Process-Oriented Digitalization in Port Systems: Evidence from the Port of Trieste

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Abstract. This paper analyses the role of digitalisation in port systems within the context of the major transformations currently affecting the contemporary port sector, including technological, energy and geopolitical transitions. The study presented here stems from a research project that, starting with an analysis of existing processes related to port digitization, sought to develop a digital tool that would serve as an orchestrator, with the aim of simplifying a particularly fragmented and complex process: the procedure for semi-trailers to obtain port access permits.

The analysis was based on an applied qualitative approach, in which, in an initial phase, a series of unstructured interviews were conducted with key stakeholders to understand the operational processes that could be implemented, identifying a systemic gap attributable to the fragmentation of information flows and limited interoperability between the Port Community System (Sinfomar) and Terminal Operating Systems. This gap is particularly evident in truck access management processes, characterized by duplication of tasks, the use of parallel tools and a high incidence of manual operations. In a second phase the development of a digital process orchestration tool was implemented, designed as an intermediate layer of integration between existing systems. The application of the solution to the access process for departing lorries has yielded significant results, with operational times reduced from several minutes to a few seconds, accompanied by a decrease in errors and smoother flows.

Keywords: Port Digital Transition · Smart Port · Port Community System · PCS · Port of Trieste

1 Introduction

The digital transition represents one of the main drivers of innovation and change within the port sector. It is embedded in and develops as part of a broader reconfiguration of ports, characterized by the interaction between at least three major evolutionary trajectories: the digital transition, the environmental and energy transition, and the resurgence of geopolitics as a defining factor in global logistics chains [1].

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The digitalization of port processes, supported by the adoption of technologies associated with the Industry 4.0 paradigm – such as the Internet of Things, artificial intelligence, blockchain and digital twins – has profoundly altered the way operations are managed, promoting automation, data sharing and information integration among stakeholders in the port community [2]. Port Community Systems (PCS), in particular, have established themselves as key digital infrastructures for the coordination of information flows, helping to improve operational efficiency and process transparency [3].

Despite the growing attention in the literature towards port digitalization, analysis of the concrete processes and the ways in which digital innovations translate into actual improvements in operational efficiency remains limited. In particular, there remains a persistent gap between the adoption of digital infrastructure – such as PCS – and the actual integration of processes, which often continue to be characterized by fragmentation, duplication and poor interoperability between stakeholders, particularly given the multitude of software and tools commonly in use [4].

This study fits within this framework, proposing to reflect on which digital solutions we can adopt to improve operational efficiency in the port sector. To address this issue, the analysis focuses on the case of the Port of Trieste, chosen as a case study due to its strategic importance and the already advanced level of digitalization achieved. Through a qualitative approach based on desk research, analysis of existing systems and interviews with operators, the study identified specific operational processes currently managed in an ad hoc manner, characterized by duplication of information and the presence of multiple, non-integrated solutions. Starting, therefore, with a mapping of processes, this paper proposes the development of a digital solution geared towards process orchestration, capable of addressing an operational bottleneck by seeking to improve coordination between the various stakeholders involved [5].

The work contributes to the debate on port digitalization by proposing a process-oriented approach, which moves beyond the emphasis on individual technologies to focus on operational integration and the reduction of systemic inefficiencies, adopting the following structure: the second section presents a review of the literature on port digitalization, with particular reference to Port Community Systems and key European best practices; the third section introduces the case study of the Port of Trieste; the fourth section presents the methodological framework; the fifth section presents the results obtained; and the final section is devoted to the conclusions.

2 Literature Review – Digitization and Interoperability of Port Systems

In recent years, the digitalization of ports has become one of the most significant themes in the transformation of maritime logistics systems. The modern port is increasingly characterised by the interplay of physical and information flows. Ships, lorries, trains, goods, documents, permits, customs data, operational requests and administrative procedures all move in tandem [6]. It is in this space, between the movement of goods and the circulation of information, that the digitalisation of port systems is increasingly taking on a central role [4, 7].

