, drones, and various sensors monitoring air and water quality, seamlessly integrating this data into a Digital Twin model of the port. APICA delivers real-time updates on ship movements, hazardous cargo flows, air quality, weather conditions, and even detects oil spills while performing inspections of port infrastructure and water surfaces. As data science is applied to the wealth of information within APICA, it evolved into a predictive and prescriptive tool over time.

[52] https://www.hafen-trier.de/en/homepage/

[53] https://www.schifffahrtundtechnik.de/nachrichten/binnenschifffahrt/digitalisierung-hafen-trier-erhaelt-foerder-zuschlag-fuer-projekt-tolkien-3206927

Figure 2-8: View of the Digital Twin tool used in the Port of Antwerp



Source: video screenshot from the Wim Wouters' web page[54]

2.4 Platforms and software based tools

2.4.1 Port Community Systems

A Port Community System (PCS) is an electronic platform which connects the multiple systems operated by a variety of organisations that make up a seaport, airport, or inland port community. It is shared in the sense that it is set up, organised and used by stakeholders in the same sector – in this case, a port community.[55] In addition, it is a neutral and open electronic platform enabling intelligent and secure exchange of information between public and private stakeholders in order to improve the competitive position of the ports' communities.[56] PCS enables creating a network composed of shipping agents, shippers, freight forwarders, transporters, terminals, logistics platforms, and public entities. PCS focuses on service level, partner networks, vessel services, freight services, logistical services, and advanced port services.[57]

54 https://www.wimwouters.com/blog/port-of-antwerp-digital-twin/

55 IPCSA (2015). *How to develop a Port Community System*, IPCSA Guide. Available at: https://ipcsa.international/wp-content/uploads/2020/07/ipcsa-guide-english-2015.pdf

56 Long, A. (2016). Port Community Systems Role in Enhancing the Efficiency of European Ports, *European Sea Ports Organisation (ESPO) Conference*, Dublin. Available at: https://www.assoporti.it/media/1201/4_ipcsa-alan-long.pdf

57 Caldeirinha, V., Nabais, J.L., Pinto, C. (2022). Port Community Systems: Accelerating the Transition of Seaports toward the Physical Internet—The Portuguese Case. *Journal of Marine Science and Engineering*, 10(2). Available at: https://doi.org/10.3390/jmse10020152

Figure 2-9: Port Community System

Source: Port Economics, Management and Policy[58]

Typical features of a Port Community System include, but are not limited to:

- **Information sharing**. A PCS facilitates real-time information sharing and communication among all parties involved in port operations. It acts as a single point of access for stakeholders to exchange data, documents, and messages related to cargo handling, customs clearance, and other logistical processes.
- **Cargo tracking**. The system allows for the tracking and monitoring of cargo movements within the port, providing visibility into the location and status of shipments. This helps in better planning and coordination of cargo handling activities.
- **Customs integration**. PCS platforms often integrate with customs authorities, enabling electronic submission and processing of customs declarations and documentation. This integration streamlines the clearance process and reduces paperwork.
- **Booking and reservations**. Users can make bookings for port services, such as vessel berths, container storage, and truck appointments, through the PCS. This helps in optimizing resource allocation and reducing congestion.
- **Document management**. PCS platforms facilitate the electronic storage and retrieval of documents, including bills of lading, invoices, and certificates. This reduces the reliance on paper-based documentation and simplifies record-keeping.
- **Security and compliance**. PCS systems often include security features to protect sensitive data and ensure compliance with regulatory requirements. Access to certain information and functionalities may be restricted based on user roles and permissions.
- **Billing and invoicing**. The system can automate billing and invoicing processes, generating invoices based on actual port services rendered. This streamlines financial transactions and reduces billing errors.
- **Performance analytics**. PCS platforms provide data analytics and reporting tools that offer insights into port performance, including cargo throughput, turnaround times, and efficiency metrics. This data supports informed decision-making and process optimisation.
- **Community collaboration**. A PCS fosters collaboration and information sharing among all stakeholders in the port community. It helps in resolving disputes, addressing operational challenges, and improving overall port efficiency.

[58] Notteboom, T., Athanasios, P. and Rodrigue, J.P. (2022). *Port Economics, Management and Policy*, New York: Routledge. Available at: https://doi.org/10.4324/9780429318184

- **Real-time notifications**. Users receive real-time notifications and alerts regarding critical events, such as vessel arrivals, customs clearances, and cargo releases. This ensures timely responses to changing circumstances.
- **Scalability**. PCS systems are designed to accommodate the growth and evolving needs of inland ports and their communities. They can adapt to handle increasing cargo volumes and expanding services.

A Port Community System offers a highly valuable capability by automating the extraction of necessary data, such as the Customs manifest, from private port operators' information exchanges. This extracted data can then be seamlessly transmitted to Customs authorities without the need for additional manual intervention. While Port Community Systems typically operate with their internal standards, they establish connectivity with other Port Community Systems and Trade Communities through internationally recognised standards, notably those crafted by UNECE-UN/CEFACT.[59]

Implementing a Port Community System in an inland port can significantly enhance efficiency, transparency, and competitiveness. It streamlines operations, reduces paperwork, minimizes delays, and improves the overall user experience for all stakeholders involved in port-related activities.

There is a large number of Port Community System software developers and manufacturers in Europe. For example, the French public company Compagnie Nationale du Rhône[60], acting as an inland port authority for the ports on the Rhône River, uses a Ci5 Port Community System[61], developed by company MGI. Ci5 is an intelligent PCS dedicated to the management of the flow of goods which delivers fluidity, traceability, security and competitiveness for all terminals in order to create an ever-more efficient supply-chain. By integrating new technologies and innovations from Big Data, IoT, Artificial Intelligence, smart container and blockchain to name a few, Ci5 allows better control and management of supply chains. Ci5 represents the next generation of Ports Community System for a more efficient supply chain. It ensures increased operational productivity through features such as personalized interfaces, user-friendly input methods, and simplified data retrieval. With access to real-time information, participants in the supply chain can proactively strategize and organize all land and maritime activities in advance of a vessel's arrival or departure, as well as for other transport modes. For instance, utilizing the Ci5 mobile application, the entry of carriers at the gate is systematically documented, while truck drivers swiftly input container and seal numbers. This streamlined process significantly minimizes data transmission times and expedites the movement of goods.[62]

Port Community System can also be considered a type of *multimodal collaboration platform*, although its primary focus is on facilitating collaboration and information exchange within the waterborne transport and port logistics sector. PCSs are typically designed to connect various stakeholders involved in port and maritime operations, enabling efficient communication, data sharing, and coordination among these parties. While the core function of a PCS revolves around port-related activities, it often interacts with other transportation modes and supply chain participants, making it a valuable component of multimodal logistics.
The following features of a PCS give it characteristics of a multimodal collaboration platform:

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59 https://tfig.unece.org/contents/unece-uncefact-recommendations.htm

60 https://www.cnr.tm.fr/en/

61 https://www.mgi-ci5.com/en/solution/ci5/

62 PT Team (2021). Ci5 and OSCAR system fully interoperable with MGI and TGI collaboration. Article in *Port Technology International*. Available at: https://www.porttechnology.org/news/ci5-and-oscar-system-fully-interoperable-with-mgi-and-tgi-collaboration/

- **Connectivity across modes**. A PCS serves as a central hub for stakeholders such as shippers, freight forwarders, customs authorities, terminal operators, shipping lines, and transport companies. It facilitates communication and data exchange for activities within the port, but it also accommodates the flow of information related to various transportation modes, including road, rail, and inland waterways.
- **Integration with transport modes**. Many PCSs are designed to integrate with other transportation management systems, including road and rail logistics. This allows for the seamless exchange of information, such as booking cargo for multiple modes of transport within a single platform.
- **Intermodal capabilities**. Inland ports often serve as key hubs where cargo is transferred between different transport modes. A PCS used by an inland port can support these intermodal activities, ensuring that cargo flows smoothly between road, rail, and waterborne transport.
- **Data sharing**. PCSs support data sharing related to cargo movements, customs documentation, vessel schedules, and more. This information can be essential for multimodal transport planning and execution.
- **Supply chain visibility**. A PCS contributes to supply chain visibility, which is crucial for multimodal logistics. Stakeholders can track cargo from its origin to destination, even when it involves multiple transport modes.
- **Environmental considerations**. The collaboration facilitated by a PCS often extends to sustainability initiatives, such as optimising transport routes and reducing environmental impacts. This aligns with the goals of multimodal logistics to enhance efficiency and minimise environmental effects.

While PCSs primarily serve the waterborne transport and port sectors, they play a pivotal role in multimodal transportation by fostering collaboration, data sharing, and coordination among various transport stakeholders. This interconnection is vital for the efficient movement of goods across different modes of transport in the broader supply chain.

2.4.2 Port management systems

Port management system (PMS), also referred to as port management information system (PMIS), is a comprehensive software solution designed to manage and optimize the operations of a seaport or inland port. It serves as a central platform that provides oversight, coordination, and control of various activities within the port environment. The primary goal of a Port Management System is to enhance the efficiency, safety, and overall performance of port operations. It needs to be distinguished from a Terminal Operating System (TOS), whose functions are to manage the operations of a single terminal within a port, such as a container terminal, bulk terminal, or general cargo terminal and to optimise and automate terminal-specific processes, such as container handling, gate operations, and yard management.

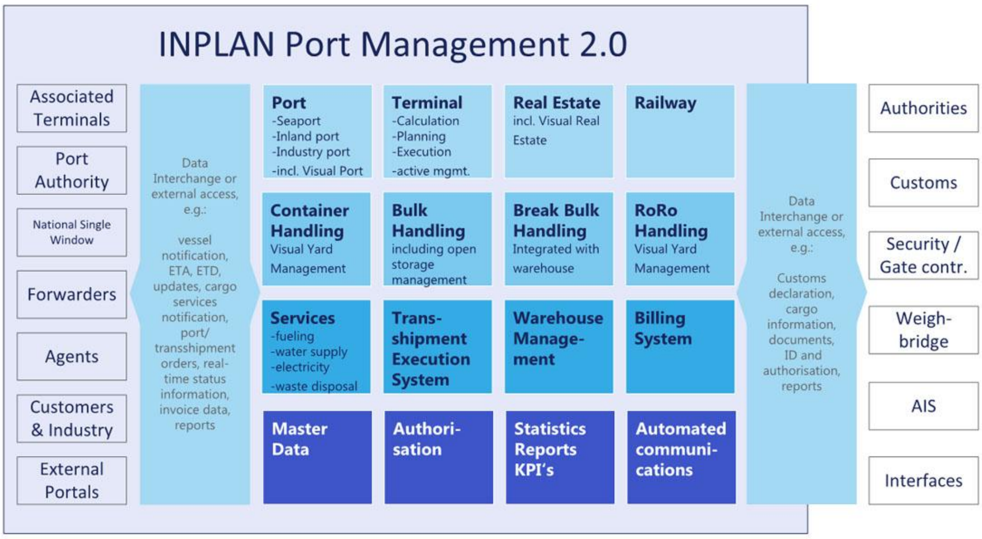
PMS can be very useful for the following aspects of port management:

- **Resource allocation**. PMS helps allocate and manage critical port resources, such as berths, quay cranes, yard space, and equipment, to ensure efficient and optimal utilization. It optimizes the allocation of these resources based on vessel schedules, cargo volume, and other factors.
- **Traffic management**. It manages the flow of traffic within the port, including the entry and exit of trucks, cargo, and personnel. PMS may include gate management systems to streamline entry procedures and reduce congestion at port entrances.
- **Vessel traffic management**. PMS tracks and manages vessel movements, including arrival and departure schedules, berthing assignments, and cargo handling operations. It ensures safe and efficient vessel traffic flow within the port.

- **Yard management**. The system optimizes the layout and utilization of container yards, including the stacking and retrieval of containers. It helps minimize yard congestion and ensures timely retrieval of containers for transportation.
- **Cargo tracking**. PMS provides real-time visibility into cargo movements, allowing stakeholders to monitor the location and status of cargo containers as they move through the port. This information enhances cargo tracking and improves logistics planning.
- **Integration**. PMS often integrates with other systems within the port, such as Terminal Operating Systems (TOS), Customs systems, PCS, security systems, and financial systems. This integration streamlines data exchange and ensures seamless coordination.
- **Security and safety**. PMS includes security features to monitor and control access to sensitive areas within the port. It also assists in managing safety protocols and emergency response procedures.
- **Documentation and reporting**. The system facilitates digital documentation and reporting, reducing the reliance on paper-based records. It generates reports on port activities, performance metrics, and compliance with regulations.
- **Environmental monitoring**. Some PMS solutions include environmental monitoring features to track and manage environmental factors within the port, such as air quality, noise levels, and emissions.
- **User access control**. PMS provides role-based access control to ensure that authorized personnel have access to specific functionalities and data while maintaining data security.
- **Data analytics**. PMS often includes data analytics capabilities, allowing port authorities and stakeholders to analyse operational data, identify trends, and make informed decisions for process optimisation.
- **Scalability**. Port Management Systems are designed to scale and adapt to the changing needs of a port as it grows and evolves over time.

One of the many software solutions used as Port Management Systems in inland ports in Europe is INPLAN Port Management 2.0.[63]

Figure 2-10: INPLAN Port Management modules



Source: INPLAN[64]

The scope of the software solution of INPLAN Port Management 2.0 can vary, encompassing relatively straightforward core systems or expanding to encompass intricate operations that involve

[63] https://www.inplan.de//software.php?page=Overview&module=2

[64] Ibid.

service delivery, cargo handling, warehousing, and billing processes. It is important to note that INPLAN modules function as discrete components, affording flexibility in project customization. Thus, projects can be tailored to specific areas of business, with the option to introduce additional processes at later stages of port development, omit processes that are unnecessary, or integrate with existing systems. In cases where integration is required, interfaces facilitate seamless data exchange between INPLAN and third-party systems.

INPLAN's adaptability is further underscored by its ability to accommodate diverse technical procedures for the same business process, thanks to a multitude of configurable parameters. This versatility obviates the need for custom software development for individual cases. Furthermore, the standard software undergoes continuous improvement, with enhancements regularly provided as part of the maintenance agreement. Ongoing development efforts include rigorous testing to ensure compatibility with new operating system releases, browsers, and mobile applications, ensuring the software remains up to date and functional.

2.4.3 Terminal planning and operating systems

Terminal Planning and Operating Systems (TOS) are specialized software solutions designed to manage and optimize the operations of container terminals, multipurpose terminals, general and break-bulk cargo terminals, bulk terminals, intermodal facilities, and other logistics hubs. These systems are crucial for ensuring efficient cargo handling, maximizing terminal productivity, and enhancing overall operational performance.[65] TOS uses all available data inputs from various sensors, IoT devices, big data analytics and other digitalisation technologies combined with the purpose of managing and optimising operations in port terminals.

Although the planning and operating components of a TOS are very closely interrelated, they can be divided in the following way:

Table 2-1: Planning components (modules) of a Terminal Operating System

Port activity	Planning component
Resource allocation	TOS helps allocate critical terminal resources, including berths, quay cranes, yard space, and equipment, to ensure efficient utilization. It optimizes resource allocation based on vessel schedules, cargo volume, and other operational parameters.
Vessel scheduling	TOS manages vessel scheduling, ensuring the efficient berthing and departure of ships. It coordinates vessel arrivals, departures, and cargo handling activities to minimize turnaround times.
Yard management	The system optimizes the layout and utilization of container yards, including the stacking and retrieval of containers. It provides real-time visibility into yard operations and container locations.
Gate operations	TOS automates gate activities, including truck registration, appointment scheduling, and container verification. This streamlines the entry and exit of trucks and reduces congestion at terminal gates.
Cargo handling	TOS oversees cargo handling processes, including the loading and unloading of containers from vessels and the movement of containers within the terminal. It manages the operation of quay cranes, straddle carriers, and other equipment.

[65] https://www.altexsoft.com/blog/terminal-operating-system/

Port activity	Planning component
Equipment control	The system controls and monitors the operation of terminal equipment, ensuring that cranes, forklifts, and other machinery operate efficiently and safely.

Source: Consortium

Table 2-2: Operating components (modules) of a Terminal Operating System

Port activity	Operating component
Real-time monitoring	TOS provides real-time visibility into terminal operations, allowing terminal operators to monitor the status of vessels, equipment, and cargo movements. This information helps in making timely decisions and responding to operational challenges.
Documentation and reporting	TOS facilitates the digital documentation of cargo movements and generates reports on key performance metrics. It reduces paperwork and enhances record-keeping.
Integration	TOS often integrates with other systems within the port or logistics ecosystem, including Port Community Systems (PCS), customs systems, and logistics management platforms. Integration ensures seamless data exchange and coordination with external stakeholders.
Safety and security	The system includes security features to monitor access to sensitive areas within the terminal. It also supports safety protocols and emergency response procedures.
User access control	TOS provides role-based access control to ensure that authorized personnel have access to specific functionalities and data. This enhances data security.
Billing and invoicing	Some TOS solutions offer billing and invoicing capabilities, automating the generation of invoices based on actual services rendered at the terminal.
Environmental monitoring	In some cases, TOS may include environmental monitoring features to track and manage environmental factors within the terminal, such as emissions and noise levels.

Source: Consortium

The TOS market is currently a “target rich environment”, meaning that there is a vast number of TOS providers and solutions available. Below are the most popular (based on the desk research) providers and their products:

Table 2-3: Example of TOS solutions

TOS provider + product	Cargo type	Basic features
iPortman TOS	Containers	Provides an all-in-one solution for vessel operation, loading or unloading operations, yard operation, gate operations and billing operations. Helps in effective planning – be it related to the vessel, yard, truck, rail or loading or unloading.
iPortman General cargo	General cargo	Handles loading/unloading and lighterage operation for bulk and break-bulk projects. Monitoring and improving berth occupancy, berth utilization, reducing vessels’ turnaround time, equipment utilization and crew utilization. Monitors stack utilization, equipment utilization, vacant and occupied properties, gross land/area that can be let out, land capacity.
Navis Master Terminal	Containers, general cargo,	Solves the complex problem of managing a variety of general cargo including bulk, break bulk, project cargo, RORO (Roll-

TOS provider + product	Cargo type	Basic features
	project cargo, bulk cargo, project cargo	On/Roll-Off), and container cargo. Deals with shipments made up of various components that need disassembly for shipment and reassembly after delivery.
Cargoes TOS+ Cargoes GC+	Containers General cargo	Terminal Operating System software and related solutions, with support for automation and micro-level job optimisation. General cargo digitalisation and operations solution, with custom mobile application, yard utilisation management, etc.
LogStar TOS	Containers, General cargo	Delay Recording, Manifest Processing, Auction Process, Container & Cargo Management, Booking Management, Warehouse Planning and Execution, Yard Planning & Execution, Resource Planning & Execution, Gate Planning and Execution, In Terminal CFS Operations
TBA Autostore TOS CommTrac	Containers, General cargo	Fully customisable or off-the-shelf for all types of coastal, inland or river terminals. Extensive suite of mobile field apps for use on strengthened personal devices. Seamless integration with CommTrac bulk and breakbulk TOS solution for multi-purpose terminals. Integrates terminal data across management, planning, supervision, operations, finance and your customers for improved decision-making.
TCS DynaPORT	Containers	Architecture is designed to provide terminal specific configurable solutions for manual, semi-automated & fully automated terminals. Provides dynamic response to meet real- time operational requirements.
INPLAN TOS	All cargo	Covers different transport modes, storage and warehouse management, handling of call-off goods, performance management, sales support and billing processes.

Source: Consortium, based on desk-research and providers' web pages

Overall, Terminal Planning and Operating Systems are critical tools for managing the complex and dynamic operations of cargo terminals and logistics facilities. They help optimize resource utilization, improve efficiency, enhance cargo visibility, and ensure the smooth flow of goods through the supply chain.

2.4.4 Land traffic management in ports

Land Traffic Management Systems (LTMS) are closely related to Port Management Systems and Terminal Operating Systems, but they have a specific focus on managing and optimizing land-based traffic within port areas. Here are some more specific aspects of LTMS in the context of land traffic management:

- **Gate operations optimisation**. LTMS streamlines gate processes, including vehicle registration, security checks, and documentation verification, to minimize truck waiting times at the entrance and exit gates.
- **Appointment scheduling**. The system allows for the scheduling of appointments for truck arrivals and departures, helping to balance the flow of traffic and reduce congestion during peak hours.

- **Queue management**. LTMS efficiently manages and optimizes truck queues at gate entrances and container yards, ensuring that trucks are processed in an orderly manner and that wait times are minimized.
- **Traffic routing**. LTMS provides real-time traffic routing guidance for trucks within the port area, optimizing routes to and from terminal facilities, container yards, and other relevant destinations.
- **Truck tracking**. The system offers real-time tracking and monitoring of trucks within the port, enabling port authorities to have visibility into the location and status of each vehicle.
- **Yard allocation**. LTMS assists in the allocation of yard space for container storage and retrieval, ensuring that containers are handled efficiently and reducing congestion in the yard.
- **Safety and compliance**. The system supports safety and compliance measures by monitoring vehicle speeds, enforcing safety regulations, and ensuring that trucks adhere to port-specific rules and guidelines.
- **Communication and alerts**. LTMS facilitates communication between the port and trucking companies, providing notifications and alerts related to gate processes, appointments, traffic conditions, and safety protocols.
- **Reporting and analytics**. The system generates reports and provides analytics on traffic patterns, queue lengths, gate wait times, and other key performance metrics to help port authorities make data-driven decisions.
- **Integration**. LTMS can integrate with other port systems, including PMS and TOS, to ensure seamless coordination between land traffic management and terminal operations.
- **Environmental monitoring**. Some LTMS solutions include environmental monitoring features to track and manage emissions, noise levels, and other environmental factors specifically related to land-based traffic within the port.
- **User access control**. LTMS provides role-based access control to restrict access to sensitive areas, functions, and data within the system, ensuring security and compliance.

In summary, while LTMS shares some similarities with PMS and TOS, it is tailored to the specific challenges and requirements of managing land-based traffic flows within port areas. Its primary goal is to optimize the movement of trucks, cargo, and personnel on the road network within the port to improve efficiency, reduce congestion, enhance safety, and ensure smooth traffic flow.

There are many commercially available LTMS solutions, such as SMATS iNode[66], Access Time[67] or Terminal Tracker[68], offering various approaches to solutions for port traffic management for trucks in the port area. The SMATS hardware and software solution provide greater visibility to the port's truck activities with various performance measures for operational and long-term planning, as well as decision-making.

2.4.5 Vessel traffic management

Vessel Traffic Management System (VTMS) is designed to effectively manage vessel traffic in ports, harbours, and coastal areas. It provides tools for a coordinated, global approach to maritime traffic control, monitoring and decision support. When VTMS platforms are designed specifically for inland ports they have a critical role in managing vessel movements and ensuring the safety and efficiency of waterborne traffic within inland waterways, rivers, and canals. These software solutions are tailored to the unique needs and challenges of inland port operations and are used primarily in very large inland or maritime-inland ports.

