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Addressing digitalization though out a prototyping framework for agile smart services development: the case of Livorno Port

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Abstract. One of the crucial challenges of maritime transport is digitalization through the implementation of proper IT solutions. Development and deployment of such solutions allows seaports to increase their overall efficiency, to lower costs and improve performance times of the intra-terminal operations, to improve information flow and decision-making and to decrease the environmental footprint by addressing the sustainability. Nevertheless, the digitalization levels are heterogeneous and depend on different factors, such as seaport size, cargo volumes and type, stakeholders' needs, business models and investments. We propose a prototyping framework for agile smart service development relying on a set of standard and open-source technologies. The proposed framework is validated at The Port Network Authority of the Northern Tyrrhenian Sea (Port of Livorno) and the transferability of research results is assessed against the Port of Singapore, the most important hub of the Asian region.

1. Introduction

One of the crucial challenges of maritime transport is digitalization through the implementation of proper IT solutions.

Development and deployment of such solutions allows seaports to increase their overall efficiency, to lower costs and improve performance times of the intra-terminal operations, to improve information flow and decision-making and to decrease the environmental footprint by addressing the sustainability. The logistics and port sector is facing enormous changes caused by the penetration of information and communication technologies into operational and management processes. Nevertheless, the digitalization levels are heterogeneous and depend on different factors, such as seaport size, cargo volumes and type, stakeholders' needs, business models and investments. Although different studies are still ongoing to come up with a common and comprehensive way to assess the level of digitalization and innovation of the seaport with the aim of meeting the requirements of the next-generation seaport (namely the Port of the Future). Erroneously, ports are historically considered static realities, with little inclination to change and whose activities are considered accessory and without added value. Port logistics is a strategic sector in which there is creation and diffusion of value in terms of optimization of logistics processes and in terms of environment and collective well-being. Therefore, anticipating the demand without being caught unprepared by disrupting innovation is essential. Ports have been involved in the digitalization era, where everything is connected in a smart way, businesses and their industrial processes have been reengineered according to the so called 4.0 paradigm. Smartness usually refers to the principles of automatic computing. However, a globally accepted definition of smart port has not been well defined in the literature, as well as an internationally accepted and standard definition for the word smart does not exist in the context of port industries and maritime scenario [1]. The Ports of the Future, increasingly smart and interconnected, are turning into real hubs for the creation of value and knowledge, based on technology transfer. Information and communication technologies enable a set of new digital services (user-centric, innovative and based on standard architectures, networks and data) that allow the continuous improvement of operational and environmental performances. In this context, we propose a prototyping framework for agile smart service development relying on a set of standard and open-source technologies. The proposed framework is validated at The Northern Tyrrhenian Sea Port Authority System (Port of Livorno) and the transferability of research results is assessed against the Port of Singapore, the most important hub of the Asian region. As a matter of fact, the Port of Singapore has positioned itself to be competitive to other ports and has relentlessly driven comparative advantage. There is immense scope to increase this advantage from digital transformation to improve operational efficiency and sustainability by positioning as smart and agile port. We propose technological solutions and strategies to accelerate maritime digitization, connectivity and cybersecurity in Singapore and the regional based on experience and lessons learnt in the Port of Livorno. Our approach is based on ICT state-of-the-art analysis for the Port of Singapore by considering some key factors driving port digitization and sustainability. According to this approach, we come up with the most effective strategy to accelerate and benefit from maritime digitization, connectivity and cybersecurity by addressing the operational efficiency and sustainability though out a prototyping ICT framework for agile services development as an effective tool to address the Port Community needs and requirements.

2. State-of-the-art analysis

Singapore has redefined the container logistic processes and operations through the adoption of different digital technologies such as Artificial Intelligence, Blockchain [2], Cloud Computing and Internet of Things [3].