In the past, ports were viewed primarily in terms of their physical infrastructure: quays, water depths, cranes, yards, warehouses, and rail and road connections. This perspective remains essential to ensure that port environments continue to function as efficient infrastructure, but a port's competitive capacity increasingly depends on the quality of its information systems: in this sense, a port must be able to manage not only goods but also information flows, circulating them among the various stakeholders, making them available at the right time, avoiding duplication, reducing errors and facilitating coordination between operators [8].

The literature on smart ports and Port 4.0 emphasises precisely this point: the port is progressively becoming a connected system, in which automation, sustainability and the dematerialisation of information flows represent three fundamental directions of digital transformation [9, 10].

Port digitalisation can be analysed at several levels. A first level concerns the conversion of paper documents into electronic documents. This is the most immediate step: files, forms, requests, authorisations and communications are managed through IT systems. This saves time and improves the traceability of operations. A second level concerns the organisation of processes, influencing the way in which stakeholders work, communicate and make decisions. A procedure may be uploaded to a digital platform, but if the operator then has to re-enter the same data into another management system, the benefit is reduced. Digitalisation produces more substantial effects when it allows the operational flow to be rethought as a whole. A third level concerns the transformation of port governance, where digital platforms change the way information is produced, controlled and shared [11]. This affects relations between Port System Authorities, terminal operators, freight forwarders, shipping agents, customs, road hauliers, rail companies and other parties involved in the logistics chain. In this sense, the port is a collective system. No single stakeholder governs the entire process alone. Every operation depends on a sequence of steps, and each step requires a multitude of data [12].

In the literature, numerous authors have examined port evolution processes, and recently, the topic of digitalisation has come to the fore in discussions on the subject: ports are, in fact, evolving from simple infrastructure hubs into integrated logistics platforms. In this sense, the latest generations of ports are characterised by real-time connectivity, data exchange, collaboration between stakeholders, a focus on sustainability and the use of advanced technologies. This evolution responds to various pressures. There are economic pressures, linked to competition between ports and the need to reduce times and costs. There are logistical pressures, connected to the growth in volumes, the complexity of supply chains and the demand for greater reliability. There are environmental pressures, as ports must manage emissions, energy consumption, congestion and their impact on the local area. And there are institutional pressures, particularly regarding security, customs, traceability and the regulation of cargo flows.

In this context, the Port Community System (PCS) plays a central role [13]. The PCS is a digital platform designed to enable the interoperable exchange of information between stakeholders in the port community. Its main function is to connect parties that use different languages, procedures and information systems. Shipping agents, freight forwarders, terminal operators, hauliers, customs authorities, the Harbour Master's Office, the Guardia di Finanza, maritime health authorities, freight villages and rail

operators all play a part in the port process [14]. The PCS aims to establish a common platform for exchange. The Port Community Systems can be describe as digital platforms capable of facilitating information exchange, coordination and collaboration among port community stakeholders. Their usefulness is linked to the ability to simplify communication, automate data exchange, and enhance efficiency, transparency and security within maritime trade systems [15]. Interoperability therefore becomes the central issue. Systems must be able to connect and exchange data via compatible interfaces, protocols and architectures. This concerns the relationship between PCS, Terminal Operating Systems (TOS), customs systems, rail platforms, access systems, public databases and private management systems. The interoperability of a PCS with the entire port community is certainly a critical aspect to take into account. One need only consider the breadth of interfaces a Port Community System must handle: whilst the TOS simply concerns the port terminal and its internal operations—yard, gates, vehicles, cargo units, operational sequences, equipment, and handling planning—the PCS must be able to view port operations holistically, whilst also communicating with the various IT systems used by different operators [16, 17]. When the PCS and TOS communicate effectively, the transition between document, authorisation and physical operation becomes smoother. When communication is incomplete, operators must intervene manually. They re-enter data, check across multiple screens, use reference sheets, and send requests via email. The process remains digital, but its continuity is weak.