Some key functionalities and aspects of VTMS for inland ports:

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[66] https://www.smatstraffic.com/use-cases/port-traffic-management/
[67] https://serveis.portdebarcelona.cat/tempsacces
[68] https://www.identecsolutions.com/truck-management-terminal-tracker-module

- **Vessel tracking**. VTMS provides real-time tracking and monitoring of vessels within inland waterways. It uses Automatic Identification System (AIS) data, radar systems, and other technologies to track vessel positions, speeds, and routes.
- **Traffic monitoring**. The software assists in monitoring vessel traffic, including the identification of congestion points and potential safety hazards. It helps prevent collisions and ensures the smooth flow of traffic.
- **Safety alerts**. VTMS generates safety alerts and notifications to warn vessels about adverse conditions, low water levels, navigational hazards, or other safety concerns within the inland waterways.
- **Navigation assistance**. VTMS offers navigation assistance to vessels, including route planning, guidance on safe passage, and real-time information on water levels, currents, and weather conditions.
- **Port entry and exit management**. The software manages the entry and exit of vessels into and out of the inland port, including scheduling and coordination to prevent congestion at locks, bridges, and narrow waterways.
- **Communication**. VTMS facilitates communication between vessel operators, port authorities, and other stakeholders. It enables the exchange of messages, notifications, and requests for assistance.
- **Data logging**. VTMS records and logs vessel movements, incidents, and navigation data for analysis, reporting, and compliance with regulations.
- **Integration**. The software can integrate with other port management systems, such as Port Community Systems (PCS) and Port Management Systems (PMS), to ensure seamless coordination between waterborne and land-based operations.
- **User access control**. VTMS provides role-based access control to restrict access to sensitive data and functions within the system.
- **Reporting and analysis**. The software generates reports and provides data analysis capabilities to monitor traffic patterns, incidents, and operational performance. This data-driven insight informs decision-making and safety improvements.
- **Emergency response**. VTMS supports emergency response procedures by providing tools for rapid communication, incident management, and coordination with relevant authorities.

VTMS for inland ports is essential for enhancing the safety and efficiency of vessel traffic in inland waterways, particularly in areas with high traffic density or challenging navigational conditions, such as narrow entrances to port basins. It helps prevent accidents, optimize traffic flow, and ensure the overall effectiveness of inland port operations.

2.4.6 Booking applications

Booking applications in ports primarily refer to Vehicle Booking Systems. A Vehicle Booking System (VBS) in ports is a software solution or platform designed to manage and optimize the scheduling and coordination of truck movements within the port area. It provides a systematic approach to the allocation of time slots or appointments for trucks arriving at or departing from the port. VBS is particularly important in busy ports with high volumes of truck traffic, as it helps prevent congestion, reduces wait times, enhances efficiency, and improves overall port operations.

Key features and functionalities of a Vehicle Booking System in ports are listed in continuation:[69]

[69] https://www.altexsoft.com/blog/vehicle-booking-system/

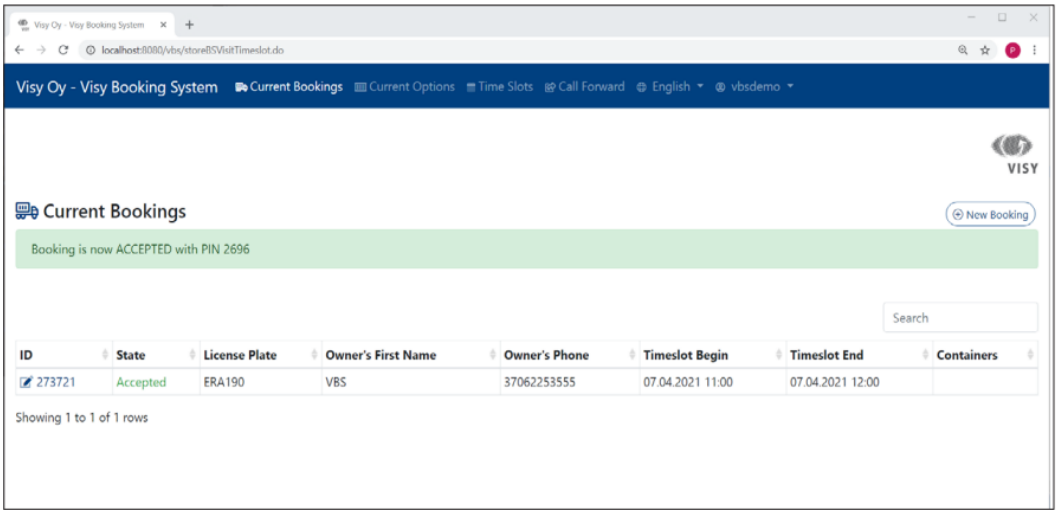
- **Appointment scheduling**. VBS allows trucking companies, freight forwarders, and other stakeholders to schedule appointments for the pick-up or drop-off of cargo at the port. Appointments are allocated based on available time slots, vessel schedules, and other operational parameters. When a trucking company (haulier) requires access to the terminal, they initiate the process by reserving an available time slot well in advance, typically 24 hours or more before the intended arrival. During this booking process, the carrier provides essential vehicle information and container details. It is important to note that without a confirmed appointment, automated ports and terminals will not grant entry to the vehicle.
- **Time slot allocation**. The system allocates specific time slots to trucks, specifying the exact arrival or departure times. This ensures a planned and organized flow of trucks throughout the day and reduces congestion.
- **Arrival verification**. Upon the vehicle's arrival at the terminal, the gate staff or an automated system conducts a thorough verification process. This step involves validating the vehicle's details against the pre-registered information provided during the scheduling phase. Some advanced systems may also verify the driver's identity through methods such as identification document (ID) scanning or biometric checks. After successful verification, the vehicle is directed to the appropriate berth, warehouse, or container depot for the loading or unloading of cargo.
- **Capacity management**. VBS monitors the capacity of various port facilities, including gate entrances, container yards, and terminal resources. It prevents overbooking and helps optimize resource utilization. By streamlining operations and managing vehicle movements, a VBS increases the overall throughput capacity of the terminal.
- **Queue management**. The system manages truck queues at gate entrances and other key locations within the port. It assigns priority based on appointment times and minimizes truck wait times.
- **Communication**. VBS facilitates communication between the port and trucking companies. It sends notifications and alerts related to appointments, gate processes, and traffic conditions, ensuring transparency and coordination.
- **Gate operations**. VBS streamlines gate processes, including truck registration, documentation verification, and security checks. It reduces congestion at gate entrances and enhances security.
- **Reporting and analytics**. The system generates reports and provides data analytics capabilities to monitor appointment adherence, queue lengths, gate wait times, and overall performance. This data-driven insight supports decision-making and process improvements.
- **Integration**. VBS often integrates with other port management systems, such as Terminal Operating Systems (TOS), Port Community Systems (PCS), and Land Traffic Management Systems (LTMS), to ensure seamless coordination between truck scheduling and terminal operations.
- **User access control**. VBS provides role-based access control to restrict access to specific functionalities and data within the system, enhancing data security.
- **Compliance**. Some VBS solutions include compliance features, ensuring that trucks meet regulatory requirements and adhere to port-specific rules and guidelines.
- **Emissions reduction**. It contributes to reducing emissions by minimising truck idling times and optimising traffic flow.
- **Billing and invoicing**. The carrier is invoiced for the booked appointments, typically on a monthly or spot basis. This billing process ensures that the terminal's services are appropriately compensated.

Hauling companies and truck drivers also gain advantages from VBS implementation. It allows them to better plan their operations, reduce waiting times, save fuel, and optimize their schedules, as they no longer need to idle in long queues at terminal gates.

Overall, a Vehicle Booking System in ports serves as a critical tool for managing truck traffic and appointments, improving operational efficiency, and enhancing the overall logistics flow within the port. It benefits both port authorities and the trucking industry by reducing wait times, minimizing congestion, and optimizing resource utilization. Vehicle Booking System not only facilitates the efficient scheduling and management of incoming and outgoing traffic but also plays a vital role in other terminal operations, including gate procedures, billing, data collection, and more.

Several providers offer off-the-shelf VBS solutions suitable for container terminals, including companies like Visy[70] Certus[71], Camco,[72] and 1-Stop[73]. Nevertheless, many modern cargo facilities choose to develop customized VBS solutions tailored to their specific operational requirements.

Figure 2-11: Visual interface of a typical VBS tool



Source: Visy[74]

2.4.7 Gate operating systems

Gate Operating Systems (GOS) in inland ports are software and hardware solutions designed to streamline and manage the flow of traffic at the entry and exit gates of a port or terminal. These systems play a crucial role in enhancing security, efficiency, and data accuracy within the port's gate operations. Important features of gate operating systems in inland ports are the following:

- **Traffic management**. GOS efficiently manage the flow of vehicles, including trucks, containers, and other transport modes, at the port's entry and exit points. They prioritize the scheduling and tracking of incoming and outgoing traffic to prevent congestion and minimize wait times.
- **Appointment scheduling**. Many GOS allow for appointment scheduling, enabling carriers to book specific time slots for arrivals and departures. This feature helps distribute traffic evenly throughout the day and reduces bottlenecks at the gate.
- **Automated vehicle identification**. GOS use various technologies, such as RFID (Radio-Frequency Identification) tags, license plate recognition, or biometric authentication, to automatically identify vehicles and drivers. This reduces the need for manual checks and speeds up the entry process.

[70] https://www.visy.fi/product/vehicle-booking-system/
[71] https://certusautomation.com/vbs-lms/
[72] https://www.camco.be/products/truck-appointment-system/
[73] https://www.1-stop.biz/operations/vehicle-booking-system/
[74] https://www.visy.fi/wp-content/uploads/2021/08/Vehicle-Booking-System.pdf

- **Access control**. Gate operating systems enforce access control by verifying the authorization of each vehicle and driver. Only vehicles with valid appointments or proper credentials are granted access to the port.
- **Security checks**. GOS often include security checks, such as scanning for hazardous materials, contraband, or illegal goods. Advanced systems may use X-ray scanners and other technologies for thorough inspections.
- **Documentation verification**. These systems verify the accuracy of documentation, including bills of lading, shipping manifests, and permits. Any discrepancies or missing documentation can trigger alerts for further inspection.
- **Integration with port systems**. GOS are typically integrated with other port management systems, such as Terminal Operating Systems (TOS) and Port Community Systems (PCS). This integration ensures seamless data exchange and coordination across various port functions.
- **Data capture and reporting**. GOS capture real-time data on vehicle movements, gate transactions, and security events. This data is essential for reporting, analysis, and compliance monitoring.
- **Billing and invoicing**. Some gate operating systems calculate fees and charges for services like gate access, security checks, and demurrage. Invoices can be generated and sent to carriers or stakeholders as needed.
- **Vehicle and cargo tracking**. These systems often include features for tracking the movement of vehicles and cargo within the port area. This information helps port authorities and operators maintain visibility and control over their assets.
- **User interfaces**. Gate operating systems provide user-friendly interfaces for gate staff, carriers, and drivers to input or access relevant information. This can include self-service kiosks for drivers to complete check-in procedures.
- **Scalability**. GOS are designed to handle varying levels of traffic, making them scalable to accommodate the needs of both small and large inland ports.
- **Environmental benefits**. GOS streamline the entry and exit of trucks and other vehicles in the port. By minimising waiting times and queues, idling times are reduced, leading to lower fuel consumption and emissions. These systems provide real-time data on gate operations and vehicle movements. Port authorities can use this data to identify bottlenecks, inefficiencies, and areas for improvement. This data-driven approach supports environmental management by allowing the port to take action to minimise negative impacts on the environment.

Inland ports rely on gate operating systems to ensure the smooth and secure entry and exit of vehicles and cargo. These systems enhance operational efficiency, reduce wait times, improve security, and provide accurate data for decision-making. By streamlining gate operations, inland ports can optimize their overall performance and contribute to a more efficient supply chain.

There are many providers of GOS, such as Visy[75], Certus Automation[76] and others.

2.4.8 Asset management systems

These systems, often referred to as Port Asset Management Systems (PAMS), are tailored to the needs of port authorities and terminal operators for efficiently managing and maintaining their diverse range of assets of value, including infrastructure, equipment, and facilities.

These systems have the following benefits and functionalities:

[75] https://www.visy.fi/product/visy-gate-operating-system/
[76] https://certusautomation.com/gate-operating-system/

- **Asset inventory**. PAMS provides a centralized database of all assets within the port, including equipment, buildings, berths, cranes, vehicles, and more. It records asset details, specifications, maintenance history, and location information.
- **Maintenance scheduling**. The system allows for the scheduling of routine maintenance, inspections, and repairs for each asset. Maintenance tasks can be automatically generated based on predefined criteria or triggered by usage and performance data.
- **Work order management**. PAMS facilitates the creation, assignment, and tracking of work orders for asset maintenance and repair tasks. It streamlines the workflow by assigning tasks to maintenance teams or contractors and tracking their progress.
- **Asset performance monitoring**. The software captures real-time data from sensors and equipment, allowing for the continuous monitoring of asset performance. It can detect anomalies and notify operators of potential issues.
- **Predictive maintenance**. Some PAMS systems leverage predictive analytics and machine learning algorithms to forecast when an asset is likely to require maintenance. This approach helps reduce downtime and maintenance costs.
- **Inventory control**. PAMS tracks spare parts and inventory levels required for maintenance and repairs. It ensures that the right parts are available when needed, reducing delays in asset servicing.
- **Asset lifecycle management**. The system manages the entire lifecycle of assets, from procurement to retirement or disposal. It helps optimize asset utilization and replacement planning.
- **Compliance and reporting**. PAMS assists in regulatory compliance by generating reports and documentation related to asset maintenance, safety, and environmental standards.
- **Asset tracking**. Some systems incorporate GPS or RFID technology to track the real-time location of assets within the port, improving visibility and security.
- **Integration**. PAMS can integrate with other port management systems, such as Terminal Operating Systems (TOS) and Enterprise Resource Planning (ERP) systems, to ensure seamless data exchange and coordination of activities.
- **Cost analysis**. The software provides cost analysis tools for assessing the total cost of ownership (TCO) for each asset, including acquisition, maintenance, and disposal costs.
- **Mobile access**. Many PAMS solutions offer mobile applications, allowing maintenance teams to access work orders, asset information, and perform inspections while in the field.
- **Environmental benefits**. PAMS offer environmental benefits by optimising resource allocation, improving maintenance planning, enhancing energy efficiency, enabling effective waste management, and facilitating environmental monitoring and compliance. Real-time data and insights help proactively plan maintenance activities, preventing environmental incidents, such as spills and leakages. Energy consumption can be monitored and analysed, leading to energy-saving measures and reduced greenhouse gas emissions. PAMS also support efficient waste management and integration of environmental monitoring systems, ensuring compliance with regulatory standards and protecting the environment.

These systems play a crucial role in optimizing asset utilization, minimizing downtime, and extending the lifespan of critical infrastructure and equipment within the port environment. Several software providers offer specialized PAMSs tailored to the unique requirements of ports and terminal operators, one of them being MainPac Asset Intelligence.[77] The application enables users to achieve improvements in the availability of equipment, reliability, transparency, and communications. By gaining more control over their assets, and integrating advanced analytics, predictions and guidance for operational planning become more reliable.

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77 https://mainpac.com/industries/ports-terminals/

Asset management in ports is a relatively new discipline in the overall port management. With the development of digital technologies, asset management is often referred to as the Digital Asset Management (DAM). The scope of Digital Asset Management (DAM) can range from a basic digital record of a port's assets to a comprehensive IoT Asset Management Tool that enables proactive tracking and oversight of the port's equipment, structures, and infrastructure. This advanced capability enables precise and proactive scheduling of maintenance tasks, ultimately minimizing disruptions to daily operations and reducing asset downtime.[78]

These are the typical services offered within digital asset management:

- **Digital transformation of asset management procedures**. Modernization of existing asset management processes through digital tools and technologies.
- **Advanced data capture techniques**. Utilization of methods such as laser scanning, bathymetry, and photogrammetry to collect accurate asset data.
- **Creation of comprehensive 3D models**. Development of fully integrated, geolocated 3D models for assets, encompassing both above and below the waterline.
- **Design planning for complex structures**. Using digital models to facilitate the design of intricate capital projects for structures lacking existing "as-built" data.
- **Airborne and waterborne drone surveys**. Conducting surveys with drones, both in the air and on and under the water for asset assessment and monitoring.
- **Asset capacity and condition evaluations**. Assessment of a port's assets to determine their capacity and overall condition.
- **Asset management planning**. Developing comprehensive asset management plans to optimize asset performance and longevity.
- **Digital twins as asset management tools**. Creating digital twins that serve as powerful asset management tools for ongoing monitoring and decision-making.
- **Digitalisation of defect and maintenance management**. Implementing digital solutions for the management of defects and maintenance processes.
- **Client training and support**. Providing training and support to clients, enabling them to effectively use digital tools for their asset management needs.

2.4.9 Reporting applications

Practically all previously elaborated digital tools and platforms are considered as reporting tools because they report on the data they collect and analyse in order to present the current status of the facilities or events and, in some cases, to recommend solutions to the identified problems, or simply to recommend a course of further action for a given activity in a port or terminal. Dedicated (purpose-built) reporting tools for ports, however, are specific software solutions that enable the collection, analysis, and visualization of data generated within a port or terminal. These tools play a crucial role in helping port operators and authorities make informed decisions, monitor performance, and meet regulatory requirements. They are very similar to Business Intelligence (BI) tools, but they have less functionalities when compared to BI tools. The primary difference between BI tools and reporting tools for ports lies in their capabilities and purposes. BI tools offer advanced analytics, data exploration, and predictive capabilities, enabling ports to gain deeper insights into their operations. Reporting tools, on the other hand, are focused on creating structured and static reports for summarizing data and meeting compliance and documentation needs. The choice between these tools depends on the specific analytical and reporting requirements of the port.

Key features and functionalities of reporting applications are given in continuation:

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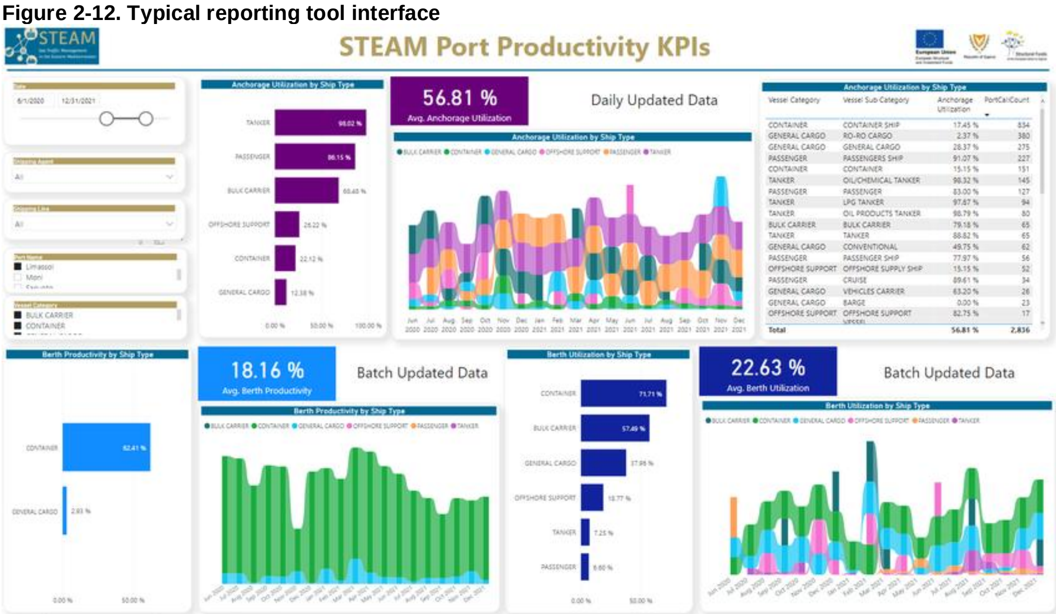
[78] https://www.niras.com/sectors/ports-and-marine/smart-and-green-ports/digital-asset-management/

- **Data collection**. Reporting tools gather data from various sources within the port, such as Terminal Operating Systems (TOS), Gate Operating Systems (GOS), Cargo Management Systems, and more.
- **Data integration**. They integrate data from multiple systems, consolidating it into a central repository. This allows for a comprehensive view of port operations.
- **Data analysis**. Some reporting tools that are integrated with BI applications use data analytics and business intelligence algorithms to process and analyse information. They can uncover trends, patterns, and anomalies.
- **Customizable reports**. Users can create customized reports tailored to their specific needs. These reports can range from operational performance metrics to financial summaries.
- **Real-time monitoring**. Some reporting tools provide real-time dashboards and alerts, allowing operators to monitor port activities and respond to issues promptly.
- **Regulatory compliance**. Reporting tools help ports comply with regulatory requirements by generating reports that detail environmental, safety, and security metrics.
- **Performance metrics**. They track key performance indicators (KPIs) such as vessel turnaround times, container dwell times, and productivity metrics for various terminal operations.
- **Visualization**. Reporting tools often offer data visualization features, including charts, graphs, and maps, to make complex data more understandable.

Figure 2-12. Typical reporting tool interface



Source: Online Analytical Processing of Port Calls for Decision Support Conference paper[79]

Reporting tools for ports are essential for managing complex operations, ensuring compliance, and improving overall efficiency. Ports should choose reporting tools that align with their specific data requirements, integration capabilities, and reporting needs to drive informed decision-making and operational excellence.

2.4.10 Predictive maintenance tools

Predictive maintenance tools for port infrastructure and equipment are advanced solutions that leverage data analytics, sensors, and machine learning to predict when maintenance is required for port assets and equipment. These tools play a crucial role in improving the reliability, efficiency, and safety of port operations.

[79] Worth, A., Televantos, A., Evmides, N., Michaelides, M. and Herodotou, H. (2022). Online Analytical Processing of Port Calls for Decision Support. *Proceedings of the 23rd IEEE International Conference on Mobile Data Management*, pp.437-439. Available at: http://dx.doi.org/10.1109/MDM55031.2022.00095

Key components and functions:

- **Data collection**. Predictive maintenance tools gather data from various sources within the port, including sensors, IoT devices, equipment logs, and historical maintenance records. This data can include information about equipment condition, temperature, vibration, fuel consumption, and more.
- **Data integration**. The tools integrate data from different systems and sources into a centralized platform, creating a comprehensive view of asset health and performance.
- **Data analytics** . Advanced analytics and machine learning algorithms analyse the integrated data to identify patterns, anomalies, and early signs of equipment degradation or failure. Predictive models are trained using historical data.
- **Predictive modelling**. Predictive maintenance models use historical and real-time data to predict when equipment is likely to fail or require maintenance. These models consider factors such as usage patterns, environmental conditions, and equipment age.
- **Failure predictions**. Predictive maintenance tools generate alerts and predictions about impending equipment failures. These predictions are often ranked by severity and likelihood to help prioritize maintenance tasks.
- **Prescriptive maintenance**. Some tools not only predict failures but also provide recommendations for maintenance actions, including the type of maintenance needed (e.g., preventive, corrective) and the optimal timing for interventions.
- **Condition monitoring**. Continuous monitoring of equipment condition is a key aspect. Sensors and data streams provide real-time information on asset health, enabling proactive responses.
- **Integration with CMMS**. Predictive maintenance tools often integrate with Computerized Maintenance Management Systems (CMMS) to schedule and manage maintenance tasks efficiently.[80]

Benefits of predictive maintenance in ports:

- **Reduced downtime**. By identifying issues before they lead to breakdowns, predictive maintenance minimizes unplanned downtime and keeps port operations running smoothly.
- **Cost savings**. Maintenance is performed when needed, reducing unnecessary maintenance costs, and extending the lifespan of equipment.
- **Improved safety**. Predictive maintenance enhances safety by preventing equipment failures that could result in accidents or injuries.
- **Efficient resource allocation**. Maintenance resources can be allocated more efficiently based on the actual condition of equipment, reducing idle time and labour costs.
- **Optimised asset performance**. Ports can achieve optimal asset performance and reduce the risk of catastrophic equipment failures.[81]
- **Environmental benefits**. Predictive maintenance tools for port infrastructure and equipment offer environmental benefits by reducing resource consumption and minimising waste generation. They lower emissions and pollution by ensuring efficient equipment operation and addressing issues promptly. These tools also prevent environmental incidents and associated cleanup costs by detecting early warning signs. Additionally, they enable better sustainability planning by providing data for equipment upgrades or replacements with more environmentally friendly alternatives. Timely maintenance can prevent equipment failures or malfunctions that could result in environmental incidents, such as spills, leaks, or releases of hazardous

[80] https://www.cloudapper.ai/cmms-for-ports-and-terminals-maintenance/

[81] Verbruggen, L. A. H., van Duin, J. H. R., Tavasszy, L. A., Schoenmaker, R., & Cornelissen, S. C. (2022). Benchmarking port asset performance. *International Journal of Transport Development and Integration*, 6(3). https://doi.org/10.2495/TDI-V6-N3-217-235

substances. Predictive maintenance tools can detect early warning signs and trigger proactive interventions, reducing the risk of environmental damage and the associated costs of cleanup and remediation.

