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# Towards smart port management: the combined contribution of IS and IoT

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**ABSTRACT: This article examines how the combined use of information systems (IS) and Internet of Things (IoT) technologies supports the transition toward smart port management. It reviews the operational roles of port management systems, transportation management systems, geographic information systems, smart sensors, RFID, LPWAN networks, drones, and connected monitoring devices. The analysis shows that IS provides the digital infrastructure for collecting, processing, sharing, and interpreting port information, while IoT extends this capacity through continuous real-time sensing of cargo, equipment, traffic, and environmental conditions. Their integration improves decision-making, port-flow coordination, predictive maintenance, container traceability, resource allocation, safety, and environmental performance. The article also identifies key implementation constraints, including cybersecurity risks, investment and maintenance costs, interoperability requirements, and organizational resistance to change. Illustrations from Rotterdam, Singapore, and Los Angeles show how smart-port initiatives combine data platforms, connected devices, automation, and sustainability measures. The study concludes that the value of digitalization does not lie in isolated technologies but in their coordinated integration within a secure, interoperable, and human-centered port ecosystem. Future port competitiveness will therefore depend on the capacity to combine technological innovation, change management, public policy, and sustainability objectives in a coherent digital transformation strategy.**

**Keywords:** Smart ports; Information systems; Internet of Things; Port management; Digital transformation; Operational efficiency; Sustainability; Cybersecurity

## 1. INTRODUCTION

Contemporary port management is at a decisive juncture, marked by the emergence of information systems (IS) and the Internet of Things (IoT) as essential levers for optimizing operations. Ports, true crossroads of international trade, are facing growing challenges such as the increase in the volume of maritime traffic, the need to improve environmental sustainability and the demand for increased operational efficiency. In this context, the seamless integration of IS and IoT is paramount to transform these infrastructures into intelligent entities that can adapt and react in real time to market requirements. Information systems, at the heart of smart port management, enable unprecedented data collection, analysis, and dissemination. Thanks to connected platforms, the various players in the logistics chain, whether port authorities, shipping companies or freight forwarders, can access critical information for decision-making. IoT, on the other hand, adds an extra dimension by facilitating the interconnection between various equipment and sensors scattered throughout port infrastructures. This makes it possible, for example, to monitor the status of cargo in real time, to optimize internal transport routes, or to guarantee safety through advanced detection devices.

The alliance between IS and IoT offers ports new perspectives, transforming traditionally static operations into a dynamic intelligent management board. The ability to thoroughly analyze real-time data and automate critical tasks lays the groundwork for operational efficiency that was previously a dream goal. In the upcoming sections, we will explore in more detail how this combination is revolutionizing the port landscape, its practical applications and its impacts on the sustainability and competitiveness of ports on a global scale.

## 2. MATERIALS AND METHODS

This article follows a conceptual and descriptive literature-based approach. It synthesizes the academic and professional sources cited throughout the manuscript on port information systems, Internet of Things applications, cybersecurity, smart logistics, and digital transformation. The analysis is organized around the respective functions of IS and IoT, their operational synergy, the principal implementation challenges, and illustrative smart-port cases from Rotterdam, Singapore, and Los Angeles. No original quantitative dataset or field experiment is reported; the contribution is therefore analytical and integrative, with the objective of clarifying how the combined use of IS and IoT can support more efficient, responsive, secure, and sustainable port management.

## 3. RESULTS AND DISCUSSION

### 3.1. Context and challenges of port management

Contemporary port management is at a critical crossroads, where the challenges inherent in globalization, environmental requirements and technological change require a complete re-evaluation of traditional practices. Ports, often seen as logistics hubs, face challenges such as increasing maritime traffic, optimizing supply chains, and the need to reduce environmental impacts. At the same time, they represent huge opportunities, especially through the adoption of advanced technologies, such as information systems (IS) and the Internet of Things (IoT). This digital transformation is not only a strategic issue, but also an essential lever to guarantee the competitiveness of ports on a global scale (KASMI & HELMI, 2025). The opportunities generated by the integration of IS and IoT into port operations are numerous. For example, these technologies allow for real-time data collection, making it easier to make informed decisions. With smart sensors, ports can monitor various indicators, ranging from container traffic to air quality, providing a much-needed overview for proactive management. In addition, advanced analytics can anticipate logistics needs, prevent bottlenecks, and optimize vessel routes, increasing operational efficiency and reducing costs. However, this transformation is not without its challenges. The increased interconnection of systems makes port infrastructure vulnerable to cyberattacks, posing a major risk to the security of operations (Taillat, 2022). The vision of a smart port is emerging, integrating sustainable practices and optimized data-driven management. The outlook for the future is that ports are not only transit points, but also key players in the global supply chain, able to adapt to market developments and societal requirements. By adopting a sustainability and innovation approach, ports can become models of resilience in the face of economic and environmental crises, while supporting local and global economic development. The future of port management thus lies in the ability to combine operational performance and social responsibility, making ports not only infrastructure, but also catalysts for sustainable progress.