Interoperability affects the port's ability to function as a unified system. A port may have good physical infrastructure yet suffer from information bottlenecks. It may have adequate draughts, major rail connections and specialised terminals, but lose efficiency in certain document or authorisation stages. Bottlenecks in transport systems can therefore be found as much in logistics yards, at entry gates, during customs checks, and in the interface between ship and train, as in the communication between different digital and IT architectures. This is why digitalisation must be analysed at the micro-operational level. Recent literature on smart ports often emphasises the technological dimension: automation, sensors, artificial intelligence, cloud platforms, and digital twins. Whilst all these elements are particularly relevant to day-to-day port operations, the success of digitalisation often depends on more minute details: a screen that communicates with another, a field filled in just once, a list that can be selected in bulk, a document priority correctly read by the system, an authorisation that passes from the PCS to the terminal without further steps: it is these details that determine a significant increase in efficiency in the field of port digitalisation [18].

The digital tools a port can adopt also include GPS systems, OCR, RFID, automated gates, PCS modules, access control systems and management platforms. The presence of these tools indicates a path towards modernisation. Their coordination, however, indicates a deeper capability: that of making the parts of the system work together. Digitalisation, then, becomes a matter of synchronisation, that is, the ability to share data and information when it is needed [19]. Too late, and the data loses its operational value. Too early, and it may still be incomplete. If incorrect, it generates additional checks. If duplicated, it increases the administrative burden. The digital port works when data is timely, reliable and shared according to clear rules.

3 Methods

3.1 Understanding Digital Port Processes

The core of this project lies in a methodological approach designed to combine qualitative research with empirical applications, aimed, in the first instance, at identifying certain systemic issues within port processes and, in a second phase, at developing a digital solution capable of addressing one of these inefficiencies in an effective manner. The first phase of the research was exploratory in nature and focused on establishing a comprehensive understanding of digital port processes. During this phase, desk research was conducted, along with an analysis of the main best practices at European and international level regarding port digitalization, Port Community Systems (PCS) and tools geared towards the integrated management of logistics flows.

This analysis was then applied to the port of Trieste through a study of the Sinfomar PCS, considered the central digital infrastructure for coordinating a significant portion of port processes: in this context, the functional modules and its digital architecture were examined to understand the functionalities involved in managing information relating to ships, cargo, vehicles and rail traffic, as well as to understand the nature of the interactions between the port system as a whole and individual operators. This preliminary phase therefore provided an initial mapping of existing digital processes and identified areas where digitalization was already well-established and those where, conversely, signs of critical issues were emerging.

3.2 Identification of System Gaps

The second phase forms the core of the methodology adopted and was carried out through unstructured interviews with key stakeholders at the Port of Trieste, including terminal operators, logistics operators and rail operators. The decision to use unstructured interviews was driven by the need to capture the actual operational dynamics without imposing an overly rigid framework of observation from the outset. This approach made it possible to highlight not only the functions formally assigned to digital systems, but above all the limitations, inconsistencies and informal solutions that characterize day-to-day operations.

The evidence gathered showed that the port's digitalization is developing in layers that are only partially integrated. In particular, the Port Community System Sinfomar primarily serves as a document and institutional liaison, whilst the internal management of terminal operations falls to the Terminal Operating Systems, which each operator adopts independently in accordance with their own organizational needs.

It is precisely in the relationship between Sinfomar and the terminal systems that a systemic weakness requiring intervention has been identified. The interviews highlighted how, in various areas, the lack of interoperability between the PCS and TOS leads to a duplication of processes and a fragmentation of information flows, particularly regarding the authorization of lorries' pre-entry to the terminal via the digital traffic light system linked to Sinfomar, the overview of this system is presented into the Fig. 1.

The Ro-Ro access management process, as currently structured requires a series of manual steps often in a rather laborious manner. The control room operator logs

into Sinfomar PCS, searches for the truck's license plate among the registered vehicles, matches it to the correct booking, and only then can they authorize the green light at the Ferretti traffic signal. An operation that, taken individually, seems manageable. The problem is that it must be repeated every time, for every single vehicle, one at a time.