2.4.11 Multimodal booking and transport management platforms

The logistics and transportation industry are witnessing a transformative wave of digitalisation and innovation. In the digital era, where the movement of goods across various transport modes is a complex and critical process, multimodal cargo booking platforms have emerged as key enablers of efficient and streamlined logistics operations. These platforms provide a digital ecosystem for connecting shippers, cargo owners, transport providers, and various stakeholders, facilitating the booking, management, and tracking of cargo movements across different modes of transportation.

Multimodal cargo booking platforms, often referred to as multimodal transport platforms or digital freight marketplaces, are comprehensive digital ecosystems designed to optimise the movement of cargo across multiple transport modes, including road, rail, water, and air. These platforms offer a unified space where shippers and cargo owners can seamlessly book, manage, and track their cargo as it travels through a combination of transportation options.

Multimodal platforms enable efficient cargo booking, as shippers can choose the best transport options based on cost, transit time, and specific requirements. This efficiency extends to the handling of cargo across different modes, contributing to shorter transit times and reduced costs. Shippers no longer need to engage with multiple carriers or operators for various legs of the journey. Multimodal platforms provide a single point of access, simplifying the booking process and reducing administrative overhead. These platforms offer intelligent route optimisation, ensuring that cargo follows the most efficient path, whether it involves road, rail, water, or air transport.[82] This optimisation minimises delays and maximises the utilisation of transport capacity. By facilitating cargo consolidation and optimising routes, multimodal platforms help shippers and cargo owners reduce overall transportation costs. Shared cargo space and the selection of cost-effective transport options are common features. The efficiency and optimisation enabled by these platforms have environmental benefits. Reduced travel distances and improved cargo consolidation lead to lower carbon emissions and a more sustainable logistics ecosystem. They also offer real-time visibility into cargo movements. Shippers and cargo owners can track their shipments as they traverse different transport modes, providing full transparency into the logistics process. Data generated by these platforms offer insights that empower stakeholders to make informed decisions. This data can include information about cargo status, estimated arrival times, route performance, and more. They often incorporate customs and regulatory compliance features, ensuring that cargo seamlessly transitions between transport modes without unnecessary regulatory complications. Multimodal platforms encourage collaboration among various stakeholders, including shippers, transport providers, carriers, and terminal operators, leading to a more connected and efficient logistics ecosystem.

Inland ports are increasingly involved in multimodal digital platforms for booking and transport management to enhance efficiency, coordination, and the overall flow of goods. Inland ports are typically engaged in such platforms in following ways:

- **Platform integration**. Inland ports connect to multimodal digital platforms through integration. These platforms act as intermediaries that bring together multiple transport modes and various stakeholders in the supply chain. Inland ports integrate their systems with these platforms to seamlessly exchange data and collaborate with other participants.

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[82] https://www.shipthis.co/blog/digital-freight-forwarding-platform

- **Intermodal booking**. Multimodal digital platforms allow cargo owners, shippers, and logistics providers to book transport services involving different modes of transport, including road, rail, water, and air. Inland ports offer intermodal transport services, and they are listed as service providers on these platforms. Users can book transport solutions that include inland port services.
- **Coordination with inland transportation**. Inland ports coordinate with various transportation providers, including road and rail carriers. Multimodal platforms facilitate this coordination by allowing inland ports to share cargo details and requirements with these providers. This helps ensure smooth cargo movement between the inland port and other locations.
- **Visibility and trackability**. Inland ports provide real-time information about cargo status, availability, and transit times. Multimodal platforms display this data to shippers and other stakeholders, offering them visibility into the progress of their cargo across different transport modes.
- **Cargo consolidation**. Some inland ports offer cargo consolidation services. They consolidate shipments from various sources and create larger, more efficient transport units. Multimodal digital platforms support these consolidation efforts by helping shippers find opportunities to share cargo space, reduce costs, and optimize transport routes.
- **Data sharing**. Inland ports share data on cargo movements, vessel arrivals, storage capacity, and other relevant information with the digital platforms. This data is used by the platform to enhance the booking and transport management process.
- **Efficient customs and regulatory compliance**. Multimodal platforms often incorporate customs and regulatory compliance features. Inland ports work with these platforms to streamline customs documentation, ensuring that cargo can move seamlessly between transport modes without unnecessary delays or complications.
- **Environmental considerations**. Multimodal platforms may focus on sustainability and environmental efficiency. Inland ports collaborate to contribute to these goals, supporting greener transportation solutions, optimising routes to minimise environmental impacts, and sharing relevant data for emissions reduction initiatives.
- **Capacity planning**. Inland ports provide information about their capacity and resource availability. Multimodal platforms use this data to assist users in making informed decisions about cargo movement and selecting the most suitable transport providers and routes.
- **Cargo security and risk management**. Multimodal platforms often include features related to cargo security and risk management. Inland ports contribute to these efforts by providing data on cargo handling, security measures, and risk assessments.

By participating in multimodal digital platforms, inland ports play a pivotal role in enhancing the efficiency, sustainability, and coordination of cargo movements across various transportation modes. This collaboration helps stakeholders in the supply chain make data-driven decisions, optimize routes, and improve overall transport management.

Nowadays, there is a large number of commercial multimodal cargo booking platforms available, including Flexport®[83], myCEVA®[84] and Beacon®[85]. Some of these multimodal platforms monitor the carbon footprint of every forwarder and carrier port-to-port.

[83] www.flexport.com
[84] https://my.cevalogistics.com
[85] www.beacon.com

2.5 Port automation and autonomation

2.5.1 Differences between digitalisation and automation

Even though port digitalisation and port automation are closely related they are significantly different. While port digitalisation refers to the use of digital technologies and tools, data, and information systems to improve the overall port management and operations, port automation, on the other hand, focuses on the mechanisation and robotics of physical tasks, activities and processes in the port, typically involving the use of machinery and technology to replace or assist human labour. Although digitalisation and automation processes are closely interrelated, they can be executed independent from each other. In this way, an automated port or terminal is typically highly digitalised, while a digitalised port does not necessarily need to be automated.

Port automation includes the deployment of automated cranes, cargo handling equipment, autonomous vehicles and other technologies needed for cargo loading, unloading, and storage, as well as for movement of cargo within the port area. Objectives of port automation are to increase efficiency, reduce labour cost, minimise human error and shorten the turnaround time for vessels and barges in the port.

Since both port digitalisation and port automation are important for enhancing of the overall efficiency and competitiveness of inland ports, and they complement each other when implemented together, this section is dedicated to the brief overview of port automation.

2.5.2 Differences between automated ports and autonomous ports

Automated and autonomous ports are both advanced concepts in the domain of port operations and logistics, but they have distinct differences in terms of their level of technology and human involvement. Below is an overview of the key differences between automated and autonomous ports:

Table 2-4: Key differences between automated ports and autonomous ports

Key differences	Automated port	Autonomous port
Automation level	Various processes and operations are mechanized and streamlined using technology such as robotic cranes, automated guided vehicles (AGVs), and computer systems. The primary aim is to enhance efficiency and reduce human labour. However, human operators are still essential for monitoring and overseeing these automated processes.	An autonomous port takes automation to the next level. In an autonomous port, advanced technologies like artificial intelligence (AI), machine learning, and autonomous vehicles are employed to a greater extent. These ports aim to operate with minimal human intervention, with machines and systems making decisions and performing tasks independently.
Human involvement	Human operators play a significant role in supervising operations, making decisions, and handling exceptions or unexpected situations. The level of automation varies, but humans are an integral part of the operation.	The role of human operators is significantly reduced. These ports aim to have machines and systems manage operations, make decisions, and handle exceptions without requiring continuous human intervention. Human involvement may primarily be focused on oversight, maintenance, and emergency situations.
Decision-making	Typically involves pre-programmed routines and rules set by humans. While technology can optimize operations, the	AI and machine learning algorithms to make real-time decisions based on data from various sensors and systems.

Key differences	Automated port	Autonomous port
	ultimate decisions are often made by human operators.	These decisions can include route planning for autonomous vehicles, scheduling, and resource allocation.
Flexibility	Designed with specific workflows and processes in mind. Changing these workflows may require reprogramming or adjustments to the automated systems.	Designed to be more adaptable and responsive to changing conditions. They can dynamically adjust operations and resource allocation based on real-time data.
Implementation cost and complexity	Significant investment, but it may be less complex and costly than achieving full autonomy.	Full autonomy in a port is a complex and expensive endeavour, requiring advanced technologies, extensive infrastructure, and robust cybersecurity measures

Source: Consortium

In summary, automated ports focus on improving efficiency and reducing labour through technology, with human operators playing a significant role. Autonomous ports take automation a step further, aiming for a higher degree of independence for machines and systems in decision-making and operations, with reduced human involvement.

2.5.3 Inland ports automation as a game-changer of future logistics

Although inland ports can often be in the shadow of their big sea "cousins", they, too, play a very important role in global supply chains, serving as nodes for different transportation modes and as a collection or distribution points for seaports whenever there is an inland waterway connection between seaports and their hinterlands. For example, an importer of consumer electronics can be located in the small town of Willstätt, Germany, in the vicinity of the inland port of Kehl on the right bank of the Rhine River, while exporter may be located in the city of Zhaoqing, China, which hosts an inland port on the Xijiang River[86], having direct inland waterway connection with the major seaport of Guangzhou. The entire supply chain for this single cargo (e.g. container with electronics) may include several different intermodal nodes and voyages, involving trucks or train, inland waterway legs on both sides, sea voyage between the two seaports, and so on. Inland port in Zhaoqing serves as a collection point for the seaport Guangzhou for the cargo originating in the hinterland of Zhaoqing, while the port of Kehl serves as one of the distribution hubs for the seaport of Rotterdam, for the cargo destined to the hinterland of Kehl, such as the town of Willstätt. One of the ways to improve the overall efficiency of this supply chain is to digitalise inland ports on both ends and automate their container terminals, should that prove cost-efficient against a number of containers handled in both inland ports.

Benefits of inland port automation include the following:

- **Efficiency and speed enhancement**. Automated cargo handling processes are typically faster than manual ones. Automation of cargo handling equipment such as cranes and sorting systems significantly reduces loading/unloading time[87] and enables faster turnaround time for vessels and trucks. This, in turn, reduces dwell times and minimises congestion.

[86] Ding, W., Chen, Z., Wang, R., Xue, T. and Yao, H. (2023). The Review and Prospect of the Development of Guangdong-Hong Kong-Macao Greater Bay Area Port Cluster and Its River-Sea Intermodal Transport System. In: Li, Y., Hu, Y., Rigo, P., Lefler, F.E., Zhao, G. (eds) *Proceedings of PIANC Smart Rivers 2022*. PIANC 2022. Lecture Notes in Civil Engineering, vol 264. Springer, Singapore. https://doi.org/10.1007/978-981-19-6138-0_139

[87] See for example: https://safetowork.com.au/bhp-unveils-world-first-automated-shiploaders/

- **Cost reductions**. The initial investment in automation technology may be significant, depending on the size and scope of automation, but on the long-term it leads to cost-savings. It reduces the cost of labour, cost of fuel and energy, and costs caused by errors. This leads to optimised utilisation of resources and improved financial sustainability.
- **Environmental sustainability**. Inland port automation can lead to reduced energy consumption and thereafter to lower emissions. By optimising port operations and cutting on idle times, automation can contribute to environmental sustainability goals.
- **Improved safety**. Since manual labour is significantly reduced in automated ports, especially in potentially hazardous tasks, labour safety is increased, while the risk of accidents is considerably reduced.
- **Resilience**. Automated systems can operate continuously, even in adverse conditions, making inland ports more resilient to disruptions caused by weather or unforeseen events.

Despite the numerous advantages, automation of inland ports carries a number of challenges as well:

- **High initial costs**. The upfront investment required for automation infrastructure, technology, and maintenance can be a barrier for some port operators, especially in small and medium-sized ports, and most of inland ports are of small to medium size. As a result, a compromised version of semi-automated ports having technology as a secondary support for manual labour is brought into practice.[88]
- **Lack of skilled workforce**. Implementation of automation in inland ports may require retraining or reskilling of the workforce[89] to manage and maintain advanced technologies.
- **Integration complexity**. Integration of various automated systems and ensuring compatibility with existing processes can be a barrier for some port operators.
- **Cybersecurity concerns**. This aspect is equally challenging for both port digitalisation and automation as the ports become more vulnerable to cyberattacks with the increase of their digitalisation/automation level.

2.5.4 Automated cargo handling equipment

Automated cargo handling equipment in ports refers to machinery and systems designed to efficiently and autonomously load, unload, transport and handle various cargo within a port area. Automated cargo handling equipment is used in modern ports with the aim to improve operational efficiency, reduce labour costs, and enhance safety.

Examples of automated cargo handling equipment are given in continuation.

- **Automated cranes**. This type of cargo handling equipment refers to large gantry or slewing cranes primarily located on the quay for the purpose of loading/unloading vessels. These cranes are equipped with automation technology such as sensors and computer systems to precisely load/unload cargo from/to vessels alongside the quay wall (berth). Automated cranes are frequently referred to as Automatic Robot Cranes (ARC).[90] These cranes are integrated with Artificial Intelligence (AI) technology and Internet of Things (IoT) sensors and devices and they can perform the tasks fully autonomously or under human remote control. Some of the sensors that these cranes can have are sensors for object detection, enabling the cranes to identify workers or other movable or fixed objects and thus avoid collisions, accidents, and operational

[88] https://www.shmgroup.com/blog/everything-need-know-port-automation/

[89] Vaggelas, G.K., Leotta, C. (2019). Port labour in the era of automation and digitalisation. What's next? *Electronic Journal of Management*, 3.

[90] Global Infrastructure Hub (2020). *Automated Robot Cranes for Ports*. Overview paper. Available at: https://cdn.gihub.org/umbraco/media/3179/3-automated-robot-cranes-use-case.pdf

delays. AI and IoT devices integrated with cranes can optimise loading/unloading tasks and at the same time reduce the risks of accidents, delays, and mistakes. This can result in significant cost reductions.

Figure 2-13: Autonomous discharging crane

Source: www.macgregor.com

- **Automated guided vehicles (AGV)**. Automated guided vehicles are vehicles controlled and operated with the help of automated technological systems and equipment instead of the more traditional manual operations. AGVs are used to horizontally transport containers between the quayside and the container yard. The autonomic navigation and self-monitoring capabilities make AGVs the perfect solution for container transport. By replacing yard tractors and eliminating the need for a labour force to drive the tractors, AGVs are creating a rapid, economical, and safer container transport system within the port area. They are able to transport containers between quayside and the stacking yards using various sensors and positioning systems to properly navigate. They are almost exclusively electric with a charge of about 6 to 8 hours and a power down mode when not in use. Charging is usually achieved by swapping their batteries with a charged pack, while the uncharged pack is being recharged.[91]

Figure 2-14: Automated guided vehicle

[91] Notteboom, T., Athanasios, P. and Rodrigue, J.P. (2022). *Port Economics, Management and Policy*, New York: Routledge. Available at: https://doi.org/10.4324/9780429318184

Source: www.sick.com

- **Automated stacking cranes (ASC)**. Automated stacking cranes automatically load containers from both ends of the stacking yard. When on the quayside, containers can be brought and retrieved by AGVs while on the gate side they are usually brought and retrieved by chassis and trucks. Each stacking yard contains at least two ASC; one for quayside operations and the other for gate side operations. During low activity cycles, such as nighttime, ASCs usually reposition containers in light of the anticipated activity, such as an inbound ship to be loaded with a series of containers that are easier to retrieve sequentially.[92]
- **Automated straddle carriers (ASTRAD)**. An automated straddle carrier combines stacking and transportation capabilities. Straddle carrier operations are typically suited for medium-sized terminals. When increased volumes require a higher stacking density, the automated straddle carriers can still provide transportation to an automated stacking crane. This also makes the straddle carriers suited for use in larger facilities where ASTRADs are deployed.[93]

2.5.5 Connected cranes

Connected cranes are cranes that are digitally interconnected by the integration of modern technologies and data systems to enhance the efficiency, safety, and productivity of crane operations in a port. Connected cranes can be interconnected between each other for safer operations and avoidance of disturbances from one another during simultaneous operations, and they can be connected to a control or monitoring centre in the port operations room.

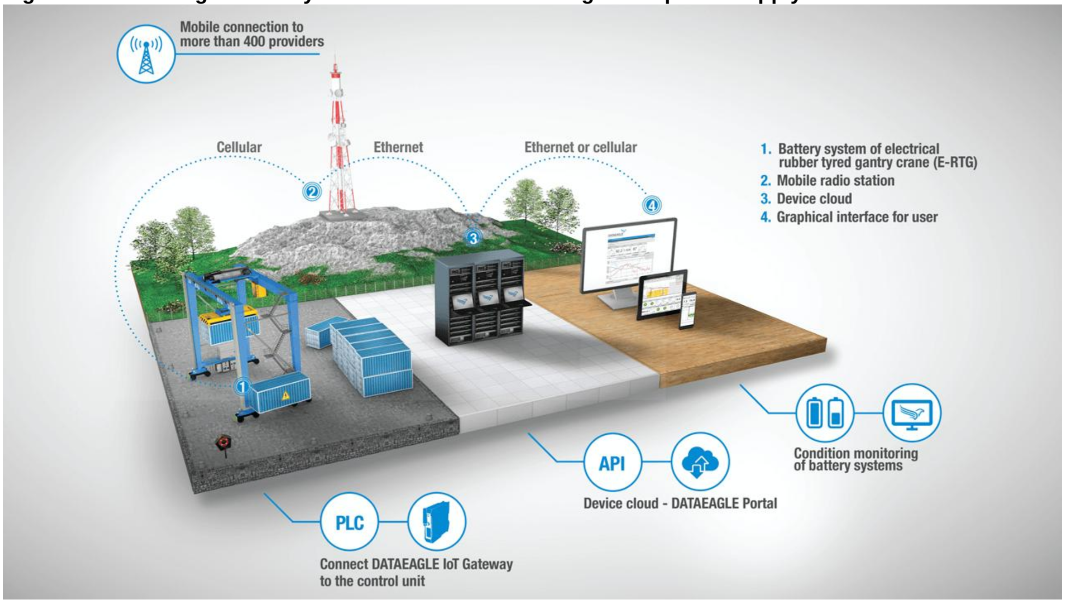
These cranes are typically equipped with a network of sensors, such as load sensors, power supply sensors, position sensors, object identification sensors, environmental sensors, etc. These sensors continuously collect and transmit data on the crane's status and its immediate surroundings. The data is collected in real-time, allowing port operators to monitor the performance and condition of each crane remotely. Digital connectivity enables automation, meaning that cranes can be programmed to perform certain tasks autonomously and simultaneously as a system. This greatly reduces the need for manual intervention. Cranes are connected to a larger network within the port, allowing for seamless communication between different equipment, such as cranes, trucks, and ships. This improves coordination and reduces bottlenecks. In some cases, operators can remotely control cranes from a central control room, which can enhance safety and efficiency further. The data from digitally connected cranes can be integrated with other port systems, such as inventory management and logistics software, to streamline the entire supply chain process.

Connected cranes have positive environmental impact. By optimizing operations, digitally connected cranes can reduce energy consumption and emissions, contributing to more sustainable port operations. Moreover, this positive environmental impact is even stronger in case of, for example, rubber tyred gantry cranes (RTG) which are electrified, thus becoming E-RTG. Some of these E-RTGs relied on onboard diesel generators for the production of electricity, which lead to a somewhat paradox situation from the environmental point of view. This was necessary as diesel generators were the only reliable source of stable electric power for RTGs, apart from the conductor lines and motorized cable reels which can be used only when an RTG is moving along container corridors. Latest technologies allow onboard battery containers to be mounted on E-RTGs.[94] These battery containers are sophisticated devices packed with state-of-the-art components that need to be monitored by sensors to secure flawless operation and maximum uptime. IoT sensors transmit data on voltage, temperature, pressure, and humidity measurements to an industrial cloud for

[92] Ibid.
[93] https://www.kalmarglobal.com/automation/kalmarone/autostrad-application/
[94] https://www.profibus.com/technology/case-studies/wirelessprofinetcranes

visualization and evaluation. Since the cranes are situated in different locations around the world, it is crucial that data can flow freely all the way from source to destination.

Figure 2-15: IoT Edge-Gateway enables remote monitoring of the power supply for E-RTG cranes



Source: Industrial Ethernet Book[95]

2.5.6 Remotely controlled ship-to-shore (STS) cranes

Remotely controlled STS cranes, also known as remotely operated quay cranes (ROC), are operated by crane operators from a remote location, typically from a control room on the terminal premises. This allows for safer and more efficient operation, as the operator has a better view of the entire process and can make precise movements. The crane incorporates various automated systems to enable remote operation. The primary phase of the crane's operation is executed fully automatically by the crane control system, while the operator's role is primarily supervisory in overseeing the crane's movements.[96] A work order is initiated either by the operator or generated directly by the terminal operating system (TOS) and is subsequently transmitted to the crane. Upon the operator's confirmation, the crane begins its motion. Through automation, the operator can concentrate on the critical final stages of the operation.

When the crane is equipped with a lashing platform or a vehicle alignment system, landside operations can be entirely automated. The implementation of automation systems for lashing and vehicle guidance also entails control over both the crane itself and the individuals in the vicinity, thereby creating a safer environment for all individuals participating in the operation.

Benefits of remotely controlled STS cranes are numerous, some of them being the following:

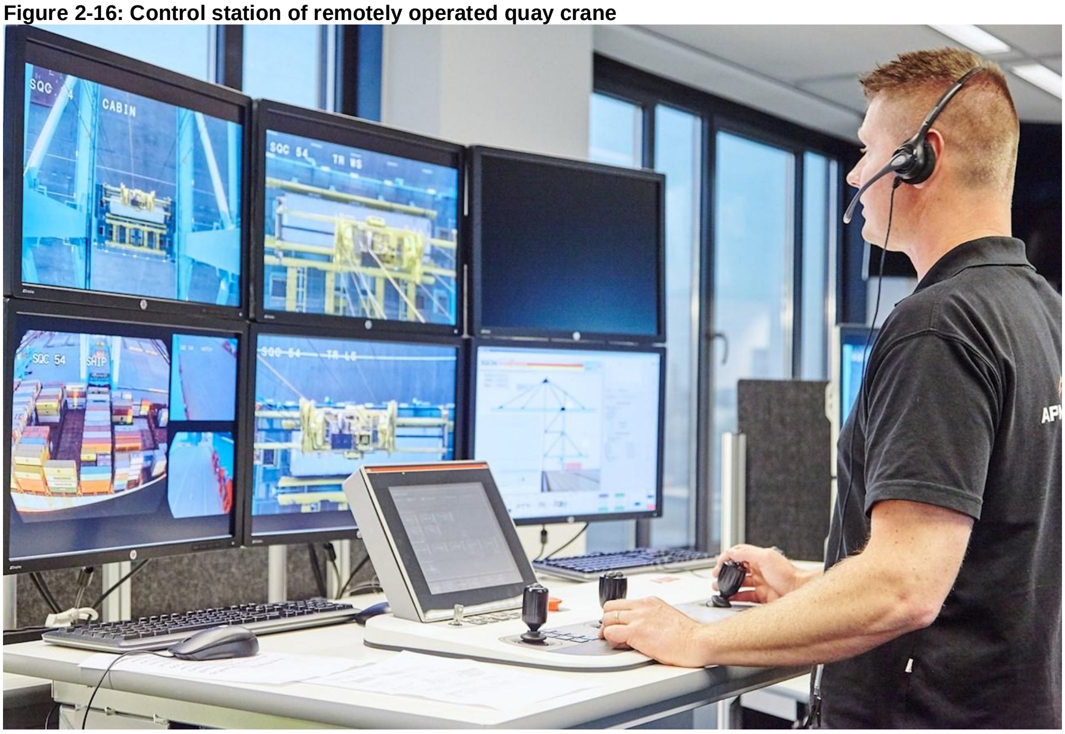
- **Safety**. Remote control eliminates the need for operators to be physically present on the crane, reducing the risk of accidents and injuries. Operators can also respond more quickly to emergency situations.
- **Productivity**. These cranes are known for their high throughput capabilities. They can handle a large number of containers per hour, making them essential for busy container terminals handling large number of containers.