### 3.2. Information systems in the port sector

In the modern port sector, information systems play a crucial role in operational efficiency and strategic decision-making. These systems, which encompass a multitude of technologies and platforms, make it possible to perform three types of technologies, which are summarized in the following figure.

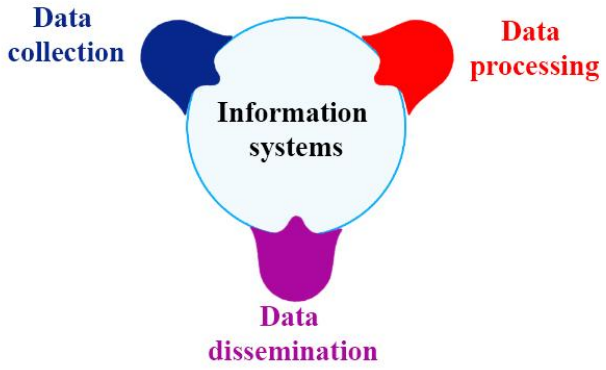


**Fig. 1. Key roles of the Port Information System**

*Source. Author's elaboration*

By integrating information flows from various sources, such as cargoes, ships and infrastructure, IS allows a global and real-time view of port activities, which is essential for optimizing operations (Serroukh and El2024). Three main types of information systems are commonly used in ports, as shown in the following figure.

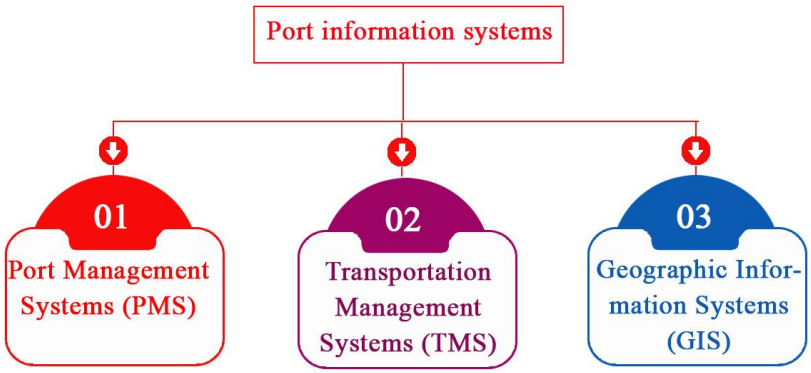


**Fig. 2. Main components of the Port Information System**

*Source. Author's elaboration*

PMS focuses on the coordination of port activities, including the management of docks, cargoes and human resources. TMSs, on the other hand, oversee the tracking of goods movements and associated logistics, improving the fluidity of intermodal transport. GIS plays a vital role in providing geospatial visualization of operations and infrastructure, which helps to better manage available resources and proactively plan for facility expansion or reorganization (Daoud, 2021).

The benefits of integrating information systems in the port sector are multiple and significant. First, they improve responsiveness to unforeseen events, allowing for more effective risk management. Second, they help reduce operational costs by optimizing resources and minimizing downtime. In addition, information systems facilitate regulatory compliance by centralizing the information needed to meet local and international requirements. When combined with Internet of Things (IoT) technologies, these systems become even more powerful, offering predictive solutions through advanced data analytics. Together, IS and IoT are essential levers for the future of smart ports, promoting integrated port management that adapts to contemporary challenges while accelerating digital transformation (Guennoun and Bennouna2023).

### 3.2.1. Definition and role of IS

Information systems play a central role in modern port management, acting as enablers for operational efficiency and strategic decision-making. By definition, an information system consists of a harmonized set of resources, including hardware, software, data, and procedures, that interact to collect, store, process, and

disseminate information. In the port context, these systems are crucial for synchronizing complex activities related to maritime logistics, cargo management and coordination of different actors such as port authorities, carriers and customs agents (HANA2025). The role of IS is not limited to data management; they also facilitate the integration and analysis of information from various sources, including IoT, thus representing a vector of innovation. Thanks to integrated platforms, ports can monitor vessel movements in real time, optimize loading and unloading operations, and improve human and material resource management. By providing increased visibility into operational processes, IS helps identify bottlenecks and anticipate potential issues, resulting in reduced costs and wait times. In addition, the integration of information systems with IoT technologies enhances their efficiency, enabling instant feedback and unprecedented adaptability (Hrouga & Said, 2024). IoT sensors, for example, can provide real-time data on container status, weather conditions, or dock occupancy, enriching decision-making. Thus, the combination of IS and IoT contributes to building smart port management, promoting not only the competitiveness of ports, but also their sustainability by reducing the carbon footprint and encouraging more responsible operational practices. In this evolving context, the strategic adoption of IS is becoming essential for ports seeking to navigate efficiently in an increasingly complex economic environment.