Once access is granted, the event must be recorded in an external Excel file, a parallel tool, manually updated by the control room, which serves as a log of authorized trucks. That data is then imported into the Terminal Operating System to synchronize the information in the terminal's management system. Three different environments, essentially to record the same thing.

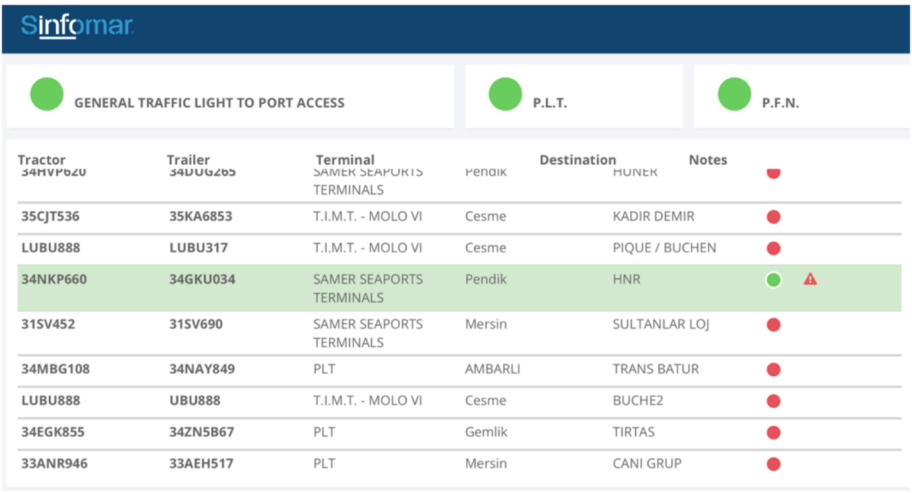

Fig. 1. Traffic light system for access to the new free zone on the Sinfomar website of the Port System Authority of the Eastern Adriatic Sea. Source: https://sinfomar.porto.trieste.it/GPF/mezzifermifernetti.jsp last access: 07/05/2026

Further complicating the picture are emails: the requests for terminal access, infact, often arrive via email, while bookings are generated directly by the TOS. The operator is therefore forced to manually transfer the information from the terminal management system to PCS and then back to Excel. Every transfer is an extra step, a moment when something can go wrong—a wrong license plate, an outdated booking, a mismatch between systems.

The result is a fragmented information flow, in which the same data is rewritten and rechecked multiple times, in different contexts, without any of the systems involved ever having an up-to-date and complete view of the situation in real time. Those working in the control room must piece together the operational picture bit by bit, cross-referencing different sources, with all that this entails in terms of time and margin for error.

3.3 Development of the Digital Solution

Once the system gap requiring intervention had been identified, the third phase of the research focused on designing and implementing a digital solution aimed at resolving

that specific problem. The approach adopted was problem-driven, in the sense that the technological tool was not developed prior to the analysis but rather after identifying the vulnerable process requiring intervention. In this regard, the tool was conceived as what could be defined as a process innovation designed to address an operational problem that clearly emerged from discussions with port stakeholders [20]. The analysis of port processes, highlighted in the previous phase, thus identified a particularly significant bottleneck in the duplication of access operations to the multipurpose terminal, and, on this basis, a prototype orchestrator was developed, designed as an intermediate layer between the Port Community System (PCS) and the Terminal Operating Systems (TOS). The function of the orchestrator developed in this project is to reduce the manual steps that the terminal control room is required to perform, thereby also reducing information fragmentation and eliminating the duplication of activities, creating an interface capable of direct communication between IT systems through a tool that enables platforms currently operating separately to communicate with one another.

The development of the orchestrator therefore aims to create an automated flow of information between the PCS and the TOS, eliminating the need for external manual interventions such as the use of Excel files or email communications for operational monitoring. In the specific application regarding truck access to the terminal, the tool was designed to address the most rigid aspects of the process, leading to fully automated management of access authorizations, in which the digital tool serves as the interface between the various platforms, completely reorganizing the process for semi-trailers to request pre-entry into the port terminal.