[95] https://iebmedia.com/applications/transportation/connecting-container-cranes-across-the-globe/

[96] Holmgren, C. (2019). Remotely controlled quay cranes: safer and more productive, Technical Paper, *Port Technology International*, May 2019. Available at: https://www.porttechnology.org/wp-content/uploads/2019/05/PT50-21.pdf

- **Spatial efficiency**. STS cranes are typically huge movable structures, even in inland ports. Their remote control allows for precise manoeuvring within limited space. This is especially important in densely packed container terminals.
- **Reduced downtime**. Remote diagnostics and maintenance capabilities can help identify and address issues more quickly, reducing downtime and improving overall operational efficiency.
- **Energy efficiency**. Many modern remotely controlled quay cranes are designed with energy-efficient features, such as regenerative braking systems[97], to reduce power consumption and environmental impact.
- **Flexibility**. Operators can easily switch between different cranes and workstations, allowing for more flexible scheduling and resource allocation.
- **Integration**. These cranes are often integrated into the broader logistics and container tracking systems used in modern ports. This enables better coordination of container movements and enhances supply chain visibility.
- **Cost savings**. While the initial investment in remote-controlled STS cranes can be significant, the long-term benefits in terms of increased productivity, reduced labour costs, and improved safety can lead to cost savings over time.

Figure 2-16: Control station of remotely operated quay crane



Source: www.abb.com

Remotely controlled STS cranes are not so frequent in inland ports as they are cost efficient primarily for large amounts of containers handled in a port, which is often not the case in inland ports. However, exceptions are possible and one of those exceptions is the larger inland port in Europe, in Duisburg, Germany. Duisport[98] (the company managing the port) recently tested the intelligent control of semi-automated container cranes through 5G networks. So far, semi-automated control of mobile cargo handling equipment in inland ports has not been possible.[99] The reason for this lays primarily in the lack of necessary coverage of tailored low-latency and high-speed 5G networks in inland ports areas. Semi-automation with the help of 5G should increase the

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97 https://www.konecranes.com/discover/what-is-dynamic-braking

98 https://www.duisport.de/?lang=en

99 Geelen, A. (2022). Start for 5G project in the Port of Duisburg: Test field for semi-automated container cranes, Article, Telekom. Available at: https://www.telekom.com/en/media/media-information/archive/start-for-5g-project-in-the-port-of-duisburg-1020288

capacity of the cranes. This would increase container turnover without the port needing additional floorspace.
While container handling cranes automation and their digital remote control is well advanced, the digital remote control of other types of port cranes in inland ports is currently not so developed.

2.5.7 Airborne and waterborne drones

Both airborne and waterborne drones are increasingly being utilized in various industries and sectors, including inland ports, to enhance operational efficiency, safety, security, and overall productivity. The levels of automation and autonomy of such drones vary from remotely operated drones to fully automated and autonomous drones. Inland ports, which are transportation hubs located in the interior of a country, often connected to seaports or other modes of transportation, can benefit from drone technology in several ways:

- **Surveillance and Security**. Drones equipped with high-resolution cameras and thermal imaging can be used to patrol and monitor the perimeter of inland ports. They can identify potential security breaches or suspicious activities, providing real-time data to security personnel. In the event of a security breach, drones can quickly reach the scene and provide live video feeds to law enforcement, helping them assess the situation and plan their response effectively.
- **Inventory Management**. Drones equipped with RFID or GPS technology can be used to track the movement and location of containers, cargo, and equipment within the port, ensuring accurate inventory management and reducing the risk of theft or loss.
- **Infrastructure Inspection and Maintenance**. Drones can inspect infrastructure such as bridges, roads, rail tracks, underwater structures, and storage facilities, identifying maintenance needs, structural issues, or potential hazards. This proactive approach can help prevent accidents and costly downtime.
- **Environmental Monitoring**. Inland ports often have environmental responsibilities. Drones with onboard sensors and high-resolution cameras can monitor air quality, water pollution, noise, and even wildlife activity, helping port authorities comply with environmental regulations in a speedy, cost-effective and consistent manner. In this way, drone technologies will have a massive impact on meeting the sustainability development goals, notably for all forms of emissions and noise,[100] helping inland ports assess their impact on the surrounding ecosystem and make informed decisions regarding sustainable practices. Even illegal fishing and other activities within the port limits can also be kept under control with the well-equipped and well-networked drones constantly scanning the waters under jurisdiction of port authorities for violations.
- **Transportation and Logistics**. Drones can be employed for last-mile delivery of small cargo parcels or packages within the port, reducing the need for vehicles and thus contribute to the minimisation of the traffic congestion.
- **Inventory Replenishment**: Drones can deliver spare parts or supplies to different areas of the port, improving the service quality to various stakeholders. Delivery of supplies or documents to/from vessels wating at anchor is way more cost effective than using a launch for such small deliveries.
- **Traffic Management**. Drones can provide real-time data on traffic congestion, enabling port operators to optimize traffic flow and reduce waiting times for vehicles. Artificial intelligence enables the timely provision of essential features like collision prediction and warning to the operator.[101]

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100 https://www.rivieramm.com/news-content-hub/news-content-hub/port-should-test-drones-to-improve-safety-and-profitability-61293

101 https://ideaforgetech.com/blogs/using-drones-in-port-operations-is-the-move-world-commerce-needs

- **Search and Rescue**. In the case of accidents or emergencies involving vessels or personnel within the port, drones can assist in search and rescue operations by covering a larger area quickly and providing aerial views of the situation.
- **Data Analytics**. The data collected by drones can be processed and analysed to identify trends, improve operational efficiency, and make data-driven decisions.

It is important to note that the successful integration of drones into inland port operations requires adherence to regulatory requirements, safety protocols, and privacy considerations. Additionally, the choice of drone technology, such as fixed-wing or quadcopters, floating or submersible, payload capacity, and communication systems, should be align with the specific needs and objectives of the inland port. These needs and objectives are usually a part of the port's digitalisation and automation strategy.

3 Cyber security aspects

3.1 What is cyber security?

The International Telecommunications Union, an international organisation, defines cyber security as “the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organisation and user’s assets.”[102] The Comité Européen pour l’Élaboration de Standards dans le Domaine de Navigation Intérieure (CESNI) (*English: European Committee for Drawing Up Standards in Inland Navigation*) “Good practice guide on Cybersecurity in inland navigation”[103] defines it as the “implementation of a suite of techniques, practices, resources and tools for protecting information systems and their data”.

3.2 What are the motivations behind a cyber-attack?

Both, the Institution of Engineering and Technology (IET)[104] and CESNI, have a similar approach to the motivation behind a cyber-attack. The latter lists the following as possible motivations:

Table 3-1: Potential threat actors and motivations

Actor type	Action	Sample application in the context of inland navigation poorly trained or unsensitized employee
Malicious employee or one who is insufficiently trained, or unaware	Unaware (intentionally or otherwise) of cybersecurity good hygiene measures, this threat actor may nor may not have any malicious motivations. But be that as it may, his actions may endanger his organisation, whether deliberately or simply through negligence.	Clicking on an unsafe link sent in an email by an attacker, leading to the download of malicious files on port IT systems.
Criminal	Driven by financial gain, this actor engages in actions such as theft, smuggling of goods and people, evasion of taxes, criminal damage.	Intercepting communications to steal containers or smuggle them without paying duties, stealing cargo from a craft, sending ransomware to freeze port IT assets, and requesting payment.
Competitors	Driven by the desire to obtain business or market information, these actors aim to intercept information to gain an economic competitive advantage.	Obtaining classified information on port management processes to use for own business development.
Activist or “Hacktivist”	Motivated by civil disobedience, this actor uses the Internet to spread its	Steering a craft to block a port entrance in protest.

[102] International Telecommunications Union (2008). Overview of cyber security. ITU-T X.1250, Geneva, Switzerland. Available at: https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=9136&lang=en

[103] CESNI (2023). Good practice guide on cybersecurity in inland navigation. Especially for ports, p.11. Available at: https://www.cesni.eu/wp-content/uploads/2023/05/Guide_cybersecurite_en.pdf

[104] Boyes, H., et.al. (2020). Good Practice Guide Cyber Security for Ports and Port Systems. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/859925/cyber-security-for-ports-and-port-systems-code-of-practice.pdf

Actor type	Action	Sample application in the context of inland navigation poorly trained or unsensitized employee
	idealism or create pressure on behalf of a specific cause.	Tampering with river infrastructure works (bridge, lock etc.) to disorganise the system
Nation State	Working for a nation State or other sovereign government structure, these actors are driven by a desire to disrupt or stop activities as a form of warfare (declared or otherwise).	Executing a denial-of-service attack on port assets to block access to a river or body of water, such as a lock system.
Terrorist	Use of the Internet to instil fear or cause some type of physical or economic chaos.	Taking control of a craft to damage a port, inflict casualties. Intercepting information regarding the arrival of dangerous material to the port and using this material to spread a form of chaos.
Espionage	Exploitation of connected devices to obtain secret or sensitive data, for resale or informant purposes. Espionage can be conducted by other States or by competitors.	Other nation States obtaining information on sensitive cargo material transiting via a port (for example vaccines, medical equipment). Spying on port operations to obtain competitor information.

Source: CESNI Guide on Cybersecurity in Inland Navigation

Some instances in the table presented above, like the terrorist threat, fall outside the purview of this guide because ports, at their individual level, may not possess the means to effectively mitigate these risks. Nevertheless, it remains imperative to consider these threats when orchestrating cybersecurity efforts in collaboration between ports and other stakeholders in inland navigation.

Main port assets that can be under cyber-attack are the following:

- Craft (vessel) reception and docking
- Security and safety
- Authorities and customs
- Passengers and tourist craft systems
- IT systems involved in traffic planning such at Vessel Traffic Services (VTS)
- Support services
- Mooring of the craft
- Automatic Identification System (AIS)
- Container storage and staying
- Energy service
- Distribution service
- Craft (vessel) communicating between the craft and the port or other land locations.

3.3 Threat taxonomy

Considering the characteristics and potential threat actors outlined in previous section, a range of threat scenarios can be delineated. These scenarios form the basis for constructing a port threat taxonomy, which enumerates the various threats that an inland port may be susceptible to, contingent upon its unique attributes.

A threat taxonomy offers an overview of cybersecurity events that have the potential to result in various impacts. The subsequent threat categories have been identified through a review of existing literature concerning threats to ships and maritime ports and have been adapted to be relevant to the port environment.

CESNI Guide on cybersecurity in inland navigation lists the following threat types to inland port cybersecurity:

Table 3-2: Types of cybersecurity threats in ports

Description applicable to ports	Example
Failures, malfunctions Systems or devices necessary for port operations are compromised and cannot operate to necessary extent.	The bridge or lock operation system is compromised by a denial-of-service attack, freezing operations and leading to the interruption of bridge or lock operations.
Physical attacks A cyber-attack is combined with an operational technology (OT) system, leading to the physical takeover of a machine for fraud, sabotage, vandalism, theft, terrorism, hacktivism, or unauthorised access.	A craft machinery system is taken over by activating an advanced threat attack. The craft is then driven into a port for terrorist purposes.
Eavesdropping, interception, hijacking Malicious actions on the network lead to the interception of sensitive data or network traffic or the hijacking of a user session.	Data stored in the application for container management with information about containers with dangerous goods is intercepted by terrorists for the interception of these goods.
Information spoofing or jamming Disguise of a communication or data source (sender of an SMS, GPS position) to make it seem as if it originates from a known, trusted information source when it is in fact information that has been modified or created by the attacker.	GPS information is spoofed to give wrong location leading to a threat to navigation
Disaster Environmental or natural disaster is caused to the port ecosystem from the exploitation of vulnerabilities in connected port assets.	A hacker tampers with container management application data, leading to mishandling of dangerous containers. This, in turn, can lead to a port fire, causing serious physical damage to the port assets.
Outages Supplies of resources to ports necessary to conduct operations are interrupted. Resources can include network, personnel, fuel, water and electricity.	A widespread attack on a connected power grid leads to a major power outage and the freeze of port operations, delaying the transport of goods.
Unintentional damage Damage to port data, systems or physical infrastructure is caused due to accidental manipulations of an insider.	An employee downloads a file with ransomware, freezing the entirety of the port's IT systems. A ransom demand is displayed on the locked screen.

Source: CESNI Guide on cybersecurity in inland navigation

3.4 Potential impacts

Threats are a cause for concern because, when leveraged, they possess the potential to cause tangible harm to an organization. The cybersecurity characteristics mentioned earlier, if breached, can lead to a wide array of consequences for the port or its affiliated businesses. Below is a compilation of potential impacts that may arise from the exploitation of vulnerabilities by cybersecurity threats.

CESNI Guide on cybersecurity in inland navigation lists the following impacts of cyber-attacks on inland ports:

Type of impact	Details
Reputational impact	A cyber-breach or incident can cause lasting reputational damage to the organisation, its name and brand. Reputational damages are hard to calculate, as they are often intangible, but have multiple secondary effects such as costs to recuperate past customer trust, increased regulatory scrutiny, and foregone business.
Financial loss	Costs incurred to the organisation following a cyber-incident can be multiple, including disaster recovery and crisis management costs, lawyers' fees, insurance premium increases, merchandise loss and costs from the delay of port services.
Regulatory sanctions	A cyber-incident can result in regulatory sanctions such as fines and increased accountability measures for the organisation in question.
Destruction of property	An attack on port IT systems can cause destruction of digital property such as data and information if not properly backed up. It may also result in the destruction of physical property such as IT hardware, supervisory control and data acquisition (SCADA) systems and – because of an attack – port craft, operations assets, containers and container contents.
Human loss or injury	In the event of a terrorist inspired cyber event, people may be injured or even killed. Flooding may be caused by a lock malfunctioning. Dangerous substances may cause an explosion.
Criminal activities: fraud, illegal trafficking	Criminals may use cyber-attack techniques such as network interception to obtain information and perform illegal activities such as trafficking of unauthorised substances in containers, or smuggling humans.
Theft of property	Criminals may use cyber-attack techniques with the objective of stealing items in the port: containers, their contents, goods, or assets (machinery, vehicles, spare parts…).
Environmental disaster	A cyber-event could cause the mismanagement of dangerous materials or fuel, which could result in an environmental disaster affecting inland waterways.

Source: CESNI Guide on cybersecurity in inland navigation

3.5 Mitigating measures for cybersecurity risks in inland ports

The CESNI Guide on cybersecurity in inland navigation[105] proposes roughly 120 mitigating measures, categorized into three categories:

1. measures relating to organisational policies and procedures (OPP),
2. measures relating to information technology and operational technologies (ITOT) policy, and finally,
3. technical cybersecurity measures (TSM).

105 CESNI (2023). Good practice guide on cybersecurity in inland navigation. Especially for ports. Available at: https://www.cesni.eu/wp-content/uploads/2023/05/Guide_cybersecurite_en.pdf

Each of these categories aims to offer a broad introduction to mitigation measures that ports should contemplate. However, it is crucial to note that the CESNI guidelines do not serve as a substitute for cybersecurity requirements outlined in audits, regulations established by certification agencies, individual states, or other regulatory entities. The proposed mitigation measures have been systematically arranged based on ascending levels of cyber maturity (low, medium, high).

Categories of measures are briefly explained in the following subsections, and for the detailed list of measures the reader is referred to the aforementioned CESNI Guide on cybersecurity in inland navigation.

3.5.1 Organisational policy and procedures

This subsection offers a glimpse into the organizational policies and protocols suitable for a well-established cybersecurity entity. These steps can be put into practice by the Chief Information Security Officer within the port. In smaller ports or organizations, another managerial role may assume this responsibility. The effectiveness of these measures is typically universal, but their extent and breadth can fluctuate according to the varying resources accessible to the port.

Roles and responsibilities

Establishing unambiguous roles and responsibilities marks the initial stride in introducing accountability and enhancing an organization's cybersecurity maturity. Ports are advised to put into effect the ensuing measures to address this area effectively.

Organisational processes

After delineating roles and responsibilities, the subsequent stage involves documenting these procedures and prerequisites. This documentation serves multiple purposes, including ensuring uninterrupted service delivery, adherence to specific security regulations, and facilitating the orderly transmission of information in case of service reorganization within the port.

Physical security

In the cybersecurity context, "physical security" is a term used when it becomes necessary to protect IT equipment physically. It is often used in contrast to "logical security," which involves safeguarding IT equipment in terms of access through software or the network. However, physical security constitutes an independent dimension within cybersecurity because it can be relevant in various attack scenarios. For instance, gaining access to a simple on/off button can disrupt a server, just as accessing a USB port can introduce malware by bypassing network security measures. Physical security encompasses aspects such as fire safety, protection against power surges, and contingency plans for power outages.

When formulating a cybersecurity plan, it's essential to incorporate considerations for physical security requirements. Critical IT infrastructure can be susceptible to vulnerabilities if accessible to external individuals with potentially malicious intentions. Therefore, cybersecurity plans should encompass strategies for mitigating risks stemming from breaches in physical security.

Incidence response and crisis management

It is essential to establish and put into practice well-defined policies and procedures when confronting a cybersecurity incident or crisis. These recommendations differentiate between cybersecurity incidents (situations that can be addressed by IT/security personnel without the need for escalation and consultation) and cybersecurity crises (situations of greater magnitude that disrupt the operations of the inland port and demand involvement from multiple managerial stakeholders).

Training and awareness

Conducting training and awareness initiatives targeting all stakeholders holds paramount importance in promoting cybersecurity best practices. Cybercriminals frequently exploit the human factor, which is a crucial element in most real-world cyberattack scenarios. Related measures can effectively mitigate the human factor risk by raising employees' awareness of the pivotal role they play in upholding cybersecurity.

3.5.2 Information technology (IT) / Operational technology (OT) policies for ports

This subsection, applicable to both ports and their suppliers, aims to present general best practices for securing IT/OT systems. In simple terms, IT encompasses systems related to data processing, while OT involves systems designed to interact with physical objects. These two types of systems can, of course, interact with each other, which is particularly relevant when discussing "IT/OT systems."

This subsection is specifically directed toward stakeholders in ports who work with operational systems and the equipment commonly found in ports. IT/OT systems can exhibit variation from one port to another but are generally characterised as systems that execute operational or physical tasks, often controlled through a computer or connected gateway. Within the context of ports, these systems may include, but are not restricted to:

- Port traffic control systems (e.g., traffic monitoring, berth management, weather monitoring tools).
- Navigation devices that communicate with port networks (e.g., AIS, GNSS).
- Terminal operations management systems, encompassing operational machinery, transshipment and warehouse systems, and terminal operating systems.
- Security and safety systems, such as access control, intrusion detectors, surveillance systems, and other alert mechanisms.

IT/OT systems hold particular relevance in port cybersecurity due to their increasing interconnectivity, especially with the expanding adoption of Internet of Things (IoT) devices. These systems are susceptible to vulnerabilities because they have often been designed without contemporary cybersecurity considerations that are standard in modern IT software. Moreover, they frequently operate on legacy systems with limited or no update capabilities, and they are sometimes omitted from cybersecurity initiatives and maintenance plans.

IT/OT General responsibilities

In conjunction with the establishment of the overarching roles and responsibilities detailed in the preceding subsection, management with a focus on sensitivity should allocate specific responsibilities, particularly in the realm of IT/OT systems. It is worth noting that the team responsible for these systems may differ substantially from the team overseeing port operations and IT systems. Therefore, it is crucial to acknowledge that individuals operating machinery and systems critical to port operations hold a significant role in cybersecurity. These operational systems must be integrated into the cybersecurity risk assessments conducted for the port.

Identity and access management (IAM)

Ports should establish well-defined policies governing the access and utilisation of industrial systems, interconnected machinery, and other operational systems essential for conducting port operations.

Physical security

Given that operational systems, industrial systems, and various machinery are typically physically accessible, unlike other assets such as data, IT components, software, and applications, it is imperative to formulate and enact tailored physical security measures for these systems.

Maintenance and operation of IT/OT systems

IT/OT systems frequently remain susceptible to cyberattacks because they commonly operate on legacy systems and are omitted from conventional cybersecurity measures like system updates and patching. Routine maintenance is also conducted on IT/OT systems. A cybersecurity best practice involves integrating fundamental security principles into the maintenance procedures of IT/OT systems. Moreover, security considerations should extend to the decommissioning and disposal of IT/OT systems.

Technical security measures for IT/OT systems

Port personnel responsible for network configuration, the establishment and setup of operational systems, and overall technical maintenance of these systems should consider these technical security measures. As a standard practice, it is essential to prioritise the isolation of critical systems from publicly accessible networks and the broader IT infrastructure, whenever feasible.

Monitoring IT/OT systems

Monitoring operational systems may pose challenges for ports with limited operational assets or constrained resource capacities. Nonetheless, management should contemplate implementing these measures, particularly when their operational systems hold pivotal roles in port operations and when it is a strategic cybersecurity imperative to detect and pre-empt cybersecurity threats targeting these systems.

Incident response and crisis management for IT/OT systems

In addition to the incident response and crisis management protocols outlined in the organisational policies and procedures subsection, these measures are specifically targeted at stakeholders who interact with IT/OT systems.

Securing navigation systems

This section has been incorporated to offer mitigation measures specifically pertaining to IT/OT navigation systems that establish connections between ports and navigating vessels. To maintain focus, only systems relevant to ports have been included in the CESNI Guide on cybersecurity in inland navigation, while systems exclusively concerning the crew or vessels have been excluded from consideration.

3.5.3 Technical cybersecurity measures for ports

The technical cybersecurity measures in this category are primarily aimed at the IT or information security departments of ports or organizations involved with ports. These recommended measures have been tailored to suit the port context but encompass general IT security practices that are applicable to all organizations with robust information security policies. It is important to acknowledge that not all measures may be applicable or feasible for ports with limited resources and staff, such as those lacking a dedicated IT department. However, it is advisable to review this category of measures as they can serve as a fundamental reference point for essential security considerations as an organization progresses in terms of IT maturity.

Identity and access management (IAM)

To maintain clarity and relevance, the CESNI Guide on cybersecurity in inland navigation distinguishes between Identity and Access Management (IAM) measures applicable to typical IT systems and those relevant to operational technologies.

System security

This subcategory of measures outlines the operations necessary to bolster the security of IT systems and assets. These tasks typically demand the expertise of an IT or IT security professional due to the specific configuration requirements for IT assets.