### 3.2.2. Types of information systems used

In the port sector, various types of information systems are used to optimize operations, improve security and strengthen logistics management. One of the most important categories is the Port Management System (PMS), which incorporates various functionalities to coordinate all port activities. This type of system facilitates ship planning, cargo tracking, and the management of human and material resources within the port. With intuitive user interfaces, the PMS allows port operators to access real-time data and make proactive adjustments to operations. Geographic Information Systems (GIS) also have a crucial role in port management. They allow a spatial visualization of operations, thus facilitating the analysis of geographical data relating to port infrastructures and ship movements. Using GIS tools, managers can plan space use, assess environmental impacts, and coordinate emergency services. By combining these different systems, ports can create an integrated digital ecosystem that promotes efficiency and sustainability, which is essential in an increasingly competitive economic environment. Thanks to this diversity of IS, port management is not limited to simple logistics optimization, but is moving towards a holistic approach, integrating operational performance and technological innovations (Vadnais, 2024).

### 3.2.3. Advantages of IS in port management

Information systems play a fundamental role in modern port management, providing a multitude of benefits that transform port operations into more efficient, transparent and interconnected processes. First of all, the integration of IS makes it possible to optimize logistics management by facilitating the circulation of information between the various players, such as port authorities, carriers and stevedoring companies. Through centralized digital platforms, these stakeholders can share real-time data, see the status of goods and containers, anticipate wait times, and make informed decisions, reducing congestion and improving the fluidity of operations (Bahou et al., 2022). In addition, IS contributes to proactive and predictive management of port resources and infrastructure. Analysis of historical data and ongoing trends enables the implementation of preventive maintenance strategies, minimizing downtime of critical equipment. In addition, the use of advanced analysis tools makes it possible to anticipate the demand for port services, adjust operations accordingly and improve the allocation of resources. This information is crucial for informed decision-making, allowing ports to quickly adapt to market fluctuations and meet increasing demands for sustainability and energy efficiency.

## 3.3. The Internet of Things (IoT) and its applications

The Internet of Things (IoT) is a revolutionary technology that interconnects devices via the Internet, enabling data exchange and automating different processes. At the heart of this transformation is the ability of smart sensors, devices, and systems to communicate in real-time. In the port context, IoT stands out for its potential to optimize operations, improve resource management, and enhance security. This interconnection enables accurate and anticipatory visualization of logistics flows, thus improving the efficiency of maritime supply chains (Notteboom2024). Some of the IoT technologies relevant to ports

include environmental sensors, telemetry systems, and satellite tracking devices. These technologies are designed to collect data on various parameters, such as air quality, temperature, and even cargo status. For example, sensors installed on containers can monitor temperature and humidity, ensuring that sensitive products are stored in optimal conditions. In addition, the use of drones, equipped with IoT sensors, to monitor quays and port infrastructure is a significant step forward. These drones can quickly detect anomalies or obstacles, increasing the safety of port operations (Imane, 2022).

Real-world use cases for IoT in ports include smart energy management and predictive equipment maintenance. For example, the integration of smart meters allows real-time monitoring of energy consumption within port facilities. Similarly, predictive maintenance systems, powered by IoT data, allow managers to plan repairs before equipment fails, reducing downtime and associated costs. These applications demonstrate how IoT can transform the port sector by facilitating a more thoughtful and proactive approach to contemporary challenges, promoting not only operational efficiency but also increased sustainability in an environment where environmental issues are increasingly pressing.

### 3.3.1. Definition of IoT

The Internet of Things (IoT) is defined as a network of physical objects, integrating sensors, software, and other technologies, allowing data to be connected and exchanged with other devices and systems via the Internet. This concept is based on the idea that everyday objects, ranging from industrial equipment to vehicles to household appliances, can be equipped with communication and analysis capabilities. By linking these smart objects to information systems, IoT enables real-time data collection and analysis, thereby optimizing operations, efficiency, and decision-making in various industries, including port management (Abbad et al., 2024). Within ports, IoT represents a potential revolution for the management of maritime infrastructure and operations. Through a multitude of interconnected devices, such as environmental condition monitoring sensors, cargo tracking devices, and failure alert systems, IoT facilitates more accurate and responsive supervision of port activities (Sylvanus, 2023). For example, sensors built into containers can provide data on location, temperature, or humidity, allowing managers to react quickly to potential problems and minimize supply chain interruptions. Thus, IoT is not only transforming operations management but also offering sustainable solutions, optimizing energy consumption and reducing the carbon footprint of ports. In addition, this technology gives rise to predictive models that are based on the analysis of historical data. By anticipating maintenance needs or anticipating fluctuations in port traffic, facility managers can develop proactive strategies. In short, the Internet of Things is an essential lever for the future of ports, by promoting a smarter, collaborative and more responsive operating environment, aligned with the sustainability and efficiency ambitions of modern port infrastructure.