The result achieved through the development of the orchestrator is to transform a system based on various redundant and complicated steps into a continuous flow of information, where physical terminal operators are required only to perform a document verification role, while the task of entering information is delegated to an automated system.

4 Case Study: The Digitalisation of Port Processes at the Port of Trieste

The case study presented in this paper focuses on the Port of Trieste, an infrastructure with a complex logistics structure in which maritime traffic, rail freight, road transport, customs procedures, document management, and terminal operations are all intertwined. The volume of goods transported by rail annually (with over 8,000 trains handled in 2025) and the free port regime make this port a unique port ecosystem on a national scale [4]. It is precisely this exceptional nature that makes digitization a crucial step, because, as mentioned earlier, the port's operations increasingly depend on the ability to circulate accurate information in a timely manner to meet operational needs.

At the heart of the port digitization process in Trieste is Sinfomar, the Port Community System of the Port of Trieste, adopted in 2014. Its introduction marked the start of the most structured phase of the port's digitization, following earlier initiatives—such as the Black Box system—which were primarily focused on collecting statistical and commercial data related to the Free Port. Sinfomar was thus created with a specific purpose: to establish a common platform through which the various stakeholders in the port

community could communicate while coordinating information flows. Even today, this platform serves as a link between the Port System Authority, terminal operators, customs, freight forwarders, carriers, rail operators, and other entities involved in logistics activities; its modular architecture allows it to cover various operational areas: management of ships, cargo, vehicles, trains, people, and statistics [16]. Sinfomar thus builds a shared information base, useful both for administrative procedures and for monitoring the physical flows passing through the port. A schematic representation of the operations managed by Sinfomar is shown in Fig. 2. From a functional standpoint, Sinfomar has helped improve certain aspects of port management, with a particular focus on the digitization of information flows and the streamlining of document processing, thereby enhancing the traceability of operations. The presence of a common platform thus helps reduce some of the document fragmentation that traditionally characterizes port environments. One of the most concrete and immediate results has been the digitization of customs documentation. Ship arrival and departure manifests, summary declarations for incoming and outgoing goods, and advance notices for road traffic: procedures that previously existed on paper—often in duplicate—are now managed electronically through the system. Each shipment of goods is identified by unique codes that link logistics data to customs data, ensuring precise matching and the automatic generation of reliable statistics. This is no minor detail in a port where the Free Port regime requires particularly strict customs control [21].

Over time, other technological solutions have developed around Sinfomar, with varying degrees of integration. One of the most visible concerns the management of semi-trailer traffic, a particularly significant issue given that hundreds of thousands of trucks pass through the port each year (360,000 in 2025), causing congestion problems both within the port area and on urban roads [20].

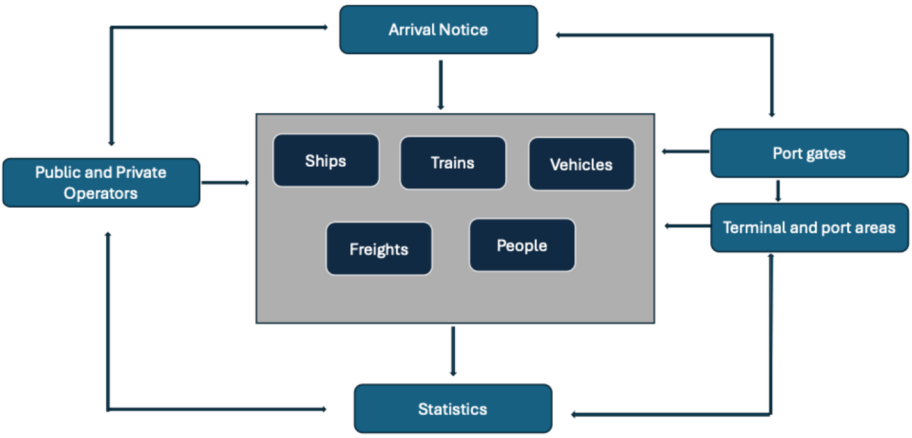

Fig. 2. Schematic representation of the operations managed by the Port Community System of the port of Trieste – Sinfomar. Source: Author's Elaboration