Digital innovation in the port of Singapore has been disruptive, and case study [4] has presented how the port leveraged the information technologies to stay competitive in the industry. The Port Authority of Singapore (MPA) has employed mobile technology and wireless connectivity to improve efficiency, communications, and crew satisfaction in the Port of Singapore [5]. Multiple ports in this region already adopted the Integrated Port Management System (IPMS), which incorporates multiple ports in a single platform. A mega container port is being developed at Tuas in Singapore which would eventually consolidate the existing ports at Brani, Keppel, Tanjong Pagar and Pasir Panjang. This port is currently being developed the next generation port with digital twin of the physical systems and operations. The objective is to provide visualization, connectivity, analyzability, and granularity as depicted in Figure 1. Infocomm Media 2025 [6] in a 10-year plan released in August 2015 which aims to create a globally competitive infocomm media ecosystem that enables and complements Singapore’s Smart Nation vision. This ecosystem supports people and enterprises in tapping on infocomm media to effect economic and social transformation and foster a common identity. To facilitate that objective to be achieved, a new Digital Industry Singapore, or DISG, office had been established. DISG will work with private companies to address issues on needs for securing talent and market access, building capabilities, and internationalizing. In this context, Singapore started building

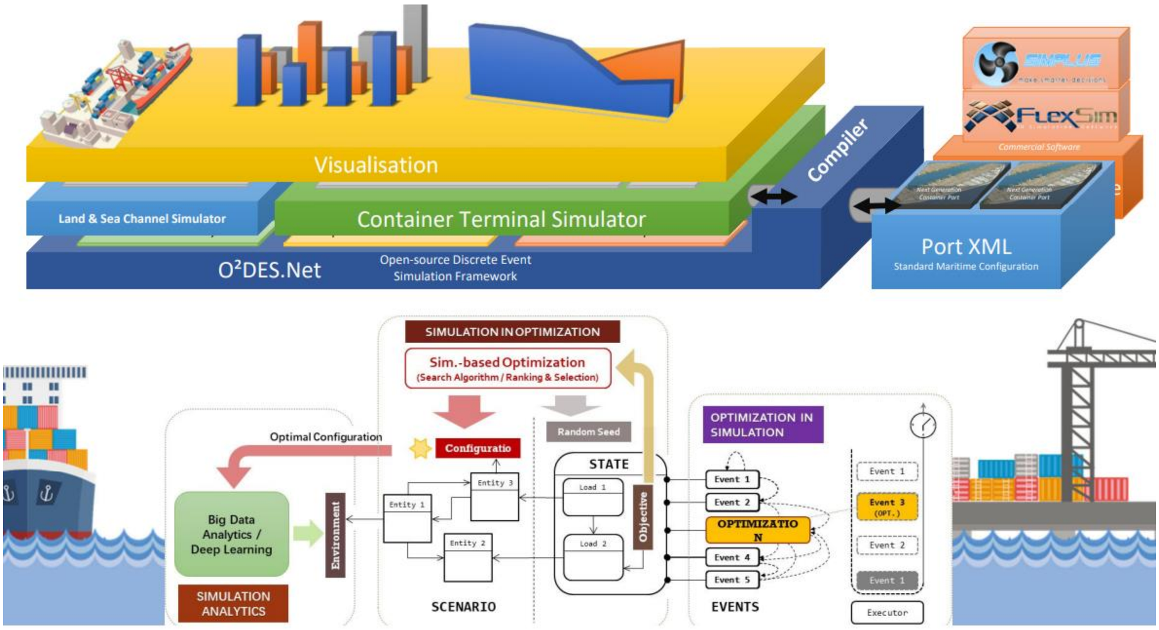

Figure 1. O2DES.Net framework for optimization in simulation.(NCSS, 2021).

on its existing R&D base, a vibrant maritime innovation cluster that is characterized by a diverse and tight-knit community of maritime enterprises (including start-ups and scale-ups), maritime technology solution providers, researchers, incubators, and venture capitalists, supported by an enabling environment. In June 2016, PSA, with the support of MPA and the Singapore Economic Development Board (EDB), committed to establish the PSA Living Lab, a living laboratory for the port and logistics industry [7]. The PSA Living Lab expects to enable technology solution providers to collaborate with PSA to develop and test-bed ideas in a live port environment, which is amongst the world's busiest container hubs. An example of a technology test-bedded at the PSA Living Lab is the Automated Guided Vehicle (AGV) system, which would be deployed for terminal operations at existing terminals, and eventually at Singapore's future Tuas mega port. Similarly, in March 2017, MPA announced the plan for a MPA Living Lab to provide a platform, with sufficient scale and real operating conditions, that technology providers and industry players can plug into for the co-development and piloting of innovative solutions by developing technological capabilities in the following four areas:

- Data analytics and intelligent systems;
- Smart and innovative infrastructure;
- Autonomous systems and robotics;
- Safety, security and environment.