### 3.3.2. IoT technologies relevant to ports

In the context of ports, several IoT technologies are emerging as catalysts for innovation and operational efficiency. Among these, smart sensors play a key role in facilitating the collection of real-time data on equipment, cargo, and environmental conditions. These sensors, integrated into existing infrastructures, allow for accurate monitoring of temperature, humidity, and even vibration levels, contributing to proactive resource management and optimal maintenance of goods, especially perishable goods (Rebah2022). Communication networks based on LPWAN (Low Power Wide Area Network) protocols are also proving crucial for port applications. Their ability to cover vast distances with minimal power consumption enables the connectivity of devices dispersed over large areas, such as shipping containers or material handling equipment. These networks facilitate the exchange of information between different actors in the supply chain, while ensuring interoperability that is essential for the integration of port management systems. In addition, the use of RFID (Radio Frequency Identification) technology enriches the ports' IoT ecosystem by optimizing asset and cargo tracking. With RFID tags, ports can significantly reduce container processing time, improve traceability of operations, and decrease human error. At the same time, drones and autonomous robots are starting to appear, facilitating operations such as infrastructure inspection and monitoring of loading and unloading activities (MOUHSINE et al. 2023). Together, these technologies form an integrated network, fostering smart port management that adequately addresses contemporary logistics and sustainability challenges. If implemented strategically, these IoT solutions not only optimize

daily operations, but also anticipate future challenges such as increased shipping volumes and the need for more rigorous environmental management.

### 3.3.3. IoT Use Cases in Ports

The Internet of Things (IoT) is significantly transforming port operations, bringing efficiency, safety and sustainability to a traditionally complex sector. Among the most notable use cases, container management stands out. With the integration of IoT sensors, each container can be traced in real-time, allowing for extensive visibility into the status and location of cargo. These devices, often equipped with geolocation technologies, provide valuable data on environmental conditions, such as temperature or humidity, which are essential for sensitive goods. As a result, port managers can optimize handling operations, reduce waiting times, and anticipate space needs, significantly increasing logistics efficiency (Ahmed & Mourad, 2024). Another field of application is emerging around the monitoring of port infrastructures. Sensors deployed on docks and equipment enable predictive maintenance, continuously monitoring the condition of infrastructure such as cranes, docks and energy supply systems. This real-time data collection helps detect potential anomalies or failures before they become major problems, ensuring not only the safety of operations, but also the sustainability of investments (HANA2025). At the same time, IoT also facilitates port waste management, where sensors detect and quantify the waste generated. This allows operators to plan and optimize the disposal process while complying with environmental regulations.

## 3.4. Synergy between IS and IoT

The emergence of a synergy between Information Systems (IS) and the Internet of Things (IoT) in the context of port management is a major strategic advance. The convergence of these technologies allows for a seamless interconnection between the different stages of port operations, resulting in a substantial improvement in efficiency and responsiveness to contemporary challenges in the maritime sector. IS, which are traditional in terms of data collection and analysis, see their potential considerably amplified thanks to the integration of IoT sensors. These devices, when deployed at scale, provide real-time visibility into goods in transit, environmental conditions, and operational performance. The integration of these systems also allows for enriched data collection, thus promoting decision-making. Through the advanced analytics enabled by IS, the data collected by the IoT can be transformed into relevant information. This helps port managers anticipate logistics needs, predict wait times, and identify bottlenecks before they occur. The combined use of these technologies not only makes it possible to react proactively to unforeseen events, but also to conduct predictive analyses that optimize operational flows and reduce costs related to delays or inefficiencies.

When it comes to optimizing port operations, the synergy between IS and IoT is revitalizing the logistics ecosystem. Integration allows, for example, to automate loading and unloading processes, while ensuring rigorous monitoring of safety contingencies. With smart gauges and real-time monitoring systems, ports can adjust their operations based on fluctuations in demand, improving their overall efficiency. This technological framework is also essential to meet new regulatory requirements for sustainability, thus enabling more responsible resource management (HANA2025).