5 Results and Discussion

As highlighted above, this paper stems from a research and development project, in which the most significant findings relate to the process of managing port access for departing lorries, identified during the qualitative analysis as one of the most critical issues in terms of operational integration. Indeed, under the traditional operational setup, this process relied on a highly manual and fragmented sequence, where the operator was required to identify the vehicle waiting within the Sinfomar interface, manually retrieve essential data, separately consult the Terminal Operating System to extract the information needed for the booking, prepare and submit the pre-entry request, retrieve the confirmation data, log back into Sinfomar to fill in the required fields and, finally, manually update the vehicle's status to authorize its progression [18]. The information flow generated by requests for access to the port terminal required manual intervention to coordinate various systems, ranging from reading emails containing terminal access requests, to identifying the booking via the TOS, to entering the various data obtained into Sinfomar, which involved manually filling out all the fields shown in the interface presented in Fig. 3. The estimated time required to process this procedure was approximately 7 min per unit entering the terminal. The introduction of the orchestrator—developed as an intermediate layer between the PCS, the TOS, and other IT tools such as email and Excel files—led to a substantial process innovation. The digital orchestrator was in fact designed to automatically read data from various information sources, retrieving the necessary data from the TOS and the email system, and then autonomously generating the pre-entry request to the terminal for the waiting truck, filling in the required fields within Sinfomar and simultaneously updating the terminal control room's operational report managed via an Excel file. In this way, this process—which previously consisted of several manual operations—has been reorganized into a continuous and integrated workflow, managed autonomously by an automated solution, while maintaining operator control, with the operator now performing only a supervisory role.

In terms of performance, the most striking result is the drastic reduction in the time required to complete the entire procedure. Whereas in the previous configuration the workflow could take an average of 7 min, with the new tool the same process is completed in around 12 s: the efficiency gain is therefore extremely significant, both in absolute and relative terms, and demonstrates how the intervention has redesigned the entire access authorizations process, eliminating most of the redundant activities and interruptions that characterized the original workflow[1].

In addition to the reduction in processing times, the results show a qualitative improvement in the process. Automation significantly reduces the risk of human error, particularly during data transcription between different systems and in the management of booking confirmations. At the same time, the operational centralization of the workflow helps to overcome the issue of parallel information channels, which was one of the main critical issues highlighted in the interviews. The process thus becomes more linear, more transparent and more controllable, with positive knock-on effects on the standardization of procedures and the ability to monitor their progress over time.

[1] An explanatory video about the digital orchestrator developed as part of the project can be found at the following link: https://bit.ly/Orchestrator_Port_Trieste.

The result achieved is the development of an efficient and functional technological solution, whilst also demonstrating how a system gap—linked to the lack of integration between platforms and the duplication of activities—can be addressed through an orchestration tool capable of intervening directly in the process.