As for the case of Livorno Port, the Port of Singapore relies on its own physical ICT infrastructure (with wireless connectivity, including commercial 4G and 5G technologies) to support two different types of digital systems and platforms for seaport operations management:

- Documentation Systems integrated with the Port Community System (e.g., billing, statistics and reporting operations);
- Planning and Operation Systems (e.g., berths, yard vehicles, ships and container gates management).

3. The ICT prototyping framework

The current information systems of the Livorno Port Authority are undergoing a deep digital transformation.

To address new requirements, the approach based on the usage of monolithic and technological solutions difficult to scale, has been descoped. For this reason, the Livorno Port Authority spent a lot of effort in the standardization of an ICT reference stack, named as MONICA Standard Platform [8], in order to support an agile development of innovative services for the actors from the supply chain and Livorno port community. This ICT stack is structured as a private cloud with full decoupling of the three canonical layers (data, business and application), and it is appointed by the Livorno Port Authority in current and future tenders and procurements (see Figure 2). The cloud has been deployed in a local laboratory within the Port of Livorno to allow testing and validation of the most recent functionalities, prior to the release time.

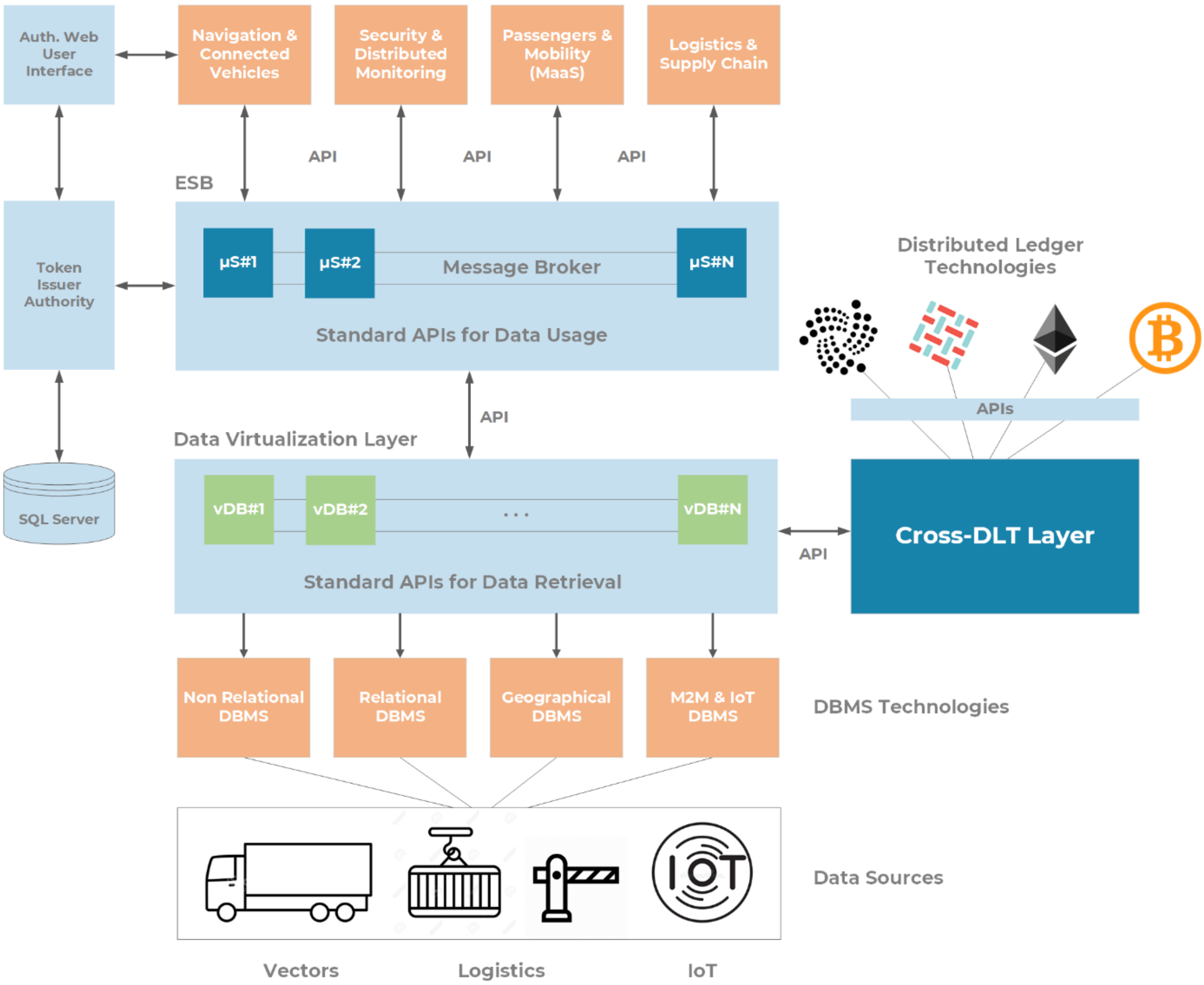

Figure 2. MONICA Standard Platform functional diagram.