### 3.4.1. Systems Integration

The integration of information systems (IS) and the Internet of Things (IoT) is a crucial step towards achieving smart port management, facilitating efficient interconnection between physical infrastructure and digital platforms. This synergy allows for real-time data collection and analysis from a variety of sources, such as vessel traffic sensors, environmental monitoring devices, and material handling equipment. By integrating these systems, ports can not only improve their responsiveness to operational challenges, but also anticipate future needs through a better understanding of logistics dynamics (Ngalamulume and Ilunga2025). The integration process often involves the implementation of standardized communication protocols, which promote interoperability between existing systems and new IoT technologies. For example, the use of open standards, such as MQTT or CoAP, allows different devices to share data seamlessly, without being blocked by technological incompatibilities. This promotes the creation of intelligent dashboards and predictive analytics that help port managers make informed decisions based on

accurate and up-to-date data. In addition, the integration of IS and IoT facilitates the networking of port assets, which optimizes operational fluidity and reduces downtime.

Another fundamental aspect of this integration is the automation of processes. Thanks to interconnection, certain tasks can be carried out autonomously, allowing cargo management systems to react instantly to events such as the arrival of ships or containers. For example, the systems can automatically trigger the mobilization of unloading equipment or alert personnel to irregularities, increasing the efficiency of the overall logistics process. In conclusion, the seamless integration of information systems and IoT technologies is key to promoting smarter port management, contributing to the optimization not only of operations, but also, ultimately, of the entire maritime logistics chain.

### 3.4.2. Improved decision-making

The integration of Information Systems (IS) and the Internet of Things (IoT) in the port sector requires a substantial improvement in decision-making, thanks to real-time data analysis and enriched information flows. In an environment as dynamic as that of ports, decisions must be based on accurate and timely data. IoT enables the continuous collection of data from sensors deployed on port equipment such as cranes, container terminals, or even ships at port calls. These sensors, combined with robust information systems, enrich the decision-making database not only by providing performance indicators, but also by identifying areas requiring attention, such as preventive maintenance of equipment. Using IS in this context is not simply a matter of data accumulation, but involves the implementation of advanced analytics and intelligent algorithms that can transform this raw data into actionable insights. For example, artificial intelligence integrated into IS can predict peaks in port traffic by analyzing historical patterns and environmental variables, providing better visibility for operations planning. As a result, port managers can make more informed decisions about resource management, optimizing berthing schedules, and allocating storage space, thereby reducing costs and improving overall efficiency (Krichen, 2024).

### 3.4.3. Optimisation of port operations

The optimization of port operations represents a crucial step in the evolution towards smart port management, where the synergy between information systems (IS) and the Internet of Things (IoT) plays a fundamental role. Through the integration of advanced technologies, ports can not only increase efficiency, but also reduce operational costs and minimize their environmental footprint. IoT sensors embedded in port equipment allow real-time data to be collected on various parameters such as container status, temperature of sensitive cargo, and cargo flow. This information feeds into information systems, thus promoting proactive management of operations. By analyzing this data, port authorities can adjust their practices based on actual field conditions. For example, real-time tracking of ship and truck movements through IoT devices helps optimize docking and unloading times, reducing wait times and the risk of congestion. In addition, predictive analytics, powered by artificial intelligence-based modeling, can anticipate traffic spikes and adapt resources accordingly. This includes intelligent dock and yard management, ensuring that the necessary equipment is available at the right time and in the right place. In addition, optimization processes can also be extended to the wider supply chain, where the interconnection of systems allows for better coordination between the different actors involved in shipping (Lo, 2023). Improved traceability of goods, facilitated by IoT, ensures increased transparency, thus strengthening mutual trust between port operators, carriers and customers. This data-driven operating model not only boosts the efficiency of port operations, but also lays the foundation for an interconnected logistics ecosystem that can adapt nimbly to the challenges of the future. In short, the optimization of port operations, rooted in the synergistic exploitation of IS and IoT, is a key driver to transform ports into smart nodes within a global supply chain.

## 3.5. Challenges of IS and IoT Implementation

The implementation of information systems (IS) and the Internet of Things (IoT) within port infrastructures comes with a series of significant challenges that can hinder the optimization of operations and the realization of expected benefits. One of the biggest hurdles is data security concerns. The increasing connectivity between IoT devices and IS exposes ports to potential cyberattacks, jeopardizing not only the confidentiality of sensitive information, but also the integrity of logistics operations. This risk is compounded by the diversity of networked systems and sensors, which makes it difficult to implement a