Network security

This subcategory elaborates on the measures that can be implemented to enhance the security of networks utilized by ports. Similar to the previous case, the execution of these measures will likely necessitate the involvement of IT (security) personnel. In instances where ports lack in-house IT security personnel, the option of engaging an external IT security provider could be contemplated.

Data protection

This subcategory addresses the management of data collected, processed, and utilized by various port stakeholders. It is important to highlight that ports situated within the European Union must adhere to the General Data Protection Regulation (GDPR)[106], enacted in 2016. In cases where GDPR is applicable, it should be prioritised as the primary reference for ensuring the appropriate handling of data and information.

Vulnerability management and systems monitoring

Vulnerability management measures are designed to gather information that can be used to effectively address identified vulnerabilities. Monitoring activities play a crucial role in detecting potentially malicious cyber behaviour within port systems.

[106] https://gdpr.eu

4 Digitalisation of environmental management tools in ports

4.1 Why digitalisation of Environmental Management Tools?

Ports apply various Environmental Management Tools for the management of their environmental impact. Environmental Management Tools (EMTs) refer to a range of strategies, methods, and instruments employed by organizations to manage and improve their environmental performance. These tools are designed to address various aspects of environmental management, such as monitoring, assessment, compliance, and sustainability. In the context of ports, EMTs can include technologies and approaches for monitoring air and water quality, waste management, energy efficiency, and overall sustainability initiatives. The goal is to use these tools to minimize the environmental impact of port operations while promoting efficiency and compliance with environmental regulations. One of such tools is an Environmental Management System (EMS) which serves as a structure for implementing measures that consider the organization's structure, plans, and resources to create, execute, and sustain an environmental protection policy.[107] One well-known Environmental Management System (EMS) is the ISO 14001 standard. ISO 14001 provides a framework for organizations to establish and operate an effective environmental management system. It outlines the criteria for an environmental management system and can be used by any organization, regardless of its size, type, or location. ISO 14001 focuses on processes for continual improvement in environmental performance, legal compliance, and pollution prevention. Organizations that implement ISO 14001 demonstrate a commitment to environmental responsibility and sustainability. ISO 14001, when properly applied, enhances a port's environmental performance, offering a systematic approach to handling environmental matters. Additionally, it plays a crucial role in establishing management structures to effectively address both immediate and long-term impacts of services and processes on the environment.

Other examples of Environmental Management Systems may include proprietary systems developed by organizations or specific tools and approaches tailored to address the environmental aspects of a particular industry or sector, such as the inland navigation or port industry.

Digitalising EMTs in inland ports offers several advantages that align with the broader trend of digital transformation in various industries. Various reasons why inland ports might want to digitalise their EMT are explained in the below table:

Table 4-1: Reasoning behind digitalisation of EMT

Reasons for EMT digitalisation	Benefits of EMT digitalisation
Efficiency and automation	Digital EMT systems can automate data collection, analysis, and reporting processes, saving time, and reducing the risk of manual errors. This efficiency gain allows port authorities to focus on strategic environmental management decisions.
Real-time monitoring	Digital EMT allows for real-time monitoring of environmental parameters. This capability enables prompt detection of anomalies, spills, or other environmental

[107] Reddy, N., Sai B. (2017) Tools of Environmental Management: Environmental impact assessment of development projects. The Earth Center. Telangana State Forest Academy Dulapally. Available at: https://www.slideshare.net/saibhaskar/tools-of-environmental-management

Reasons for EMT digitalisation	Benefits of EMT digitalisation
	issues, facilitating quicker response times and reducing the potential impact on the environment.
Data accuracy and precision	Digital tools ensure higher accuracy and precision in data collection and reporting. This is crucial for compliance with environmental regulations and standards. Accurate data also helps in making informed decisions related to environmental management.
Regulatory compliance	Inland ports are subject to various environmental regulations and standards. Digital EMT systems can assist in ensuring compliance by providing a structured approach to data management, reporting, and documentation.
Environmental Impact Assessment	Digital tools enable more sophisticated environmental impact assessments. Inland ports can simulate and model the potential impact of their activities on the environment. This proactive approach supports sustainable development and community engagement.
Transparency and stakeholder communication	Digital EMT systems enhance transparency by providing stakeholders, including the local community and regulatory bodies, with access to relevant environmental data. Improved communication can build trust and foster collaboration.
Risk management	Inland ports face various environmental risks, such as spills, emissions, or other incidents. Digital EMT allows for the development of risk management strategies, including early warning systems and contingency plans.
Cost reduction	While there may be an initial investment in digitalisation, the long-term benefits often include cost reduction. Automation and efficiency gains can lead to resource savings in data collection, analysis, and reporting.
Integration with other systems	Digital EMT systems can be integrated with other port management systems, creating a holistic approach to operations. For example, integrating environmental data with logistics and supply chain systems can provide a comprehensive view of the port's activities.
Adaptation to technological trends	Embracing digital tools aligns inland ports with broader technological trends. This can attract investment, partnerships, and collaboration with innovative entities in the transportation and logistics sector.

Source: Consortium

In conclusion, digitalising Environmental Management Tools supports inland ports in meeting environmental objectives efficiently, complying with regulations, and contributing to sustainable and responsible port management.

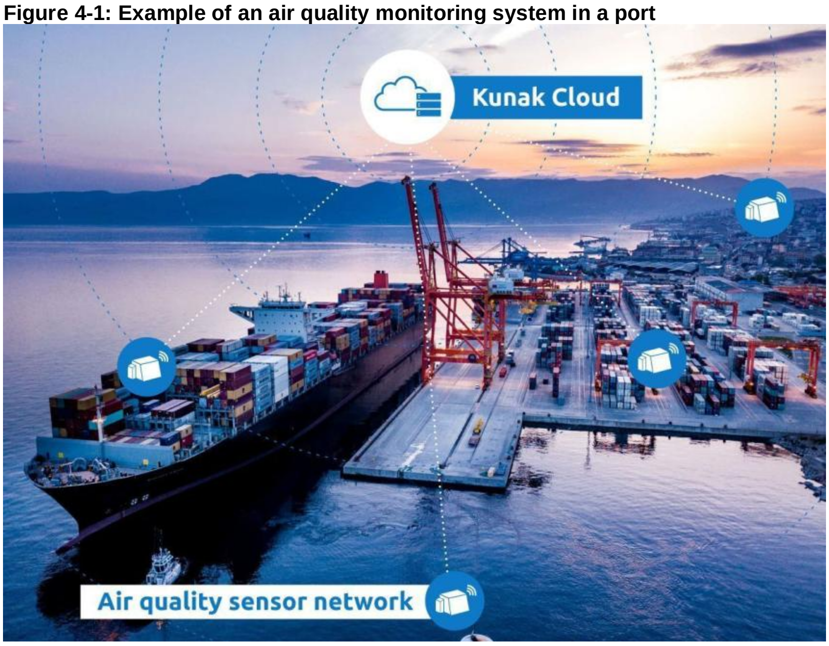
4.2 Methodologies for assessing environmental performance of ports supported by digital tools

In recent years, the transport industry has witnessed a transformative shift towards sustainable and environmentally friendly practices. Ports, as crucial hubs in trade and logistics, play a pivotal role in this transition. The adoption of digital tools has emerged as a key strategy in assessing and enhancing the environmental performance of ports. This section explores various methodologies employed in this context, encompassing digitalisation in air quality monitoring systems, water quality monitoring systems, noise monitoring systems, energy consumption monitoring systems, energy management systems, the innovative concept of Just-in-Time coordination in transport and waste management practices.

4.2.1 Digitalised air quality monitoring systems

Air quality monitoring systems measure various air pollutants to assess air quality. They can include sensors, data collection devices, data storage systems and analysis tools.

Figure 4-1: Example of an air quality monitoring system in a port



Source: Kunak[108]

The development of the monitoring systems has come hand in hand with the development of new technological developments such as the Internet of Things (IoT), thus allowing the deployment of a larger number of air quality monitoring systems.[109] Air quality measuring in inland ports can be digitalised through the deployment of such sensors and monitoring devices that are capable of collecting and sharing real-time data on air quality parameters. These sensors can be strategically placed in various locations within the port, such as cargo handling areas, vehicle transit routes, and storage facilities. The collected data, which includes information on pollutants like particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and others, is transmitted digitally to a centralised system.

The digital platform can analyse and process the data, providing insights into the air quality levels at different times and locations within the inland port. This information can be visualized through user-friendly interfaces, dashboards, or mobile apps, allowing port authorities and operators to monitor air quality in real-time. Additionally, historical data can be stored and analysed to identify trends and patterns, helping in the formulation of effective strategies for improving air quality.[110]

Air quality in ports can be measured by IoT-based devices mounted on airborne drones. This approach provides a dynamic and flexible way to monitor air quality across different areas of the port. Drones equipped with air quality sensors and IoT technology can be deployed to specific locations within the port, allowing for real-time data collection on various air pollutants.[111]

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[108] https://kunakair.com/air-quality-ports/

[109] Múnera, D., Tobon, D.P., Aguirre, J., & et al. (2021). IoT-based air quality monitoring systems for smart cities: A systematic mapping study. *International Journal of Electrical and Computer Engineering (IJECE)*, 11(4), Available at: https://doi.org/10.11591/ijece.v11i4.pp3470-3482

[110] https://enviraiot.com/air-quality-monitoring-system-ports/

[111] Ye Y, Geng P. (2023). A Review of Air Pollution Monitoring Technology for Ports. *Applied Sciences*, 13(8):5049. Available at: https://doi.org/10.3390/app13085049

The digitalisation of air quality measurement not only enhances the accuracy and efficiency of monitoring but also facilitates timely decision-making and proactive interventions to address potential environmental concerns in inland ports.

4.2.2 Digitalised water quality monitoring systems

Ensuring the preservation of water quality is essential for sustainable port operations. Digital tools facilitate the implementation of water quality monitoring systems, employing sensors to assess parameters such as chemical composition, turbidity, and pollutant levels. By continuously monitoring water quality, ports can detect anomalies promptly and initiate corrective measures. This digital approach not only safeguards inland waterway ecosystems but also aligns with stringent environmental regulations affecting port activities.

Water quality monitoring systems focus on assessing the quality of water bodies, including rivers, lakes, and coastal waters. Such systems use sensors to monitor parameters such as pH, dissolved oxygen, chemical pollutants, and temperature in water bodies within and/or near the port.

Water quality measuring in inland ports can be digitalised through the deployment of smart sensors and IoT technologies. In general, the digitalisation process can be performed as follows:

- **Smart sensors**. Smart sensors are installed in strategic locations within the port's water bodies. These sensors are designed to measure various water quality parameters such as temperature, pH levels, dissolved oxygen, turbidity, and the concentration of pollutants.[112]
- **IoT connectivity**. These smart sensors are then connected to an IoT network. The sensors are equipped with communication modules that allow them to transmit real-time data wirelessly.
- **Data transmission.** The smart sensors continuously collect water quality data, and this data is transmitted in real-time to a central data hub or cloud-based platform using the IoT network. The transmission can occur through wireless communication protocols like Wi-Fi, cellular networks, or other suitable connectivity options.
- **Cloud-based analytics**. The collected data is stored in the cloud, where advanced analytics tools can process and analyse it. Cloud-based platforms provide scalable storage and computational capabilities, allowing for efficient handling of large datasets.
- **Visualization and reporting**. The analysed data can be visualized through user-friendly dashboards and reports. Port authorities and environmental managers can access this information remotely through web interfaces or mobile applications.
- **Alerts and notifications**. An automated alert system that triggers notifications in case of abnormal water quality conditions can be implemented. This ensures a rapid response to any potential environmental issues.
- **Integration with existing systems**. The water quality monitoring system is usually integrated with other port management systems for a comprehensive approach. This could include integrating data with geographic information systems (GIS) or other relevant databases.
- **Regular calibration and maintenance**. Regular calibration and maintenance of the smart sensors should be ensured to guarantee the accuracy and reliability of the collected data.

[112] https://www.boquinstruments.com/multiparameter-online-systems/

Figure 4-2: IoT digital multi-parameter water quality sensor for river and sea waters

Source: Boqu Instruments

Water quality sensor are typically placed on various places in the water body of the port and its surroundings. They can be placed in buoys, fixed to a quay wall or other port infrastructure being in the water, or they can be mobile and attached to waterborne drones.[113]

Digitalizing water quality measurement in inland ports through IoT technologies enhances the efficiency, accuracy, and timeliness of environmental monitoring. It provides port authorities with valuable insights for proactive environmental management and compliance with regulatory standards.

4.2.3 Digitalised noise monitoring systems

Noise pollution is a common concern associated with port operations, affecting both local residents and wildlife. Digital tools offer sophisticated noise monitoring systems that utilise sensors and real-time data analytics to assess and manage noise levels. For example, by identifying peak noise periods and high-impact areas, ports can implement strategies to mitigate disturbances. Digitalisation in noise monitoring enhances the overall environmental performance of ports by minimizing disruptions to surrounding communities.

Noise measurement in inland ports can be digitalised through the implementation of digital sensors and smart technologies. An overview of how the digitalisation of noise measurement works and why it is beneficial is explained in continuation:

- **Digital noise sensors**. Digital noise sensors are deployed in key locations in and around the inland port. These sensors are designed to capture and measure the levels of ambient noise in their surroundings.
- **IoT connectivity**. Digital noise sensors are connected to an IoT network. These sensors are equipped with communication modules that enable them to transmit real-time noise data wirelessly.
- **Real-time data transmission**. The digital noise sensors continuously collect noise level data, and this information is transmitted in real-time to a central data hub or cloud-based platform through the IoT network. Common communication protocols like Wi-Fi, cellular networks, or other wireless options can be utilised.

113 Beshah, W.T. et al., (2021). IoT Based Real-Time Water Quality Monitoring and Visualization System Using an Autonomous Surface Vehicle," OCEANS 2021: San Diego – Porto, San Diego, CA, USA, pp. 1-4, Available at: doi:10.23919/OCEANS44145.2021.9705673

- **Cloud-based analytics**. The transmitted data is stored and processed in the cloud. Cloud-based platforms offer the computational capacity to analyse large datasets efficiently.
- **Visualization and reporting**. Noise level data can be presented on user-friendly dashboards for easier visualisation. Port authorities and relevant stakeholders can access this information remotely through web interfaces or mobile applications.
- **Alerts and notifications**. An automated alert system that notifies port authorities when noise levels exceed predefined thresholds can be implemented. This feature allows for timely responses to potential noise-related issues.
- **Integration with other systems**. The noise monitoring system can be integrated with other port management systems, such as environmental management tools or geographic information systems (GIS), to provide a holistic view of the port's environmental conditions.

Figure 4-3: Benefits of digitalising noise measurement in inland ports

Source: Consortium

It is worth mentioning here the European research project I^{2}PANEMA[114], where one of the research topics was the use of IoT sensors and active noise control (ANC) in ports, with a pilot in an inland port of Nuremberg, Germany. At ports, noise generated during loading processes, especially in moving and loading containers, affects nearby residents, flora and fauna. Implementing measures at the source, where individual containers are handled, is crucial for effective noise reduction. Since containers cannot have noise-reducing features, an Active Noise Control (ANC) system is employed. This adaptive system, similar to ANC headphones, uses an array of speakers to create a virtual noise barrier, actively reducing noise in real time. A demonstrator system at the port of Nuremberg employs microphones and speakers on a gantry crane to calculate and transmit inverted noise signals, minimizing residual noise and offering a networked solution for active noise control in port operations. In the context of the Internet of Things (IoT), active noise control (ANC) is a pivotal aspect of the project, leveraging IoT technologies to integrate stakeholders and data sources in the port environment. Collaborating with partners, the Fraunhofer Institute for Structural Durability and System Reliability LBF developed a dashboard for real-time monitoring of the ANC

[114] https://www.i2panema.eu

system status data. This ANC system, treated as a sensor node, can seamlessly integrate into a broader IoT network for comprehensive noise management. The demonstrated system achieved a notable reduction of 6 decibels (dB), equivalent to halving the sound pressure level. Theoretical analyses suggest that employing two-dimensional speaker arrays could potentially achieve reductions of up to 20 dB. This reduction in noise emissions not only enhances environmental sustainability but also increases handling capacity, especially during nighttime hours when noise quotas typically restrict container handling, allowing for improved overall efficiency in port operations.[115]

In summary, digitalising noise measurement in inland ports enhances environmental monitoring capabilities, promotes regulatory compliance, supports proactive measures to manage and mitigate noise-related impacts, and, in certain cases, even contributes to the increase of productivity and overall efficiency of inland ports.

4.2.4 Digitalised energy consumption monitoring systems

The transport industry is a significant energy consumer, and ports are no exception. Digital tools facilitate the implementation of energy consumption monitoring systems that track and analyse the energy usage of port facilities. Smart meters and sensors provide granular insights into energy consumption patterns, enabling ports to identify inefficiencies and implement energy-saving measures. This digital approach contributes not only to environmental sustainability but also to cost reduction and operational efficiency.

Beyond monitoring, ports are increasingly adopting comprehensive energy management systems powered by digital tools.[116] These systems integrate data from various sources to optimise energy usage, deploy smart grids, and incorporate renewable energy sources. By embracing digitalisation in energy management, ports can transition towards greener and more sustainable energy practices, reducing their carbon footprint and contributing to global climate goals.

The digitalisation of energy consumption monitoring in ports involves the use of advanced technologies and smart systems to monitor, analyse, and optimise the energy usage within the port facilities. The key aspects and benefits of digitalising energy consumption monitoring are the following:

- **Smart energy meters and sensors**. Smart energy meters and sensors[117] are deployed across different areas of the port, including warehouses, terminals, and administrative buildings. These devices are equipped with digital capabilities to measure and record energy consumption data.
- **IoT integration**. Smart meters and sensors are typically connected to an IoT network, creating a connected infrastructure.[118] IoT connectivity enables the real-time transmission of energy consumption data to a centralised data platform.
- **Real-time data analytics**. Data analytics tools can be implemented to process and analyse the real-time energy consumption data, while advanced algorithms are used to identify patterns, trends, and anomalies in energy usage.

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115 https://www.lbf.fraunhofer.de/en/projects/noise-control-ports-industrial-facilities.html

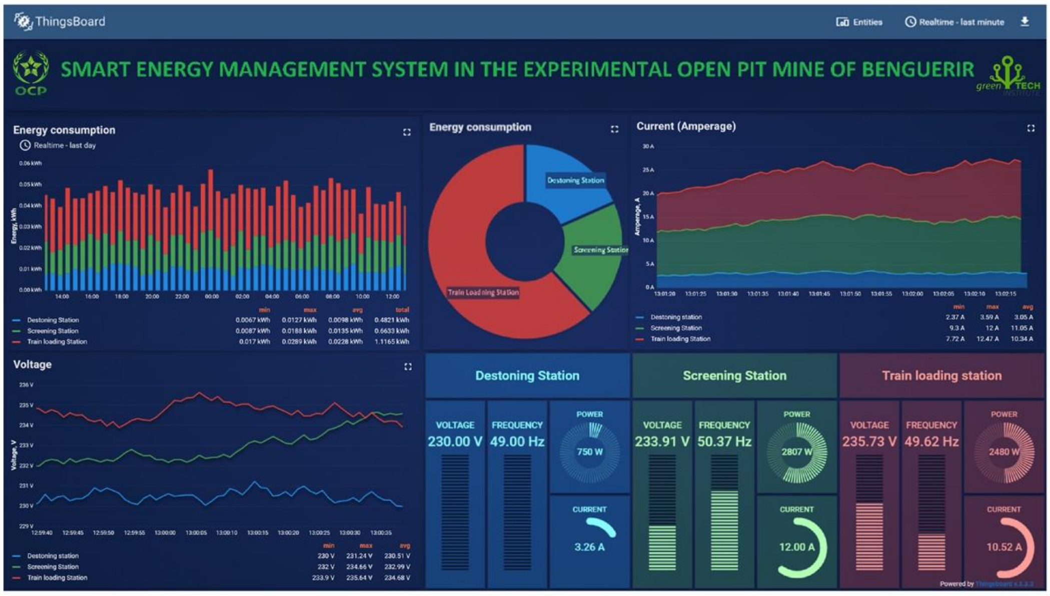
116 Bui, V.D., Nguyen, H.P., Nguyen, X.P. (2021). Optimization of energy management systems in seaports as a potential strategy for sustainable development, *Journal of Mechanical Engineering Research and Developments*, 44(8). Available at: https://jmerd.net/Paper/Vol.44,No.8(2021)/19-30.pdf

117 https://www.iea.org/articles/energy-efficiency-and-digitalisation

118 Rind YM, Raza MH, Zubair M, Mehmood MQ, Massoud Y. (2023). Smart Energy Meters for Smart Grids, an Internet of Things Perspective. *Energies,* 16(4):1974. https://doi.org/10.3390/en16041974

- **Cloud-based monitoring**. Energy consumption data are stored in a cloud-based platform that allows for secure and scalable data storage[119]. Cloud solutions provide the flexibility to access data from anywhere and support efficient data management.
- **Visualisation and reporting**. User-friendly dashboards and reports that visualise energy consumption patterns and trends provide port authorities and stakeholders with insights into energy usage and efficiency.
- **Energy efficiency recommendations**. Data analytics are to generate recommendations for improving energy efficiency and identify areas where energy savings can be achieved through equipment upgrades, process optimisation, or the adoption of renewable energy sources.
- **Integration with energy management systems**. Digital energy consumption monitoring system is typically integrated with broader energy management systems to ensure interoperability with other smart systems within the port environment.
- **Automated alerts and notifications**. Automated alert systems can notify port authorities of unusual energy consumption patterns or potential issues. Such systems also facilitate proactive responses to energy-related challenges.
- **Historical data analysis**. Historical energy consumption data can be used to identify long-term trends and assess the impact of energy-saving initiatives.

Figure 4-4: Example of an energy management dashboard



Source: Laayati, et.al.[120]

Benefits of digitalising energy consumption monitoring in ports:

- Cost savings through identification of opportunities for reducing energy costs and optimising consumption.
- Sustainability promotion by monitoring and minimising the carbon footprint.
- Regulatory compliance with energy efficiency regulations and standards.
- Operational efficiency improvement by managing energy resources more effectively.
- Enabling data-driven decision-making for energy-related initiatives and investments.

[119] Vishwanath, A., Jalali, F., Ayre, R., Alpcan, T., Hinton, K., Tucker, R. (2015). Energy Consumption of Interactive Cloud-Based and Local Applications. *IEEE Journal on Selected Areas in Communications*, 33. p.616 - 626. Available at: DOI**:** 10.1109/JSAC.2015.2393431

[120] Laayati O., Bouzi, M., Chebak, A. (2022). Smart Energy Management System: Design of a Monitoring and Peak Load Forecasting System for an Experimental Open-Pit Mine. *Applied System Innovation*, 5(1):18. https://doi.org/10.3390/asi5010018

The digitalisation of energy consumption monitoring in ports enhances visibility, efficiency, and sustainability, providing port authorities with the tools needed to make informed decisions and drive positive environmental and economic outcomes.

4.2.5 Digitalisation of Just-in-Time coordination and its use as an EMT

A novel approach to environmental performance is the concept of Just-in-Time (JIT) coordination in transport. This involves leveraging digital tools to optimise vessel arrivals, reducing idle waiting times and associated emissions. By integrating port navigation systems with vessel navigation systems, stakeholders can coordinate arrivals more efficiently, minimising fuel consumption and emissions. Just-in-Time coordination not only enhances environmental sustainability but also improves overall port efficiency.