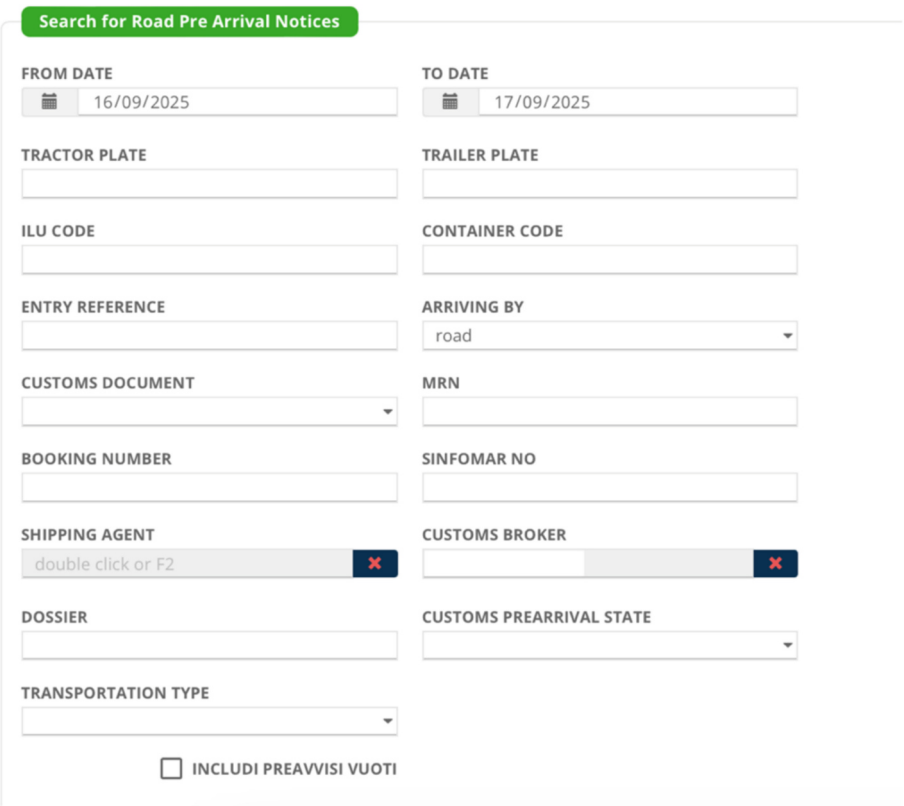

Fig. 3. Form for reporting pre-arrival at the port terminal, to be completed in order to receive approval. Source: Sinfomar

6 Conclusions

The paper analyzed the digitalization of port processes, placing it within a broader context of transformations that are redefining the role of modern ports, amidst technological, energy and geopolitical transitions. This study aims to highlight the importance of interoperability in operational processes, demonstrating that efficiency depends as much on the presence of an advanced digital infrastructure as on that infrastructure's ability to interact with the entire port ecosystem. The results show that one of the main limitations of port digitalisation lies in the fragmentation of information systems and the separation between the documentary level and the more explicitly operational level. In this regard, we have observed since the literature review that document dematerialisation can represent the first fundamental step towards highly digitalized smart ports; however, to also

improve the efficiency of the operational component, we need to take a step further and thus create an interoperable ecosystem. This is made even more complicated when one considers how many different operational systems can coexist within a single port community, where each terminal will use a different terminal operating system, and every logistics, rail, MTO and other operator will utilise different information systems: the challenge of port digitalisation lies precisely in the ability to integrate all these different components into a single system, in order to minimise duplication of procedures, manual steps that are particularly prone to error, and the disjointed management of information flows.

Specifically, in this paper we have focused on the process by which lorries request access to the terminal; in this particular case study, it was clear to see that there are inefficiencies within the process which result in long processing times, procedural rigidity and a risk of human error on the part of operators. All these factors led us to identify this process as an interesting area of application for developing a digital tool capable of offering a solution tailored to this specific operational process. The orchestrator developed has demonstrated that integration between the various existing systems is not only feasible but can also lead to effective implementations, drastically reducing operational times—which can drop from the 7 min mentioned earlier to a matter of seconds—whilst simultaneously improving the quality and reliability of the process, thanks to a reduction in potential human errors.

The approach adopted in this study, based on identifying a system gap through qualitative analysis and the subsequent design of a targeted solution, has highlighted how it is possible to take concrete action to address these critical issues. The development of a process orchestration tool has demonstrated how the integration of existing systems can yield significant improvements, drastically reducing operational times—from several minutes to a few seconds—whilst simultaneously enhancing the quality and reliability of the process [21].

From this perspective, the value of digitalization lies not so much in the proliferation of platforms, but in their ability to communicate with one another and effectively support day-to-day operations. The results indicate that targeted interventions aimed at integrating existing systems can generate significant benefits without necessarily requiring the replacement of existing digital infrastructure. This implies a greater focus on interface design, the standardization of information flows, and the development of solutions capable of reducing dependence on manual tasks and parallel tools.

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Disclosure of Interests. The authors declare any competing interests.

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