uniform and effective security strategy. As a result, ports need to invest in advanced protection technologies and continuous training to raise awareness of digital threats among their staff. Another major challenge is implementation costs. While the integration of IS and IoT promises efficiency gains, the upfront investment to modernize infrastructure can be prohibitive, especially for ports with limited financial resources. Deploying sensors, upgrading management systems, and training teams engaged in the use of these technologies require considerable budgets. In addition, funding and long-term planning must anticipate not only the costs of implementation, but also the recurring expenses related to the maintenance and updates needed to ensure the sustainability of the systems. Resistance to change in organizations is a third key challenge. Adapting to new technologies often requires a cultural transformation within operational and management teams. Employees may be apprehensive about the unknown or perceive IoT and IS as a threat to their jobs rather than a catalyst for improvement. To overcome this resistance, it is crucial to foster open communication about the benefits of these technologies, involve stakeholders from the outset of projects, and promote training and awareness-raising initiatives. Thus, an inclusive approach can not only minimize resistance, but also maximize adoption, thus making it possible to take full advantage of the innovations offered by IoT and IS.

### 3.5.1. Data Security Issues

Smart port management relies heavily on the integration of information systems (IS) and the Internet of Things (IoT), but this interconnection raises considerable data security concerns. Ports, as vital logistics hubs, generate and manipulate massive volumes of data, including sensitive information about operations, logistics, and communication between various actors. Cybercrime, which manifests itself in attacks such as ransomware, aims to exploit this data, compromising not only the security of information, but also the integrity and continuity of port operations. One of the major challenges is the diversity of IoT devices deployed, which, often with insufficient levels of security, can be vulnerable entry points for intruders. IoT sensors and devices, while effective at collecting data in real-time, sometimes lack regular security updates or robust defense architectures, making them particularly easy for malicious actors to exploit. In addition, the large number of interconnections between these devices creates a complex network, increasing attack surfaces and making it more difficult to detect threats. In addition, data protection legislation, such as the GDPR in Europe, imposes strict obligations on organizations regarding the management and protection of personal information. Ports must not only invest in secure infrastructure to protect their systems, but they must also adopt a culture of cybersecurity among their staff. This involves educating employees on security best practices, as well as implementing rigorous protocols for handling sensitive data. The complexity of data security challenges in smart port management thus calls for a proactive approach, where anticipating threats and implementing appropriate solutions become essential to protect the port ecosystem.

### 3.5.2. Implementation costs

The implementation of information systems (IS) and the Internet of Things (IoT) in the port sector represents a fundamental investment that requires a careful evaluation of the associated costs. These costs are divided into several categories (Figure 1), including hardware, software, training and maintenance costs.

**Fig. 3. Types of implementation costs of information systems (IS) and the Internet of Things (IoT) in the port sector**

*Source. Author's elaboration*

Physical infrastructure must be adapted to incorporate new technologies, which may include the acquisition of IoT sensors, communication devices, and specialized software for data processing and analysis. Together, these investments require a substantial budget, which can vary depending on the scope and complexity of the project (Tunda-Olembe, 2024). In addition to acquisition costs, it's crucial to consider the recurring expenses that come with implementing IS and IoT. System maintenance, technical support, and regular updates often result in additional costs, sometimes not expected at the outset. In addition, training employees to ensure the effective use of these new technologies generates significant costs. It is essential that these financial aspects be integrated early in the planning process to avoid budget overruns that could jeopardize the overall viability of the project. In light of these considerations, ports should undertake a rigorous business case to weigh upfront costs against potential benefits, such as improved operational efficiency, reduced wait times, and value for money. While financial investments may seem like a deterrent in the short term, the long-term benefits associated with productivity gains and the digital transformation of port operations often justify these costs. Ultimately, it is a strategic approach that, by contributing to smart port management, paves the way for increased competitiveness in an ever-changing maritime environment.

### 3.5.3. Resistance to change in organizations

Resistance to change is a crucial issue when implementing information systems (IS) and the Internet of Things (IoT) in port organizations. Diverse corporate cultures, fear of the unknown, and skepticism about new technologies often weaken innovation initiatives. This resistance can be attributed to several factors, including a lack of awareness of the potential benefits and the perception that imposed changes can threaten jobs or change the status quo. As a result, it becomes essential for managers to project a clear vision of the future where technology serves as a lever to improve port operations rather than replacing fundamental elements of existing organizational structures (Bennour and Oukassi2025). To overcome these obstacles, it is imperative to establish change management strategies, involving effective communication and proactive awareness. Integrating a training program that illustrates the added value of IS and IoT can not only support employees in acquiring the necessary skills, but also strengthen their confidence in new technologies. Participatory initiatives, where employees are invited to share their concerns and contribute to decisions, are also beneficial. This creates an environment conducive to acceptance, fostering a spirit of collective adaptation that can turn resistance into enthusiasm. Identifying champions of change within teams can also play a key role. These individuals, often respected for their expertise and influence, can act as agents of transformation, promoting the adoption of new technologies through their credibility. To the extent that key actors are mobilised to support the transition, the momentum can be fostered, reducing reluctance and fostering a climate of trust. In sum, understanding and managing resistance to change is critical to the success of digital transformation projects within ports, as it sets the stage for sustainable and holistic adoption of technological innovations.