Just-in-time transport coordination in ports is digitalised through the use of advanced technologies and data-driven solutions, transforming it into an effective environmental management tool. Digitalisation enhances JIT transport coordination for environmental sustainability in ports in the following way:

- **Real-time tracking and visibility**. Digital platforms enable real-time tracking of shipments, vessels, and transport vehicles. Port authorities and stakeholders have visibility into the movement of goods, allowing for precise coordination and scheduling.
- **Data analytics and predictive modelling**. Data analytics and predictive modelling are employed to analyse historical data and forecast future demand. Algorithms can predict arrival times, optimise transportation routes, and anticipate potential congestion, reducing unnecessary waiting and idling.
- **IoT and sensors**. IoT devices and sensors are deployed across the port infrastructure. These devices provide real-time information on cargo status, berth occupancy, vehicle locations, and environmental conditions, facilitating efficient coordination.
- **Automated decision-making**. Automated decision-making systems use algorithms to optimise transport schedules based on real-time data. These systems consider factors such as traffic conditions, weather, and port capacity, minimising delays and enhancing efficiency.
- **Collaborative platforms**. Digital platforms and collaborative tools enable effective communication and coordination among various stakeholders, including shippers, carriers, and logistics providers. Information sharing ensures that everyone is on the same page, reducing uncertainties and delays.
- **Smart port management systems**. Ports implement smart management systems that integrate various technologies for comprehensive coordination. These systems manage vessel schedules, cargo handling, and transportation, optimising resources for environmental benefits.
- **Emission monitoring and reporting**. Digital tools can monitor emissions from vehicles and vessels in real time. Emission data is collected and analysed, allowing port authorities to assess the environmental impact of transport activities and make informed decisions.
- **Mobile apps for stakeholders**. Mobile applications provide stakeholders with instant access to relevant information. Truck drivers, for example, can receive real-time updates on cargo availability and optimised routes, reducing unnecessary trips and emissions.
- **Integration with sustainable practices**. Digitalisation supports the integration of sustainable practices, such as the use of electric and autonomous vehicles and JIT coordination. The coordination system can be set to prioritise the use of environmentally friendly modes of transport or to schedule the arrivals of vessels and vehicles prioritising an optimal trade-off between the trade demands and emissions.

By leveraging digital technologies, JIT transport coordination becomes a dynamic and responsive tool for environmental management in ports. The use of real-time data, analytics, and collaborative platforms optimizes transport operations, reduces emissions, and contributes to the overall sustainability of port activities.

Many inland ports have experienced problems of extended waiting times for vessels. This situation leads to increased local emissions, elevated safety risks, and heightened coordination requirements for ports. Vessels also experience higher fuel consumption and potential revenue loss due to extended waiting times. Therefore, the implementation of coordinated Just-In-Time arrival to the port becomes crucial in enhancing the overall environmental impact of inland navigation. Just-In-Time arrival proves to be fuel-efficient by providing vessels with early and updated information about the requested time of arrival, allowing ships to adjust their speed according to changes in the port's timetable.

One of the very convenient digital platforms for JIT coordination is the Wärtsilä Navi-Port.[121] It was developed primarily for seaports, but it can as well be applied in inland ports. This platform serves as middleware that seamlessly integrates with the Wärtsilä Fleet Operations Solution System. It facilitates the exchange of the latest accurate arrival times between ports and ships. With dynamic, real-time data, coordination improves, enabling more efficient planning of port and terminal operations while mitigating congestion and reducing the risk of collisions. Early information exchange supports coordinated Just-In-Time arrival, thereby reducing vessel emissions. Connecting the port navigation system and vessel navigation system allows for automated correspondence, lightening the overall workload of various stakeholders. In a nutshell, the process of Navi-Port unfolds in the following steps:

- The terminal or port experiences a delay and generates a new requested time of arrival (RTA).
- The RTA is shared with Navi-Port and delivered to the Fleet Operations Centre.
- The Fleet Operations Centre and the Captain agree on the new RTA.
- Route and speed are optimised, resulting in a new estimated time of arrival (ETA).
- The new ETA is delivered back to Navi-Port.
- Navi-Port receives the new ETA and shares it with the terminal or port.

Key benefits:

- Reduce the required speed to a comfortable and necessary level, save fuel and reduce CO2 emission.
- Higher fuel efficiency of cargo transportation leads to lower freight costs.
- Priority service in port's operations.
- Reduce maintenance operations.

Key features:

- Increase safety with better coordination of vessel traffic and removal of traffic congestions.
- Reduce local area CO2 emissions and noise pollution with decreased anchorage time.
- Get full transparency on the ships arriving at the port and related ETA updates.
- Get a capability to communicate to ships adjusting recommendations on the requested time of arrival (RTA).
- Know in advance when the ship is coming to ensure all port services are ready to accept the ship, therefore, optimising needed resources.

[121] https://www.wartsila.com/marine/products/port-optimisation/jit-naviport

Figure 4-5: Wärtsilä Navi-Port functional diagram

Source: Wartsila[122]

4.2.6 Digitalisation of waste management in ports

Digital tools are increasingly being employed to manage waste in ports efficiently.[123] Waste management systems leverage sensors, RFID technology, and data analytics to monitor and optimise waste collection, recycling, and disposal processes. By digitising waste management, ports can reduce environmental impact, enhance recycling efforts, and ensure compliance with waste disposal regulations.

Waste management in inland ports can be digitalised through various technologies and practices to enhance efficiency and sustainability. Examples include:[124]

- **Smart bins and sensors**. Use of smart waste bins equipped with sensors that monitor waste levels in real-time. When the bins are nearing full capacity, the sensors trigger notifications to waste management teams for timely collection. This minimises unnecessary trips and reduces operational costs.
- **IoT-based waste monitoring**. IoT system can be applied to monitor waste across the entire port. IoT sensors can track waste generation, optimise collection routes, and provide data for informed decision-making. It ensures that waste is managed based on actual demand.
- **Waste sorting technology**. Ports can incorporate automated waste sorting systems that use digital sensors and robotics to separate recyclables, organic waste, and general waste. This technology improves recycling rates and reduces landfill waste.
- **Waste tracking software**. Use digital waste tracking software to monitor the flow of waste materials within the port. It helps in record-keeping, reporting, and ensuring compliance with waste regulations.
- **Blockchain for traceability**. Blockchain technology can be implemented to create a transparent and tamper-proof record of waste management processes. This ensures traceability and accountability in waste handling.

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[122] https://www.wartsila.com/media/news/19-02-2020-successful-application-of-wartsila-navi-port-highlights-benefits-of-just-in-time-sailing-3270471

[123] Business Finland (2022). Smart and Green Ports from Finland, Report, Available at: https://mediabank.businessfinland.fi/l/xJLmwxzffVzc

[124] https://www.eea.europa.eu/themes/waste/waste-management/digital-technologies-will-deliver-more

- **Predictive analytics**. Predictive analytics can be used to forecast waste generation patterns based on historical data and other factors. This allows for proactive waste management and resource allocation.
- **Mobile apps and portals**. Mobile applications or online portals allow port users, tenants, and visitors to report waste-related issues, request pickups, or access information on recycling and waste reduction.
- **Drones for surveillance**. Drones equipped with cameras and sensors can be used for surveillance of waste storage areas to detect illegal dumping or potential environmental hazards.
- **Data integration**. Data from waste management systems can be integrated with other port management systems, such as traffic management, logistics, and energy management, to achieve a holistic view of the port's sustainability efforts.
- **Environmental management software**. Ports can use dedicated environmental management software that includes modules for port-generated and ship-generated waste tracking, compliance reporting, and sustainability analysis. More focused software also exists, such as waste management software. Such software is tools designed to track, manage, and optimise waste generation, collection, recycling, and disposal processes. This software can be a part of a waste management system that tracks the types and quantities of waste generated within the port and manages recycling and disposal processes.

Digitalising waste management in inland ports not only improves operational efficiency but also enhances sustainability and environmental compliance. It enables ports to reduce waste, optimise resource use, and minimise their environmental footprint.

The methodologies discussed point out the transformative impact of digital tools on the environmental performance of ports. From air and water quality monitoring to energy management, waste management, and innovative transport coordination, digitalisation has become integral to fostering sustainability in maritime operations. As ports continue to embrace these methodologies, the industry moves towards a more environmentally conscious and efficient future. The symbiosis of digital tools with environmental management represents a powerful paradigm shift, ensuring that ports play a leading role in efforts to create a sustainable and resilient inland waterways ecosystem.

4.3 Assessment of effectiveness and efficiency of digitalisation for the greening of inland ports

Practically all digital tools and technologies described in previous chapters have environmental benefits for inland ports. Port digitalisation technologies are revolutionising the way inland ports operate, offering a multitude of environmental benefits that cannot be overlooked. As these ports embrace the power of digital innovation, they are becoming catalysts for more sustainable and eco-friendly practices.

First and foremost, digitalisation and automation streamline port processes. With the aid of IoT devices and data analytics, cargo handling and logistics are optimised, leading to a reduction in energy consumption. This, in turn, minimises emissions, making operations more environmentally friendly. Furthermore, smart infrastructure provides real-time tracking of cargo and assets, enabling precise resource allocation and reducing unnecessary vehicle movement. As a result, fuel consumption is reduced, and greenhouse gas emissions are lowered. Additionally, automated traffic management systems enhance the flow of vehicles within the port, reducing congestion, idling time, and air pollution. Reducing paper-based processes and embracing digital documentation also has a positive environmental impact. It saves countless trees and reduces waste, aligning port operations with eco-friendly practices.

Summarised overview of environmental benefits of port digitalisation technologies is given in the following table:

Table 4-2 Environmental benefits of port digitalisation technologies

Digital technologies	Environmental benefits
Internet of Things (IoT)	• IoT devices, such as sensors and actuators, can monitor and collect data on various environmental factors within the port. • This data can include air quality, water quality, noise levels, and more. • The real-time data allows port authorities to make informed decisions to mitigate environmental impacts.
Blockchain	• Paperless work by creating digital, tamper-proof ledgers for transactions and cargo documentation. • Through supply chain transparency, ports can monitor emissions and energy consumption across the entire supply chain, identifying areas for improvement. • Facilitates peer-to-peer trading of renewable energy. Excess energy generated by one part of the port can be sold to another. • Encourages green shipping practices, as smart contracts and blockchain can offer incentives for low-emission vessels. • Verifies sustainable practices, tracks resource consumption, and provides incentives for eco-friendly behaviour.
Big data analytics	• Data collected by various sources and IoT devices can be used for minimisation of environmental impact. • Ports can use the data related to vehicle, vessel, and equipment emissions to make informed decisions on adopting cleaner energy sources, providing shore-side electricity and charging stations. • Data analytics can be used to propose re-organisation of port operation practices in such way to enable reduced environmental footprint by implementing sustainable practices.
Artificial intelligence	• AI can assist ports to comply with environmental regulations by monitoring emissions and suggesting environmentally friendly practices and strategies. In this way, AI directly assists in the reduction of the environmental footprint of ports. • A supervised learning model as a subdomain of AI can learn and check the plausibility of schedules and predict the energy consumption of battery-powered automated guided vehicles (AGVs) in horizontal transportation areas.[125] • AI can predict emissions on the basis of ship activity, meteorological data, and air quality data.[126] • By predicting peak energy demand periods, AI can optimise energy distribution and reduce energy waste within ports. • By analysing emissions data, AI can identify sources of high emissions and provide recommendations for emission reduction strategies. • AI-powered logistics and transportation management systems can optimize the routes and scheduling of trucks and other transport modes within the port. By

[125] Mansoursamaei, M., Moradi, M., González-Ramírez, R., Lalla-Ruiz, E. (2023). Machine Learning for Promoting Environmental Sustainability in Ports, *Journal of Advanced Transportation*, Article ID 2144733, Available at: https://doi.org/10.1155/2023/2144733

[126] Hong, H., Jeon, H., Youn, C. and Kim, H. (2021). Incorporation of shipping activity data in recurrent neural networks and long short-term memory models to improve air quality predictions around Busan port, *Atmosphere*, 12(9). Available at: https://doi.org/10.3390/atmos12091172

Digital technologies	Environmental benefits
	minimizing travel distances and idle times, AI reduces fuel consumption and emissions.
5G networks	• Ports can use 5G to deploy sensors and monitoring systems for environmental purposes, such as real-time monitoring air quality, water (in the port basin) quality, noise levels, emissions from vessels and all vehicle and cargo handling equipment circulating in the port, etc. • Such data collection and processing can help ports comply with environmental regulations or set a good practice example of environmental sustainability. • Reduced latency can provide faster operations and greater productivity of remotely operated cargo handling equipment, thus improving the productivity/emissions ratio.
Data analytics and business intelligence	• BI tools can assist in ensuring that the port authorities and operators comply with regulatory and reporting requirements. • These tools can automatically generate compliance reports and send them to the relevant authorities.
Simulation technology	• Simulation software can help assess the environmental impact of port operations, including emissions, noise pollution, and habitat disruption.
Augmented and virtual reality technology	• AR and VR can provide real-time environmental data, such as air quality, noise levels, and weather conditions, taken over from sensors and control centres, overlaid onto the port environment. This information is valuable for monitoring and ensuring compliance with environmental regulations.
Digital Twins	• Digital twins enable precise monitoring and control of various port operations which can be used to minimise resource wastage, including energy and fuel consumption, thus reducing the environmental impact. • Digital twins provide real-time data on the performance of equipment and infrastructure which helps identify inefficiencies and opportunities for energy savings. • Digital twins can include environmental monitoring sensors that track air and water quality or noise. This data is invaluable for ensuring that port operations are not negatively impacting the surrounding environment.
Automation[127]	• Inland port automation can lead to reduced energy consumption and thereafter to lower emissions. • By optimising port operations and cutting on idle times, automation can contribute to environmental sustainability goals.

Source: Consortium

In addition to the above listed technologies, various digital tools, as products of digital technologies, can also provide direct and/or indirect environmental benefits in inland ports. Such benefits are summarised in the following table:

Table 4-3 Environmental benefits of port digitalisation tools

Digital tools	Environmental benefits
Port Community Systems	• The collaboration facilitated by a PCS often extends to sustainability initiatives, such as optimising transport routes and reducing environmental impacts. • Paperless operation. • By minimising congestion and queuing, ports can reduce vehicle idling time, which in turn lowers fuel consumption and emissions.

[127] Although not a digitalisation technology *per se*, automation is one of the results of digitalisation, highly dependent on the digitalisation levels, and is therefore included in this overview.

Digital tools	Environmental benefits
	• Efficient processes and reduced waiting times for vessels and trucks contribute to faster turnaround times for port users which, in turn, mean less time spent with engines running in port, resulting in fewer emissions.
Port management systems and Terminal planning and operating systems (PMS and TOS)	• PMS and TOS use real-time data to efficiently allocate resources like berths, cargo-handling equipment, and labour, which reduces unnecessary energy consumption, greenhouse gas emissions, and air pollution. • By minimizing congestion and waiting times, they reduce the idling time of vehicles and vessels, which leads to lower fuel consumption and emissions. • PMS and TPOS optimise the handling of cargo, ensuring quick and efficient processing, which reduces the energy use and emissions associated with cargo loading and unloading. • Improved efficiency in cargo handling and storage reduces the likelihood of cargo damage, spoilage, or loss, thereby decreasing waste and minimising the environmental impact associated with waste disposal.
Land traffic management systems (LTMS)	• Some LTMS solutions include environmental monitoring features to track and manage emissions, noise levels, and other environmental factors specifically related to land-based traffic within the port.
Vehicle booking systems	• Contribute to reducing emissions by minimising truck idling times and optimising traffic flow.
Gate operating systems (GOS)	• GOS streamline the entry and exit of trucks and other vehicles in the port. By minimising waiting times and queues, idling times are reduced, leading to lower fuel consumption and emissions. • These systems provide real-time data on gate operations and vehicle movements. Port authorities can use this data to identify bottlenecks, inefficiencies, and areas for improvement. This data-driven approach supports environmental management by allowing the port to take action to minimise negative impacts on the environment.
Multimodal booking and transport management platforms	• Multimodal platforms may focus on sustainability and environmental efficiency. Inland ports collaborate to contribute to these goals, supporting greener transportation solutions, optimising routes to minimise environmental impacts, and sharing relevant data for emissions reduction initiatives.
Port asset management systems (PAMS)	• PAMS provide real-time data and insights on the condition and performance of assets, allowing, port authorities (PA) and terminal operators (TO) to proactively plan and schedule maintenance activities. This can prevent asset failures, reducing the likelihood of environmental incidents such as spills, leaks, or emissions that could harm ecosystems or surrounding communities. • PAMS can monitor and analyse energy consumption of assets within a port allowing PA and TO to implement energy-saving measures or upgrade to more energy-efficient technologies leading to reduced energy consumption and lower greenhouse gas emissions.
Predictive maintenance tools	• These tools help avoid unnecessary or premature replacements of equipment, thus reducing the consumption of raw materials, energy, and other resources associated with manufacturing and installing new equipment. It also minimises waste generation, contributing to a more sustainable approach to resource management. • Timely maintenance can prevent equipment failures or malfunctions that could result in environmental incidents, such as spills, leaks, or releases of hazardous substances. These tools can detect early warning signs and trigger proactive interventions, reducing the risk of environmental damage and the associated costs of cleanup and remediation.

Source: Consortium

Inland ports serve as crucial nodes in the global supply chain. The integration of digitalisation and automation not only enhances their operational efficiency but also aligns them with global sustainability goals. As the world increasingly prioritizes environmentally responsible practices, these technological advancements would/could position inland ports as leaders in the green transport and logistics sector.

In a nutshell, port digitalisation and automation tools are driving the greening of inland ports by improving operational efficiency, conserving resources, reducing congestion and waste, and lowering emissions. As the port industry embraces a more eco-conscious approach, these technologies offer a sustainable solution for the future of port operations.

5 Selected digitalised Environmental Management Tools for ports

A survey among port operators and port authorities carried out in the summer of 2023, as well as the desk-research performed throughout the year, did not reveal any digital Environmental Management Tool specifically developed for inland ports. In this view, the Study team decided to present several digital EMTs developed primarily for seaports, but which could be adapted, with more or less efforts, to the use in inland ports. The following description relies primarily on the official description of the respective manufacturers or owners/providers of the tools.

5.1 Pixel platform and IoT based Port Environmental Index

PIXEL[128] was a EU funded project which was commenced in May 2018 and completed in September 2021. It was funded within the framework of European Union's Horizon 2020 research and innovation programme under grant agreement No 769355. It represents a groundbreaking solution designed to enhance environmental sustainability and operational efficiency within port ecosystems using IoT technology. It stands as the first of its kind, offering a flexible and scalable approach.

PIXEL fosters a two-way partnership involving ports, multimodal transport agents, and urban areas to optimise both internal and external resources. This collaborative effort promotes sustainable economic growth and works towards mitigating environmental impacts, setting the stage for the Ports of the Future.

At its core, PIXEL is underpinned by cutting-edge interoperability technologies. It serves as a central hub where data from various information repositories, maintained by both internal and external stakeholders, converge. Leveraging an IoT-based communication framework, PIXEL facilitates the voluntary exchange of data among ports and their stakeholders. This exchange serves a singular purpose: to drive resource efficiency in port operations. PIXEL is implemented on the principle that, regardless of the size of the port, it is possible for a port with limited resources (i.e. a medium and small port) to significantly minimise its environmental impacts by relying on scientific methods and innovative technologies.

Implementation strategy of the PIXEL project was the following:

- Establish a single-metric index (Port Environmental Index - PEI) to: (i) integrate diverse environmental impacts of a port, (ii) provide an applicable environmental assessment tool and (iii) serve as a standardized and transparent metric for addressing the environmental impacts of port operations.
- Employ an IoT-based infrastructure to efficiently capture operational data and connect port resources, port-city actors and sensor networks.
- Aggregate, integrate and interoperate multi-source heterogeneous data in an automatic way.
- Model, simulate and analyse port processes in order to predict their environmental impacts and propose optimisation strategies.
- Demonstrate the applicability of the above approaches using pilot ports.

[128] https://pixel-ports.eu

The scope of the project was:

- The integration of operational information exchange, instead of information regarding regulatory compliance, the latter being addressed by other initiatives (e.g. Maritime & Customs Single Windows).
- The port-city area and the respective interaction and sometimes conflicts on issues of environmental sustainability, instead of focusing only on the impacts occurring within the port area.
- Ports possessing average or limited capabilities & resources, instead of focusing on the limited number of ports with abundant resources.
- Multipurpose port operations (e.g. containers, general cargo, bulk, passengers) vs dedicated ones (e.g. only containers), aiming to tackle the complexity of handling different types of cargo.

In a nutshell, PIXEL is the first modular solution combining strong methodology and smart technology for small and medium port ecosystems enabling optimisation of operations through IoT while reducing environmental impact.

At par with a lack of tools for environmental impact assessment, an effective integration of operational data is far from optimal in the majority of ports. In addition to this, digitalisation does not reach equally every ecosystem, creating considerable gaps between large and small ports. PIXEL addresses every of those issues by providing an easy-to-use open-source smart platform for operational data interchange in ports and its associated agents (e.g. cities). The project aimed at improving several indicators in varying use-cases (e.g. 5% in energy consumption, 6% average cost per passenger or 85% in average waiting time for vessels and trucks).

Furthermore, PIXEL provides tools and guidelines leveraging technology with a unique approach: creating a single environmental metric for ports and modelling and optimizing processes after gathering any information available.

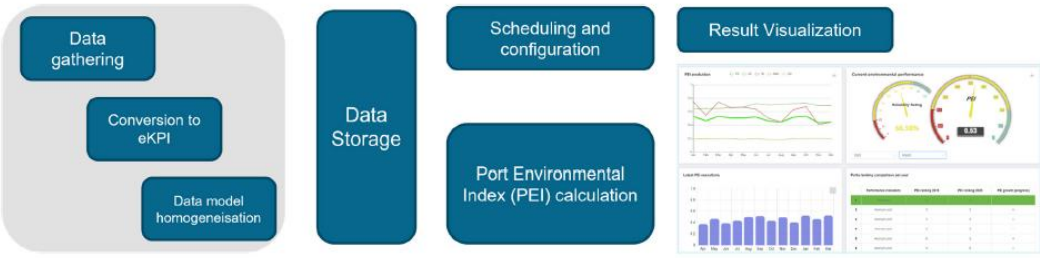
The Port Environmental Index (PEI) is a quantitative composite indicator of the overall environmental performance of a port. The core idea behind PEI is to devise a comprehensive, standardised, and transparent methodology to be used as an integrator of all the significant environmental aspects of ports and the related impacts into a single metric. The metric is used by ports to:

- Evaluate their own environmental performance in a comprehensive integrative manner.
- Compare their environmental performance to other ports that have deployed the metric.

The differentiating points of PEI in relation to the existing approaches are that the methodological approach which will be used to construct the PEI is quantitative (data based) and it by-passes the self-assessment procedure. Thus, the PEI will accurately depict the true environmental performance of a port and will allow for inter-port environmental comparisons. In addition, since PEI is built on automated real-time data collection system obtained through IoT it makes it possible to monitor the environmental performance of a port in a comprehensive manner (meaning that all environmental aspects have been considered). Even though the PEI is primarily developed for seaports, future modifications can likely make it applicable for inland ports as well.

The PEI is a software program endorsed by the execution of a specific backend software (running under a web server) and visualised in a custom user interface. It runs in the Port of Thessaloniki, relying on the deployment of the state-of-the-art IoT platform.[129]

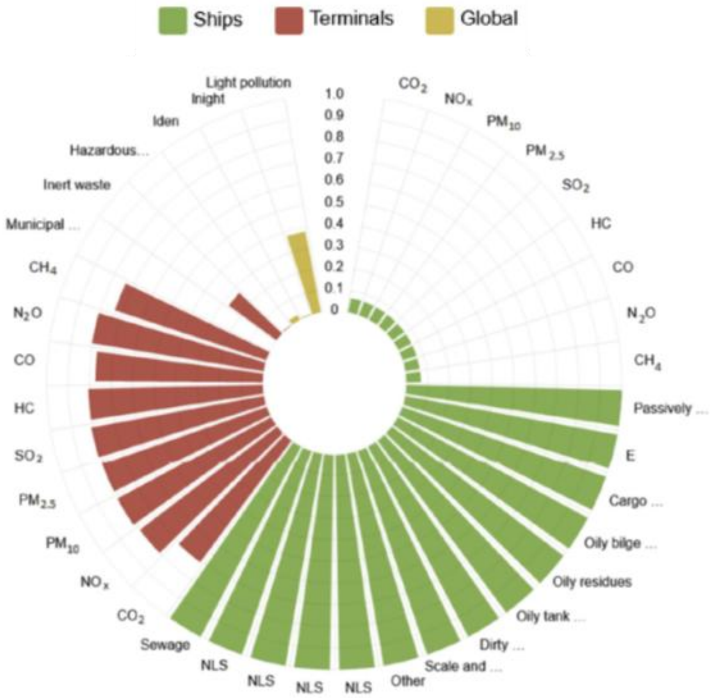
Figure 5-1 Modules of the IoT architecture used for deploying Port Environmental Index in the port of Thessaloniki



Source: Milošević, et.al.

Figure 5-2 depicts a polar chart displaying the normalised (values between zero and one) value of each environmental key performance indicator (eKPI) of the given PEI calculation. The eKPIs are gathered and coloured with different colours depending on the PEI index (ships-SEI, terminals-TEI, global-GEI) that they pertain to.

Figure 5-2: Visualisation of port's environmental KPIs (eKPI)



Source: Milošević, et.al.

The PEI assumes a multifaceted role in the management of port operations, offering a comprehensive perspective on environmental performance and sustainability. One of its primary advantages lies in providing port authorities with an all-encompassing understanding of the environmental repercussions stemming from their activities. Through the quantification of crucial metrics encompassing emissions, energy consumption, waste generation, and water quality, PEI

[129] Milošević, T., Piličić, S., Široka, M., Úbeda, I., Belsa, A., Garcia, R., Salvador, C., Garnier, C. Tserga, E., Traven, L. (2023). The Port Environmental Index: A Quantitative IoT-Based Tool for Assessing the Environmental Performance of Ports. *Journal of Marine Science and Engineering*. 11(1969). Available at: http://dx.doi.org/10.3390/jmse11101969

facilitates port managers to pinpoint areas that require attention and prioritize remedial measures. This data-centred approach supports making well-informed decisions concerning investments in green technologies and the adoption of sustainable practices.

Moreover, PEI serves as a pivotal instrument for adhering to environmental regulations and standards. Ports are beholden to a diverse array of local, national, and international environmental statutes, and PEI contributes to the assurance that a port's operations remain compliant with these regulations. It facilitates the monitoring of performance indicators over time, enabling a consistent assessment of environmental achievements and compliance.

The PEI fulfils a twofold role: it serves as the basis for monitoring a port's environmental advancements and facilitates cross-port comparisons. Additionally, PEI provides invaluable perspectives into a port's environmental hurdles and aids in their effective management. It further serves as a mechanism for conveying environmental achievements to stakeholders, potentially serving as a promotional instrument. Ultimately, PEI's primary objective is to furnish comprehensive, quantitative data regarding a port's overall environmental performance in an objective manner.

The Port Environmental Index (PEI) functions as a comprehensive tool to advocate environmental concerns within ports. Leveraging IoT technology, it quantifies and evaluates environmental performance, offering a vital resource for comparative assessments among various ports. PEI equips port operators with valuable insights to make well-informed decisions regarding environmental management. With its user-friendly design and visualization features, it facilitates accessibility and action for port authorities. This, in turn, aids in enhancing technological processes, reducing expenses, and optimizing port operations by pinpointing areas for environmental enhancement. Moreover, PEI can rank similar port terminals based on their environmental performance, fostering healthy competition and advancement. It supports environmental evaluations, trend identification, and the assessment of long-term sustainability in port regions. Port authorities can employ PEI analyses to initiate and prioritize eco-friendly projects that bolster sustainability. Furthermore, PEI allows for continuous monitoring and assessment of environmental initiatives, promoting ongoing enhancements and accountability.

5.2 GISGRO Green

GISGRO Green® is a new generation of environmental management software that uses port environmental information to facilitate ports' efforts to achieve their sustainability goals. With GISGRO Green, ports can monitor automatically calculated environmental emissions and utilise up-to-date data whenever needed in planning and decision-making.[130]

The data sources can be either manual or automatised, depending on the availability of digital information in ports.

Variations of the software can assist ports in the following activities:

- Compliance with the legislative requirements.
- Implementation of an effective environmental management system.
- Continuous monitoring and/or mandatory annual reporting.
- Identification of causes of and drivers behind the most significant environmental impacts.

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130 https://www.gisgro.com/sustainability-goals-are-a-lot-closer-with-gisgro-green-an-easy-tool-to-monitor-environmental-impacts-in-ports/

- Assess the effectiveness of decisions and investments.
- Choose the environmental aspects to be monitored and choose reporting methods according to the needs.

Environmental aspects to be monitored can be the following:
- Air quality (vessel traffic, land traffic, work equipment).
- Emissions from energy consumption (electricity, heating).
- Water consumption, waste management.
- Greenhouse gas emission from different sources (GHG Protocol).

Vessel emissions are calculated on the basis of the port call data which is integrated into GISGRO Green (e.g., through PMIS or AIS integration). This calculation encompasses not only greenhouse gases but also other substances that impact air quality in the vicinity of the port, including CO_2, CO, NO_X, PM10, CH_4, N_2O, HC, SO_2, and PM2,5. The computation takes into consideration specific vessel attributes, such as vessel type and individual vessel details like the main engine power and fuel consumption, as well as the distances travelled within the defined port area. This emission calculation methodology adheres to Tier 3 standards as outlined in the EMEP/EEA air pollutant emission inventory guidebook for 2019 (updated in December 2021)[131]. To facilitate this process, GISGRO relies on a comprehensive vessel registry, regularly updated by the port itself, providing access to individual vessel information. Vessel emissions can be visually represented or reported based on criteria such as vessel type, time, geographical area, or specific activities.

Emissions from land traffic can encompass a variety of sources, including work machinery and hinterland transport. Calculations for emissions may be based on factors such as the type of vehicle, hours or distances travelled within a port area, and the number of cars or trucks. When detailed technical specifications of machinery or vehicles are used as the basis for calculations, this method complies with Tier 3 standards. The emissions to be considered include CO_2, CO, NOX, PM10, CH_4, N_2O, HC, SO_2, and PM2,5. Emission data can be visualized or reported based on criteria like vehicle type, time, and specific geographical areas. For cases where a more detailed analysis is not required or when specific data is unavailable, emissions resulting from fuel consumption can be calculated within the Energy section. This section can also encompass source data from various energy sources, such as electricity and district heating, contributing to a more comprehensive approach to emission reporting.

The Greenhouse Gas (GHG) protocol[132] is a widely recognised method for reporting emissions that contribute to global warming. It categorizes GHG emissions into three scopes based on their sources. Within the port context, a significant portion of emissions falls under scope 3, primarily due to air emissions generated by vessel traffic. Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organisation, but that the organisation indirectly affects in its value chain. When considering emissions from the port's own energy consumption, such as vehicles and electricity, other scopes also become relevant for reporting. Utilizing the GHG Protocol for emission reporting proves beneficial, especially when faced with new reporting obligations like the Corporate Sustainability Reporting Directive (CSRD) or when various stakeholders request information on the port's sustainability practices. Additionally, it serves as a well-established method for emission reporting when a port aims to highlight its environmental objectives for the public. GISGRO Green fully supports GHG Protocol reporting and provides intuitive visualizations that facilitate the communication of a port's greenhouse gas emissions.

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131 https://www.eea.europa.eu/themes/air/air-pollution-sources-1/emep-eea-air-pollutant-emission-inventory-guidebook

132 World Business Council for Sustainable Development and World Resources Institute, (2024). The Greenhouse Gas Protocol, Revised Edition. Available: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

Figure 5-3: GISGRO Green screenshot

Source: GISGRO Green

5.3 RightShip's Maritime Emissions Portal

RightShip's Maritime Emissions Portal (MEP) combines sophisticated Automatic Identification System (AIS) vessel movement data and RightShip's unique vessel insight data to identify problem areas and opportunities to reduce environmental impact.[133]

By merging exclusive data from RightShip's GHG Rating, encompassing vessel details and supplementary energy-efficient apparatus, with continuously updated vessel positioning information, the MEP offers a comprehensive insight into a port's emissions characteristics. In a nutshell, the portal combines the data on vessels, their engines and computed emissions with the AIS generated tracking of vessel position, generating a quantified and visual insight into the emissions of vessels in a defined area.
Employing state-of-the-art heatmap and zoning technologies, the MEP furnishes a transparent environmental overview spanning any specified duration. This allows practical choices for the regulation of emission levels. The MEP can be configured for any port or for specific terminals to oversee and scrutinize up to 14 distinct emission categories. This opens the door to sustained progress in emission oversight and mitigation.

[133] https://rightship.com/solutions/ports-terminals/maritime-emissions-portal

Figure 5-4: Visualisation of MEP user interface

Source: RightShip

This user-friendly online application offers ports immediate access to an emissions inventory dataset, complemented by analytical capabilities for reporting and extracting inventory information. This resource enables ports to make more informed decisions when it comes to managing local air quality. The MEP harnesses RightShip's specialised emissions calculation method for individual vessels, its one-of-a-kind vessel database, and, when integrated with the Automatic Identification System (AIS), provides an estimate of emissions originating from ships. The emissions inventory is furnished for CO_2, SO_x, NO_x, PM10, PM2.5, and VOC, specifically attributed to port operations.

Emissions inventory approach

The MEP utilises a well-established methodology grounded in validated data and proprietary techniques to construct comprehensive emissions inventories on a per-vessel basis.

Vessel Tracking Through Satellite (AIS) Data

Automatic Identification System (AIS) data is an automated tracking system widely employed in the maritime sector for the exchange of navigational data. This data delineates vessel entries and exits from port boundaries, detailing vessel movements and speeds. It is reported every three minutes while a ship is in motion and every 20 minutes when stationary. A vessel call is defined by a ship's entry and exit from the port boundary. During a call, each operational mode is computed for each vessel, and vessel location data is utilized to determine speed. AIS data is harmonized with RightShip's internal database, providing the ship characteristics necessary for emissions calculations.

Port Mapping

The port boundary is precisely defined to establish the project scope, along with subsequent terminals, anchorages, and points of interest. After mapping the port areas, each ship mode is modelled according to its emissions profile:

- Anchorage: Vessels anchored within the port boundary.

- Transiting: Vessels navigating within a ship channel or the open ocean.
- Manoeuvring: Vessels approaching a berth or terminal.
- Alongside: Vessels engaged in cargo loading or unloading.

Vessel specifics

RightShip's vessel database encompasses over 50,000 ocean-going vessels, including various tugboats, offshore support vessels, and port-specific vessels operating globally. This database incorporates a range of vessel-specific details, such as deadweight, main engines, auxiliary engines, and boilers, enabling the accurate calculation of vessel emissions. The use of specific vessel data significantly enhances the precision of emission estimates. The MEP methodology covers multiple vessel types:

- Ocean-going vessels: Bulk carriers, crude and product tankers, LPG and LNG tankers, general cargo ships, container ships, cruise and ferry vessels, and ro-ro cargo ships.
- Offshore support vessels: Vessels dedicated to operational tasks like oil exploration and maintenance/construction in open waters.
- Tugboats: Utilized for manoeuvring other vessels by pushing or pulling, whether by direct contact or using tow lines, and for towing barges.
- Other port-specific vessels: Typically stationed within or regularly visiting port areas, offering specialised services.

Vessel Emission Calculations

RightShip's exclusive emissions methodology leverages AIS tracking technology and verified vessel-specific data to compile a detailed emissions inventory. This approach aligns with industry-standard methods, including USEPA,[134] California Air Resources Board,[135] ENTEC (Entec UK Limited), and IMO guidance documents.[136] It reduces uncertainties and data burdens on ports while enhancing the precision of the emissions inventory. Ports can access their emissions data efficiently and swiftly via a custom user interface securely available online. This ensures that the most robust approach is applied for each specific air pollutant, adhering to evolving industry regulations aimed at curbing pollutants.

Peer Review

An independent peer review of the methodology was conducted by scientists to guarantee the accuracy, consistency, and adherence to high-quality scientific standards. The peer review confirmed that the methodology aligns with existing guidelines and was executed rigorously, appropriately, and defensibly.

Finally, the MEP Methodology addresses the fundamental air pollutants linked to shipping activities.

[134] https://www.epa.gov/clean-air-act-overview/air-pollution-current-and-future-challenges
[135] https://ww2.arb.ca.gov
[136] https://www.imo.org/en/OurWork/Environment/Pages/Pollution-Prevention.aspx

6 Port digitalisation in practice – results of the 1st survey

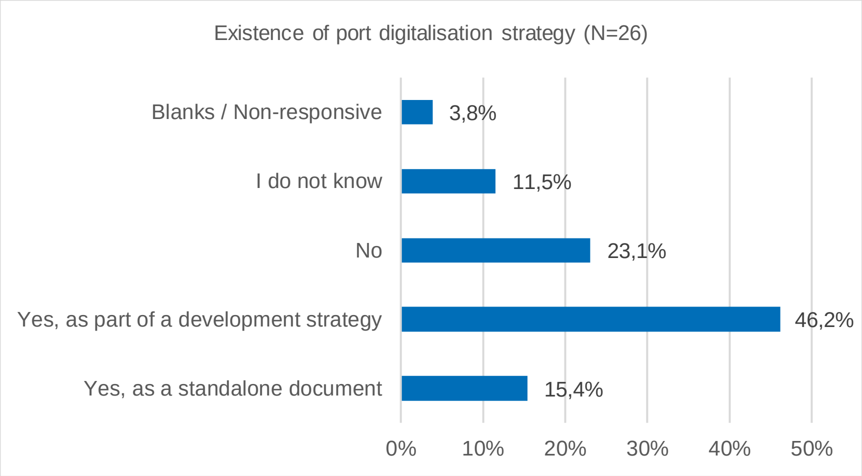
This Chapter contains the results of the first survey among port authorities and port operators, conducted in summer of 2023.

The objective of the survey (its part on digitalisation) was to obtain first insights on the current degrees of inland port digitalisation, type of digital tools used in ports, features and functionalities of applied digital tools, as well as to check the share of ports using digital means to measure operational and environmental KPIs.

6.1 Digitalisation strategy

As an introductory question, the survey aimed to obtain an insight in the share of inland ports aware of digitalisation processes in ports, showing such awareness through the existence of the digitalisation strategy. The digital revolution is transforming the transport industry, and inland ports need to adapt to remain relevant in the long term. Having a digitalisation strategy ensures that ports are prepared for future technological advancements and evolving customer expectations. It enables them to embrace emerging technologies, such as blockchain, Internet of Things, Digital Twins and autonomous systems, and develop hand in hand with the digitalisation trends.

Figure 6-1: Existence of port digitalisation strategy



Source: Consortium

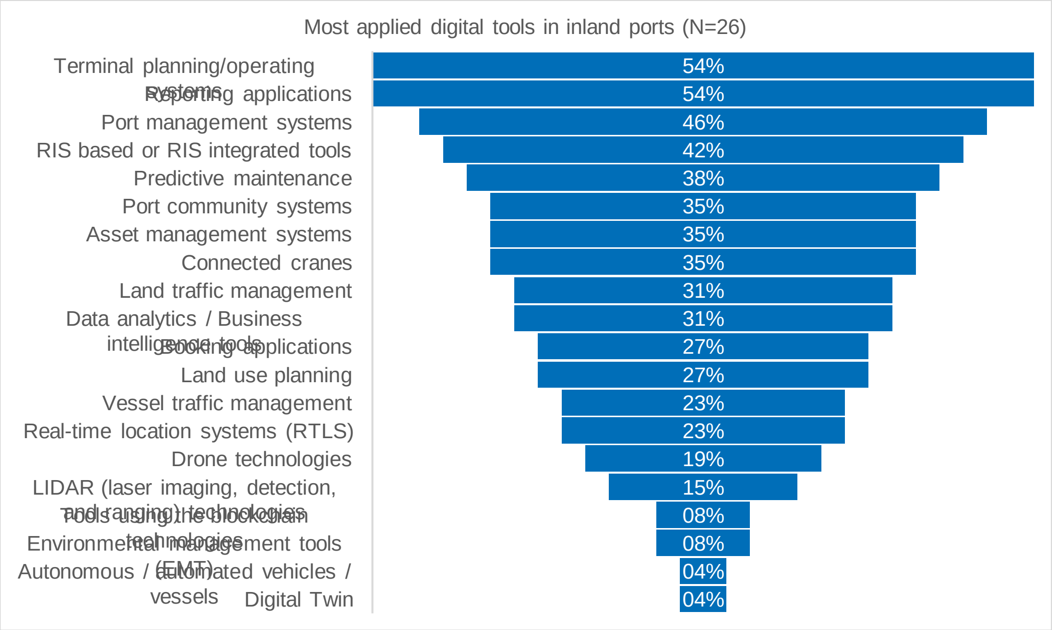
Figure 6-1 demonstrates the high rate of digitalisation awareness among participating inland ports. The fact that more than 60% of responding ports already have digitalisation strategy confirms that ports understand the importance of digitalisation, especially from the aspects of increased efficiency and effectiveness.

Having a digitalisation strategy is crucial for inland ports to unlock the benefits of digital transformation, improve efficiency, remain competitive, reduce costs, promote sustainability, foster collaboration, and prepare for future challenges and opportunities. It serves as a roadmap for harnessing the power of technology and innovation to drive the growth and development of inland ports.

6.2 Most prevalent digital tools and devices

In today's rapidly evolving transport landscape, the integration of digital tools has become a pivotal aspect of port operations. With the aim of providing a comprehensive overview, this section delves into the realm of digitalisation, exploring the cutting-edge technologies that have gained prominence within the contemporary port industry.

Figure 6-2: Applied digital tools and devices in contemporary inland ports



Source: Consortium

The fact that the most common digital tools are Terminal Planning and Operating Systems and various reporting application is not surprising, and more than half of responding ports reported their usage. Terminal operations are most labour and resource intensive activities in ports and it is logical that such digital tools are most commonly applied as they greatly assist and facilitate operational procedures and physical movements of cargo and handling equipment. On par with the TOS are various reporting applications. Such applications save a lot of time, manual work and paperwork, while determined information are visible to all authorised stakeholders in the loop of related activities. Port management systems are very similar to TOS, but they are related to the entire port, not just specific terminals. Predictive maintenance assisted by digital tools is another very important aspect currently exploited in inland ports. It is followed by port community systems (PCS), asset management systems (AMS) and connected cranes.

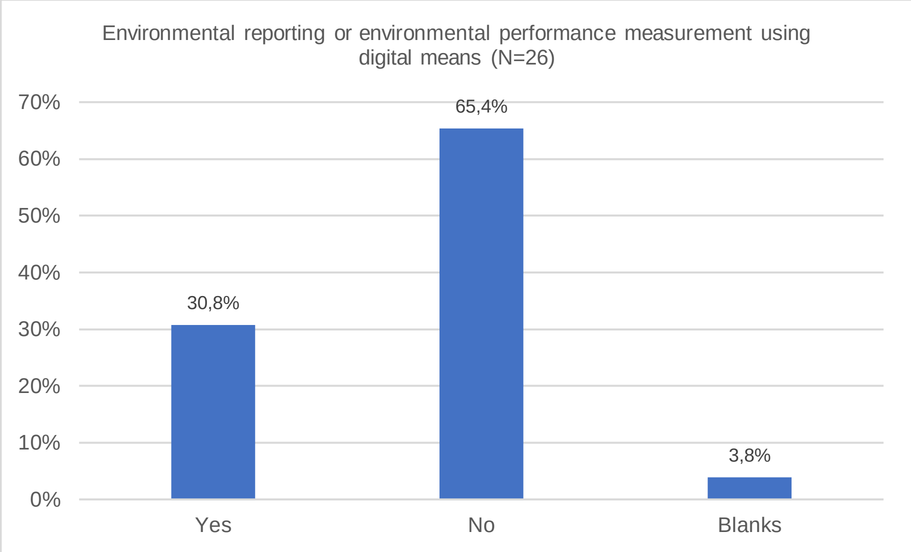
In terms of digital environmental management tools, only 7.7% of ports reported their utilisation, but none of those ports disclosed what kind (commercially available, custom-made, etc.) of digital tools they were using. The Study team expects to revisit this issue in Sub-task 3.5 where interviews with various port stakeholders are foreseen.

6.3 Digitalised environmental reporting and performance measurement

Next aspect that was investigated in the survey was environmental reporting or environmental performance measurement by digital tools. Digitalised environmental reporting and digital measurement of environmental performance in inland ports can play a crucial role in monitoring and improving sustainability efforts. As elaborated in previous chapters, by leveraging digital tools and technologies, ports can streamline the collection, analysis, and reporting of environmental data, leading to more accurate and efficient measurement of their environmental performance.

As a reminder, one aspect of digitalised environmental reporting involves the implementation of real-time monitoring systems. These systems utilise sensors, Internet of Things (IoT) devices, and data analytics to continuously collect and analyse environmental data, such as air quality, water quality, noise levels, and energy consumption. This real-time data provides valuable insights into the environmental impact of port activities, enabling proactive decision-making and prompt corrective actions when necessary.

Figure 6-3: Use of digital means for environmental reporting and performance measurement



Source: Consortium

Figure 6-3 demonstrates that only 30.8% of ports use digital tools for the purposes of environmental reporting and environmental performance measurement, meaning that there is still significant room for improvement in this particular part of inland port digitalisation. Digitalised environmental reporting and digital measurement of environmental performance empower inland ports to make data-driven decisions, enhance transparency, and drive sustainable practices. By harnessing the potential of digital tools, ports can effectively monitor their environmental impact, identify opportunities for improvement, and contribute to a greener and more sustainable future.

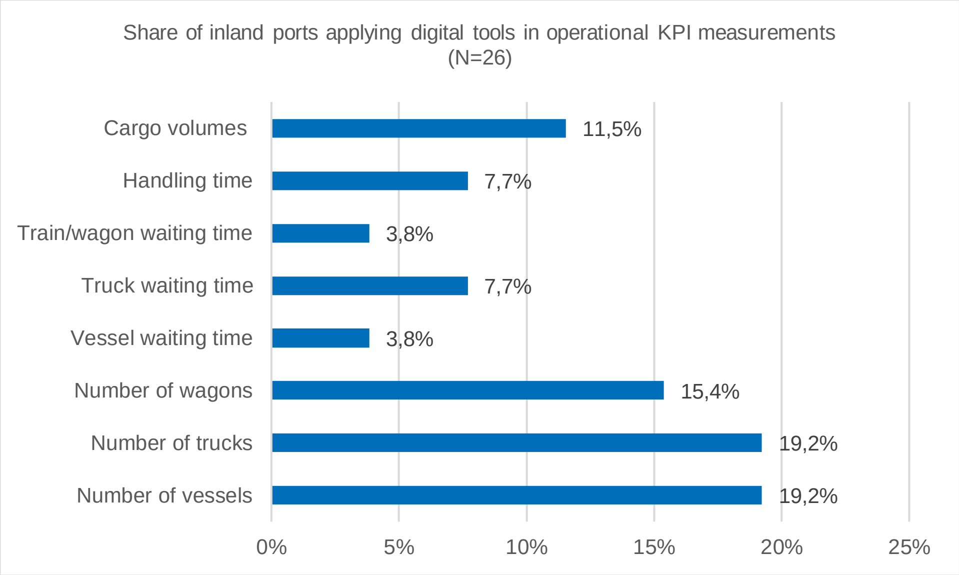
6.4 Digitalisation in measurement of operational and specific environmental KPIs

Digital tools offer a wide range of possibilities for measuring both operational KPIs and environmental KPIs in inland ports. Digital tools such as automated data collection systems and RFID tags and digital weighs can accurately track and record cargo volumes entering and leaving the port. This data can be used to measure and analyse the flow of goods, identify trends, and optimise logistics processes. IoT sensors and real-time monitoring systems can capture the time it takes to load or unload cargo from vessels, trains, and trucks. This data can be used to measure handling efficiency, identify bottlenecks, and improve overall productivity. Additionally, these systems can provide insights into waiting times for vessels, trains, and trucks at different stages of the port operations. This information helps identify areas where delays occur, enabling better planning and resource allocation.