## 3.6. Examples of Smart Ports Around the World

In the contemporary maritime landscape, several ports stand out for their innovative approach to intelligent management, integrating information systems (IS) and the Internet of Things (IoT) to optimize their operations. The Port of Rotterdam, for example, is often cited as a model of a smart port. Through the use of advanced sensors and real-time data, this port facility is able to monitor maritime traffic, manage container flows, and predict waiting times for ships, reducing waiting times and increasing the overall efficiency of shipping. The Port of the Future platform embodies this commitment to innovation, integrating technologies such as artificial intelligence for predictive analytics and resource management. On the other side of the world, the port of Singapore is also positioned as an emblematic example of a smart port. By mobilizing IoT technologies, this port optimizes its operations through the use of autonomous vehicles for container transport and the synchronization of ship arrivals. Singapore has also pioneered the implementation of software solutions for cargo tracking, allowing stakeholders to access accurate and up-

to-date information regarding the condition of cargo, which not only improves the logistics chain, but also contributes to the safety and sustainability of port operations. Finally, the Port of Los Angeles, a key hub for transpacific trade, illustrates the benefits of technological integration in the maritime sector. Using big data and advanced analytics technologies, the port has implemented supply chain management systems that not only improve container tracking, but also enable better collaboration between the port's various stakeholders, from carriers to enhancers. With a focus on sustainability, Los Angeles is also testing green solutions, such as electric power for port facilities, reducing its carbon footprint. These examples demonstrate how an integrated approach to information systems and IoT can transform ports into key players in modern logistics, while addressing contemporary environmental and operational challenges.

### 3.6.1. Port of Rotterdam

The Port of Rotterdam, one of the largest ports in Europe, stands out for its advanced integration of information systems and the Internet of Things (IoT), perfectly illustrating the transition to smart port management. This port, which has constantly evolved over the decades, is now establishing itself not only as a commercial hub, but also as a model of sustainability and technological innovation. Thanks to a sophisticated digital infrastructure, the Port of Rotterdam manages to optimise port operations, enabling smooth and efficient management of goods flows (Notteboom2024)(Sehlin, 2023). The implementation of IoT in the Port of Rotterdam is evident through the use of on-board sensors on port equipment and transport vehicles. These devices collect real-time data on various parameters such as temperature, humidity and cargo status. At the same time, the port's data exchange platform, known as "Portbase", enables seamless communication between all players in the logistics chain, from shippers to carriers to customs. This interconnection promotes fast and informed decision-making, reducing waiting times and logistics costs, while improving the safety and reliability of port operations. At the same time, the port is working to minimize its carbon footprint through innovative initiatives. One of the flagship projects concerns the development of critical infrastructure for zero-emission shipping, including terminals designed to accommodate green ships. With the implementation of a clean energy distribution network and energy storage solutions, the Port of Rotterdam is paving the way for a sustainable future while strengthening its status as a smart port. By integrating these technologies in harmony with sustainable practices, the port teaches other ports around the world how to balance operational efficiency and environmental responsibility, making Rotterdam a model to follow in the maritime sector.

### 3.6.2. Port of Singapore

The Port of Singapore, as a global maritime hub, embodies the advanced application of Information Systems (IS) and Internet of Things (IoT) for smart port management. Featuring a highly integrated infrastructure, the port uses technology platforms that connect all of its operations, facilitating informed, real-time decision-making. Thanks to strategically placed IoT sensors, the port collects a wealth of data, ranging from maritime traffic levels to weather conditions, thus allowing for constant optimization of mooring and loading processes. The application of advanced communication technologies in the Port of Singapore has enabled the deployment of Navigation Satellite Systems (GNSS) and real-time tracking technologies, providing port operators with unparalleled visibility into every container movement. Sustainability goals are at the heart of port initiatives, where the port is adopting autonomous and electric vehicles for freight transport, minimizing its carbon footprint. Moreover, the logistics management system is supported by machine learning algorithms that forecast demand and adjust operations accordingly, maximizing efficiency while reducing costs. With a focus on integrating IoT into its operations, the Port of Singapore has also made progress in improving safety and resilience. Smart surveillance cameras and drones are constantly patrolling for anomalies, while warning systems anticipate and flag potential risks, preventing costly accidents. The Port of Singapore is not only responding to contemporary challenges; it anticipates them, embodying a model of smart port management that combines technological innovation and sustainability (El Garoui, 2021). As a leader in the field, it serves as an inspiring example for other ports around the world, working towards a more efficient and responsible maritime future.