Use of digital tools in environmental KPIs, such as air quality, noise, water quality and others, is elaborated in Section 4.2.

Figure 6-4 demonstrates that the level of digitalisation of operational KPIs measurement is still very low in inland ports. The reasons for this are multiple and may include higher initial investments, necessity to procure adequate software or platform to analyse collected data and present them in a user-friendly way, reluctance to implement novelties, difficulties with change management, etc.

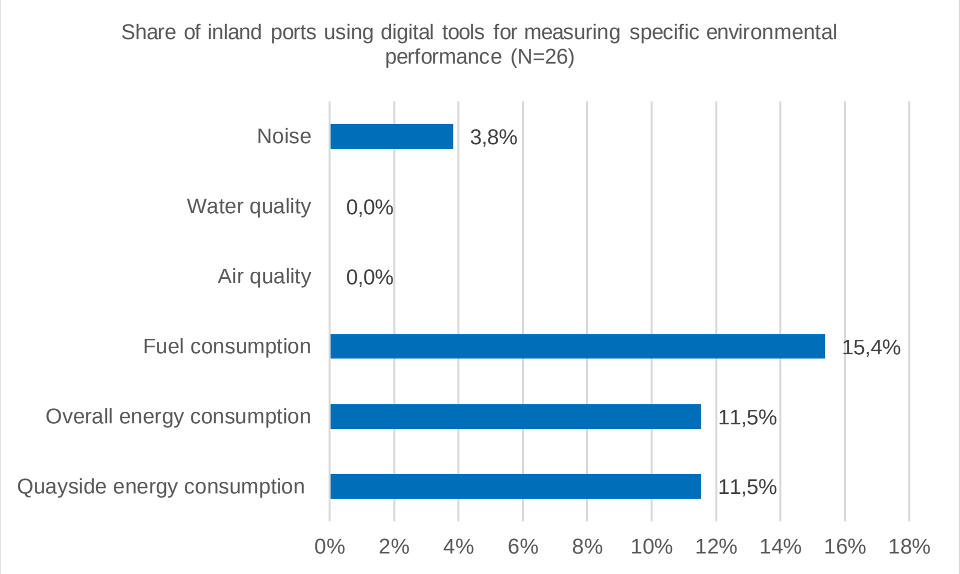
Figure 6-4: Use of digital tools in operational KPIs measurement



Source: Consortium

Figure 6-5 depicts the current situation in the use of digital tools for the measurement of specific environmental key performance indicators. It shows that very few ports use digital tools for the measurement of specific environmental KPIs such as noise, while none of the inland ports participating in the survey use digital tools to measure water quality and air quality. Slightly better situation was recorded in the digital measurement of fuel consumption and energy consumption, most likely because the devices for measurement of fuel and energy consumption are in the use for multiple decades and were subject to digitalisation much earlier than measurement of air and water quality. Development of IoT connectivity and smart sensors coupled with various environmental initiatives related with general transportation and inland ports may result in higher application of digital tools for the measurement and management of specific environmental KPIs.

Figure 6-5: Use of digital tools in environmental KPIs measurement



Source: Consortium

While the implementation of digital tools for operational and environmental KPI measurement in inland ports may require initial investments, the long-term benefits often outweigh the costs. For example, digital tools enable real-time monitoring, automation, and data analysis, leading to improved operational efficiency. By optimising processes, reducing waiting times, and enhancing resource allocation, inland ports can increase productivity and reduce costs in the long run. Similarly, the use of digital tools allows for better monitoring and management of environmental KPIs. By accurately measuring and analysing factors like noise, air quality, and water quality, inland ports can proactively address environmental concerns, comply with regulations, and mitigate the impact on surrounding communities.

6.5 Digitalisation of G2G, B2G and B2B communication and processes in ports

Various communication channels and processes between different stakeholders in inland ports can be divided into Government-to-Government channels and processes (G2G), Business-to-Government (B2G) and Business-to-Business (B2B) communication channels and processes. Typically, the following division of stakeholders can be made:

Government stakeholders:[137]

- Port Authority (PA)
- Customs Office (CA)
- Harbour Master's Office (HMO)
- Harbour Pilot (HP)
- Environmental Authorities (EA)
- Port Police (PP)

Business stakeholders:[138]

- Terminal Operator (TO) (including Port Operators, in cases of small ports or when one operator operates the entire port)
- Shipping Company (SC) (acting as ship owner, ship operator, ship manager)

[137] It is assumed that, typically, these stakeholders are public, or "government" stakeholders, as is the case in most ports globally.

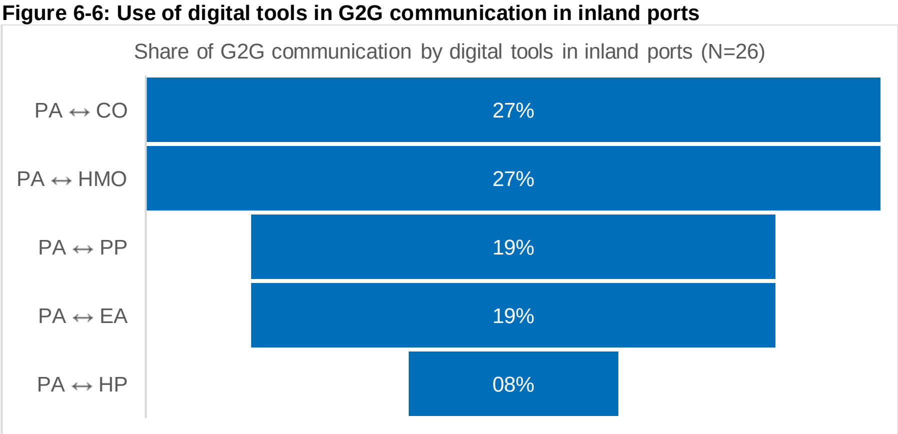
[138] It is assumed that TO, SC, FF, SA, LTC, OU are private or independent companies, not authorities.

- Freight Forwarder (FF) (acting on its own or on behalf of the cargo owner)
- Ship (or port) Agent (SA)
- Land Transport Companies (LTC) (rail and road transport operators)
- Other port users (OU)

In G2G processes, stakeholders can exchange information about vessels, cargo, estimated time of arrival (ETA), berth allocation, regulatory aspects, etc. Such information exchange can be accompanied by vessel, crew, cargo, and other documents. For these processes, both analogue and digital tools are used.

Figure 6-6 shows the share of G2G communication by digital tools in ports which participated the survey. It is noted that the use of digital tools is still of relatively low level in case of G2G communications, where such communications and processes exist. This proves that there is still a lot of room for improvement in this aspect of activities in inland ports.

Figure 6-6: Use of digital tools in G2G communication in inland ports



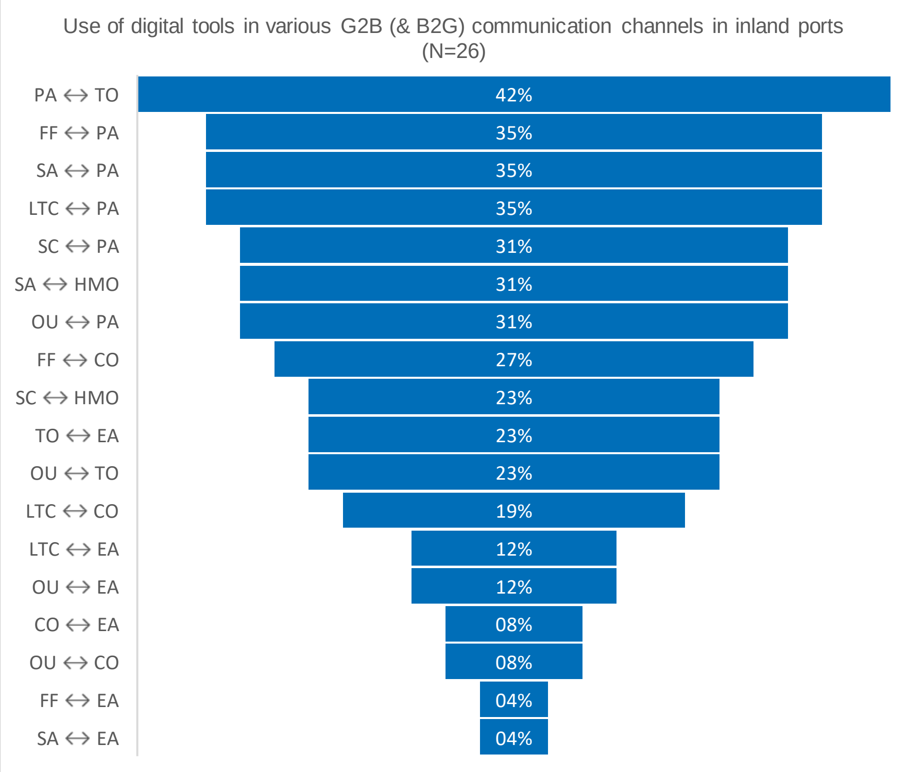
Source: Consortium

In all responding inland ports where digital tools are used for G2G communications, Port Community Systems (PCS) are used for such communication.

As regards to the communication channels and processes between business and governmental stakeholders, Figure 6-7 shows that digital tools are used to a significantly higher degree in comparison to G2G communication. In this view, the largest share of digitalisation is recorded in communication between port authorities and terminal operators (42.3%), immediately followed by communications between port authorities and freight forwarders, ship agents and port authorities, and land transport companies and port authorities (equal shares of 34.6% for each communication channel). From the operational viewpoint, these large shares are completely logical as port authority and the three aforementioned stakeholders do communicate the most, each of them for their particular reasons corresponding to the nature of their activities.

In the largest number of cases, the tool used for communicating between the governmental and business stakeholders was the Port Community System.

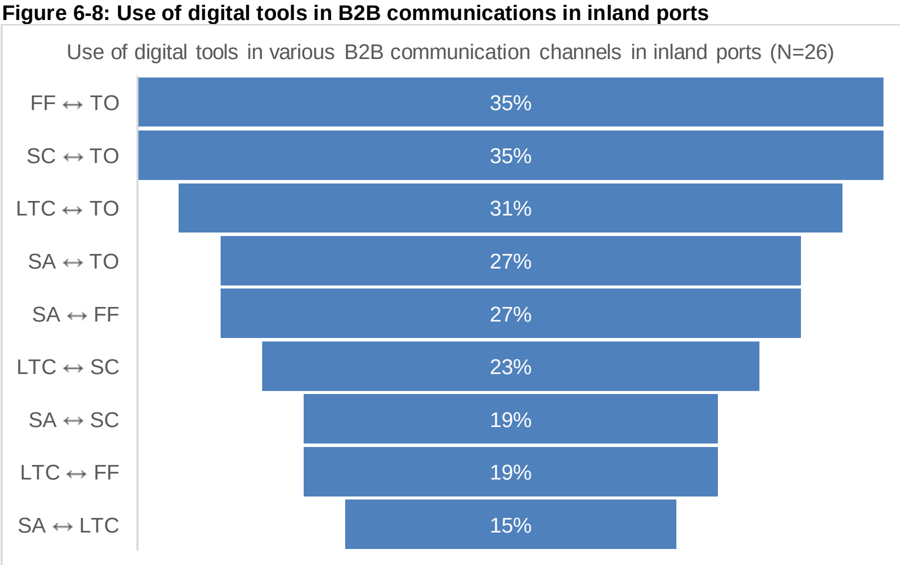
Figure 6-7: Use of digital tools in B2G communication in inland ports



Source: Consortium

Finally, Figure 6-8 demonstrates the share of digitalisation in various communication channels and processes between different business stakeholders relevant for ports. It can be noted that the top four shares reflect the importance communications between freight forwarders, shipping companies, land transport operators and ship agents on the one side, and terminal operators on the other. It is also interesting to note that almost all participating ports reported the Port Community System as the digital tool use for communication even between various business entities. This is due to the very nature of the PCS which provides for the electronic exchange of information between all port and logistics sectors and is acknowledged as the most advanced method for the exchange of information within a single or national port community infrastructure.

Figure 6-8: Use of digital tools in B2B communications in inland ports



Source: Consortium

The digitalisation of communication and processes in inland ports brings about a transformative shift in how governments, businesses, and stakeholders interact and collaborate. By embracing digital technologies, inland ports can streamline operations, improve efficiency, and enhance overall competitiveness.

Firstly, digitalisation enables seamless G2G communication, allowing government entities to efficiently exchange information, regulations, and policies with port authorities and other relevant agencies. This improves transparency, facilitates regulatory compliance, and enhances overall governance within the port ecosystem.

Secondly, digitalisation facilitates G2B communication, enabling smooth interactions between government bodies and businesses operating within the inland port. This includes processes such as licensing, permitting, and customs procedures. Through digitalisation of these processes, businesses can reduce paperwork, enhance data accuracy, and accelerate clearance, leading to faster and more efficient operations.

Thirdly, digitalisation enables B2B communication, fostering collaboration and coordination among different stakeholders in the port community. Freight forwarders, cargo owners, transport operators, and other businesses can seamlessly exchange information, track shipments, and share documentation through digital platforms. This not only improves operational efficiency but also enhances supply chain visibility, reduces delays, and minimises errors.

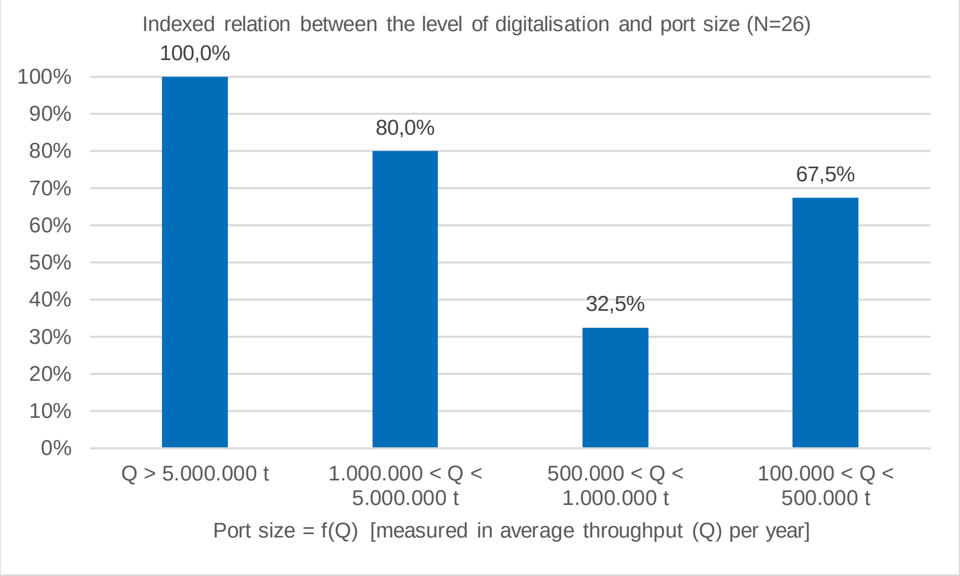
Overall, the digitalisation of G2G, G2B, and B2B communication and processes in inland ports brings numerous benefits. It leads to streamlined operations, reduced administrative burden, improved data accuracy, enhanced transparency, and increased collaboration among stakeholders. This, in turn, results in cost savings, improved customer satisfaction, and a more competitive and sustainable inland port ecosystem.

Embracing digitalisation is crucial for inland ports to stay relevant in the rapidly evolving global trade landscape. By leveraging digital technologies, inland ports can unlock new opportunities, optimise resource utilization, improve decision-making, and drive economic growth while meeting the evolving needs of the industry and ensuring a seamless and efficient flow of goods.

6.6 Relation between the inland port size and digitalisation level

Results of the survey provided an insight into the relationship between the level of digitalisation and the port size. For the purposes of establishing this relationship, the port size was measured in average annual throughput (Q – in tons/year) in four different categories (100,000 < Q < 500,000; 500,000 < Q < 1,000,000; 1,000,000 < Q < 5,000,000 and Q > 5,000,000), while the level of digitalisation was measured as the ratio of the number of different digital tools used in the given port category against the number of digital tools used benchmark port size category. In the concrete case resulting from the survey, it turned out that the largest port size category (ports having average annual throughput of more than 5,000,000 tons) also had the highest number of different digital tools used. The results are demonstrated in Figure 6-9.

Figure 6-9: Relation between the port size and digitalisation level



Source: Consortium

The above figure demonstrates that, in the case of ports that took part in the survey, the level of digitalisation tends to correlate with the size of the port. In some cases, this correlation can be reciprocal, meaning that smaller ports can have higher digitalisation levels than larger ports.

The relationship between the size of ports and the level of their digitalisation is not strictly linear or universal. While there may be a general trend that larger ports have more resources to invest in digitalisation initiatives, the correlation is influenced by various factors.

- **Resource availability**. Larger ports often have more financial resources and infrastructure, allowing them to invest in advanced digital technologies. Smaller ports, however, may have budget constraints that limit their ability to implement extensive digitalisation initiatives.
- **Operational complexity**. The size of a port does not necessarily dictate its operational complexity. Some smaller ports may have specialised operations or handle specific types of cargo that require advanced digital systems. Conversely, larger ports may have diverse operations that demand sophisticated digital solutions.
- **Strategic vision**. The level of digitalisation in a port is also influenced by the strategic vision of port authorities and management. A smaller port with a forward-thinking approach may prioritise digital initiatives to enhance efficiency and competitiveness.
- **Government policies**. Government policies and regulations can play a role. Some countries may prioritise digitalisation across all ports, regardless of size, while others may focus on larger, more strategic ports.
- **Collaboration and integration**. Ports that actively collaborate with stakeholders and integrate into broader regional or even global supply chains may be more inclined to adopt digital technologies, irrespective of their size.

In summary, while there may be a tendency for larger ports to invest more in digitalisation due to resource availability, the correlation is not strict. The digitalisation level of a port is influenced by a combination of factors, including operational complexity, strategic vision, government policies, and the port's integration into broader logistics networks.

7 Conclusions

The application of a myriad of digital tools in inland ports has ushered in a transformative era, yielding substantial importance and a multitude of benefits. The integration of Internet of Things (IoT) sensors, complex devices, blockchain technology, artificial intelligence, 5G networks, digitalised environmental management tools, big data, data analytics, business intelligence, port community systems, terminal planning and operating systems, gate operating systems, multimodal booking platforms, port automation and autonomation, smart ports, virtual reality tools, augmented reality tools, asset management systems, reporting applications, predictive maintenance tools, and others, not only has the huge potential to fundamentally redefine the landscape of inland port operations but is already doing so, according to the results of the survey carried out in summer of 2023. In addition, the digitalisation has positively transformed the dynamics of collaboration among stakeholders while simultaneously contributing to sustainability.

One of the primary benefits is the significant enhancement of operational efficiency. The utilisation of IoT sensors, coupled with, for example, data analytics and artificial intelligence, facilitates real-time monitoring and optimisation of various port processes. Complex devices such as automated cargo handling equipment and predictive maintenance tools contribute to streamlined operations, reducing human errors, increasing safety and handling speed, and prevent failure-caused delays. The integration of smart technologies, including virtual and augmented reality tools, allows for improved decision-making and overall effectiveness in managing vessel traffic, cargo handling, and logistics.

Moreover, the interconnection fostered by these digital tools extends beyond individual ports to create a more transparent and efficient supply chain. Multimodal booking platforms and port community systems enable seamless collaboration between stakeholders, including vessel operators, ports, cargo owners, and logistics companies. This collaboration not only improves communication but also ensures that relevant and timely information is accessible to all involved parties, fostering a more integrated and responsive supply chain ecosystem.

The incorporation of blockchain technology in port operations brings about increased transparency and security in data management. It ensures the integrity of transactions, reduces fraud, and establishes a reliable and traceable record of activities, thereby fostering trust among stakeholders.

The arrival of 5G networks plays a pivotal role in enabling high-speed and reliable communication, enhancing connectivity between various systems and devices within the port ecosystem. This not only supports real-time data exchange but also forms the backbone for the implementation of advanced technologies such as autonomous vehicles and drones, further boosting the efficiency of port operations.

Cybersecurity aspects are paramount in safeguarding the integrity and confidentiality of sensitive data within the digitalised port environment. Robust cybersecurity measures protect against cyber threats, ensuring the resilience and continuity of port operations.

Environmental benefits also emerge as a significant benefit of digital tool application in inland ports. The integration of digitalised environmental management tools enables precise monitoring and control of environmental parameters, leading to more sustainable and eco-friendly port operations. Furthermore, the optimisation of vehicle and vessel flows facilitated by land traffic management applications, gate operating systems and terminal operating and planning systems reduces unnecessary fuel consumption and emissions, contributing to a greener and more environmentally responsible port industry.

Utilising data analytics enables the suggestion of reorganising port operational practices to achieve a reduced environmental footprint through the implementation of sustainable methods or simply by optimising intra-port traffic flows.

The application of Artificial Intelligence systems in ports also had a strong influence on environmental footprint reduction in inland ports. AI plays a crucial role in assisting ports to adhere to environmental regulations by actively monitoring emissions and recommending eco-friendly practices, directly contributing to the reduction of ports' environmental footprint. Within the AI domain, supervised learning models specialise in validating schedules and predicting energy consumption for battery-powered automated guided vehicles in horizontal transportation zones. AI's predictive capabilities extend to forecasting emissions based on vessel activity, meteorological conditions, and air quality data. Moreover, by anticipating peak energy demand periods, AI optimises energy distribution in ports, effectively reducing energy waste. Through in-depth analysis of emissions data, AI identifies sources with high emissions and provides actionable recommendations for implementing effective reduction strategies. AI-powered logistics and transportation management systems are instrumental in optimising truck routes and scheduling within ports. This optimisation minimises travel distances and idle times, resulting in reduced fuel consumption and emissions.

Results from the survey demonstrated that many inland ports have already embarked on a digitalisation voyage. As expected, numerous inland ports have already applied digital tools where they are most needed, in the domain of cargo handling, infrastructure management and communication between different stakeholders. In this view, it is no wonder that most frequent digital tools in inland ports are terminal planning and operating systems, reporting applications, asset management systems and Port Community Systems.

Finally, it can be safely stated that the application of digital tools in inland ports is indispensable for achieving heightened operational efficiency, fostering collaboration, ensuring environmental sustainability, fostering inland waterway transport in multimodal transportation chains, and embracing the technological advancements reshaping the logistics and transport industry. As ports evolve into smart and interconnected hubs, the multifaceted benefits derived from the integration of these tools not only redefine the dynamics of port management but also contribute to a more sustainable and resilient future for the entire supply chain ecosystem. The strategic adoption of these technologies is not merely a trend but a crucial imperative for the continued growth, economic and environmental sustainability, and competitiveness of inland ports in the digital age.

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