### 3.6.3. Port of Los Angeles

The Port of Los Angeles, often considered the busiest port in the United States, embodies a vision of intelligent port management at the interface of information systems (IS) and the Internet of Things (IoT). In response to increasing pressure on maritime traffic volumes and the need for environmental sustainability, the port has implemented innovative technologies to optimize operations while reducing its carbon footprint. For example, thanks to a sophisticated IoT infrastructure, it is possible to track container movements in real time, analyze traffic flows, and predict vessel waiting times using machine learning algorithms (Chaima et al.2024). The Port of Los Angeles' digital transformation is also manifested in the integration of advanced management systems that enable communication between various players in the supply chain. Port operations, such as loading and unloading goods, are thus interconnected with land transport systems, facilitating smooth and efficient coordination. The "Port Optimizer" project, for example, was set up to share secure data among all procurement partners, enabling informed decisions to improve the fluidity of operations. By making essential information accessible, the port creates synergy between the different operators and increases not only the operational efficiency, but also the transparency of its activities. In addition, the Port of Los Angeles is not only focused on efficiency, but also on environmentally friendly initiatives. By integrating smart sensors and monitoring technologies, the port is working to reduce polluting emissions associated with maritime and land activities. The programmes dedicated to the electrification of vehicles, as well as the use of renewable energy, demonstrate a long-term commitment to sustainable port management. In this way, the Port of Los Angeles is not only a major logistics hub, but also a model of a smart port that combines efficiency and environmental awareness, setting standards for ports around the world.

## 3.7. Future prospects for port management

Modern port management is facing a fascinating turning point, marked by technological developments and growing societal expectations. Emerging technology trends, such as artificial intelligence (AI), blockchain and the Internet of Things (IoT), promise to optimize port operations, facilitating better traceability of goods and enhancing infrastructure security. AI, for example, can analyze massive volumes of data in real-time to predict traffic volumes, allowing for the anticipation and adjustment of operational resources needed. At the same time, IoT offers unprecedented connectivity, allowing sensors to collect data on environmental conditions, container status, and even dock occupancy, to make port operations more efficient. These innovations aim to reduce wait times for ships and cargo, thereby increasing the competitiveness of ports on the world stage.

Public policies also play a decisive role in the futuristic direction of port management. Governments are increasingly called upon to adopt regulations that promote the integration of new technologies while ensuring maritime safety and environmental protection. Initiatives such as Low Emission Zones and strict CO2 regulations encourage ports to invest in renewable energy solutions and sustainable infrastructure. In addition, collaboration between the public and private sectors is essential for the development of innovative projects aimed at transforming ports into smart ecosystems. A stable and proactive policy framework is crucial to foster innovation and attract the investment needed for this transition.

Finally, environmental impact and sustainability are at the heart of contemporary concerns. It is imperative that the port management of tomorrow take into account its ecological challenges, implementing strategies that promote the reduction of polluting emissions and energy efficiency. Ports are in a unique position to adopt sustainable practices, including integrating renewable energy systems, improving waste management and promoting intermodal modes of transport. By taking a holistic approach that links economic development and environmental responsibility, ports will not only be able to meet the demands of modern logistics, but also play a key role in the transition to a greener economy. Thus, the future of port management will revolve around a synergy between technological innovations, enlightened public policies and sustainable practices.

## 4. CONCLUSION

The conclusion of this study on smart port management, supported by the integration of information systems (IS) and the Internet of Things (IoT), underlines the crucial importance of technological innovation in optimizing port operations. Global ports, facing increasing challenges such as increased maritime traffic, environmental requirements, and increased competitiveness, can benefit significantly from a systematic approach towards the adoption of these revolutionary technologies. By integrating advanced digital solutions and IoT devices, ports can not only improve operational efficiency, but also reduce costs and minimize their environmental footprint. The use of IS in port management allows for the centralization of data, thus facilitating the sharing of information in real time between the various players in the sector, ranging from port managers to logistics operators. At the same time, IoT, by integrating sensors and connected devices, provides increased visibility into operations, such as container tracking, traffic management, and predictive analysis of maintenance needs. This synergy between information technology and connected devices also promotes better decision-making, enabling rapid and informed responses to critical issues. It is important for ports to commit to a targeted digital transformation, which will play a fundamental role in the sustainability and resilience of their operations. Increased collaboration between the different players in the port ecosystem, facilitated by technological innovation, is now essential not only to adapt to current market trends, but also to anticipate future developments. Ports that embrace this transition to smart and integrated management will not only be able to stand out for their responsiveness and agility, but also serve as models for sustainable adaptation to the environmental, economic and logistical challenges of the twenty-first century.

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