The local cloud is configured as a staging environment for demo applications, which are turned into funding opportunities for industries allowing them to fill the gap from the prototype to the final product or service. All cloud resources are built on top of the local connectivity layer of the Port of Livorno, which is fully covered by a fiber optic backbone that capillary serves all terminals and gates in the port area, as depicted in Figure 3. On one hand, the fiber optic star-shaped network is allowing to connect all digital resources (i.e. sensors and actuators, network adapters, ordinary and industrial PCs) to a LAN. On the other hand, the network is mitigating the digital divide suffered by certain

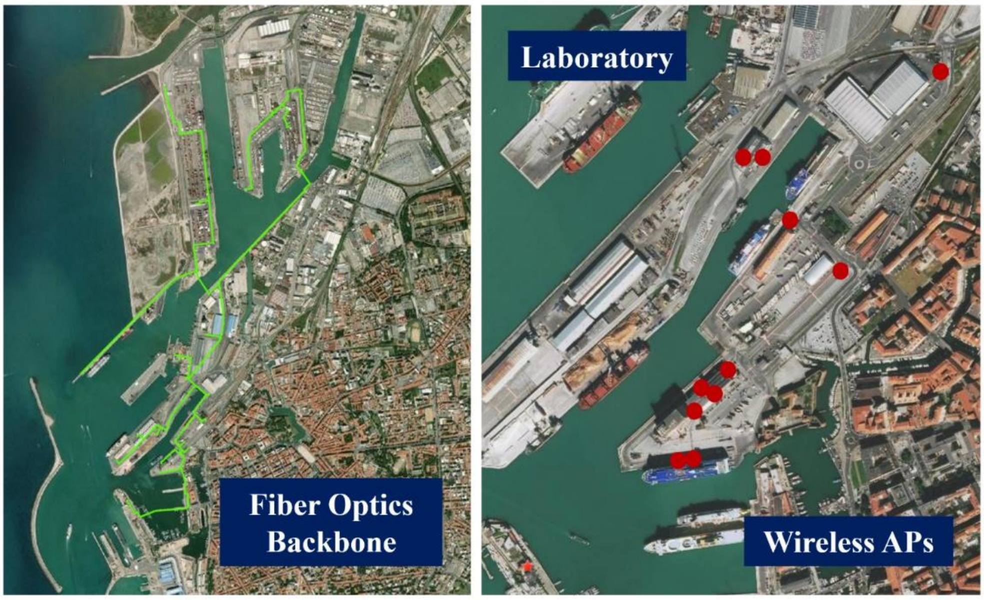

Figure 3. Staging environment and connectivity resources in the Port of Livorno.

areas, permitting to provide Internet access to government institutions (notably the Coast Guard, the State and Fiscal Police corps and Custom Agency), through the ISP selected by the Livorno Port Authority. In addition, a complementary wireless backbone is covering the maritime area with 100 Mbps Wi-Fi access points. The adoption of a standard and microservice-oriented architecture enables an agile integration of existing legacy systems into a single flexible and interoperable architecture and on the other side it enables a scalable approach for the development of new prototyping services. Furthermore, the introduction of open-source and software-based solutions such as Data Virtualization Layer (DVL) and Enterprise Service Bus (ESB) allow to define more efficient process control policies (e.g., services and data access, user management, APIs management, security, etc.) without compromising the scalability of the whole architecture. As depicted in Figure 2, MONICA Standard Platform is based on a full decoupling between the canonical layers of the three-tier architecture: data layer, business logic layer and application layer. In order to achieve this, we introduced two main software components into our ICT stack: Data Virtualization Layer and Enterprise Service Bus:

- *Data Virtualization Layer* (JBOSS Teiid [9]) is a cloud-native and open-source data virtualization platform enabling distributed databases, as well as multiple heterogeneous data sources, to be accessed by means of a common and standard set of APIs (e.g., JDBC, ODBC, REST, OData, SOAP, etc.). On one side, it allows aggregating data coming from disparate data sources, and on the other side, it permits to define a proper set of roles (according to create-read-updated-delete approach) allowing data consumers to use specific data sets. The current instance of the data virtualization layer is based on the WildFly application server [10], providing robust operations for transaction management, connection pooling, security configuration, resource management, and clustered deployment. The above-mentioned instance is deployed in the form of a docker container, running on a virtual machine with Ubuntu 20.04 Server operating system (64-bit architecture).
- *Enterprise Service Bus* (WSO2 API Gateway [11]) is an open-source, standardized, and componentized middleware platform that implements typical enterprise service bus functionalities by supporting microservices' logic development (SDK based on ASP.NET Core Framework) and APIs' life cycle management. It secures, protects, manages, and scales API calls by intercepting API requests and applying security policies. The WSO2 API

Gateway instance is deployed in a docker container, running in a virtual machine with Ubuntu 20.04 Server operating system (64-bit architecture).

As part of the overall ICT stack, a *cross-DLT layer* has been introduced to allow the interoperability with a set of most common Distributed Ledger Technologies (i.e. Bitcoin [12], Ethereum [13], IOTA [14]) as well as with commercial blockchain-based platforms (i.e. Tradelens [15]), so that data immutability can be guaranteed. Data privacy is also taken into account by implementing a pseudonymization function at DVL level in order to make sure that personal data are handled in respect to GDPR requirements [16]. Finally, the authentication and authorization aspects are properly addressed by the Authorization Server component of the ICT stack, based on industry-standard protocol OAuth2 [17]. According to this, we relied on OpenID Connect 1.0 Hybrid Flow [18] as the identity layer on top of the OAuth 2.0 protocol. This allows clients to verify the identity of the end-users based on the authentication performed by the Authorization Server, as well as to obtain basic profile information about such end-users in an interoperable and REST-like manner. The Authorization Server implements a single-sign-on (SSO) authentication scheme, and it is built upon the authorization token (JSON Web Token - JWT [19]) which is released to a specific user in order to invoke selected microservices. The JWT is emitted and validated by a token issuer authority, according to a given, as well as predefined, set of grants and access rules.

4. Validation of the proposed ICT stack

In this section, the design and development examples of three service prototypes that have been used to validate the considered ICT stack, are shortly presented and described.

The prototypes have been selected based on the needs and requirements from the Livorno Port Authority, according to the current Port Master Plan of the Livorno Port Authority [20]. This plan envisages the development of new digital innovative solution addressing (i) Rail–road and rail–sea integration (inter-modality) for people and goods, (ii) Navigation aid system for assistance to pilots and maritime authorities, as well as (iii) Integrated environmental monitoring and control of the port-logistics processes.

The first application consists in a *smart bathymetric service for seabed monitoring* in Livorno seaport. Dredging is essential for ports to remain in operation. It allows removing sediment and other materials from the sea beds. For this reason, seaports across the world dredge to enlarge and deepen access levels, ensuring safe navigation, competitive advantage by welcoming large vessels, remediation, and flood management. The seabed monitoring is based on a multibeam echo sounder probe installed on a monitoring boat from Coast Guard (see Figure 4).

Figure 4. Bathymetric probe with dock station and its installation on the monitoring boat.

The digital twin of the Livorno Port, namely Port Monitoring System (PMS), allows to visualize collected data in a form of the isarithmic map that depicts the submerged topography and physiographic features of the considered seabed as depicted in Figure 5.

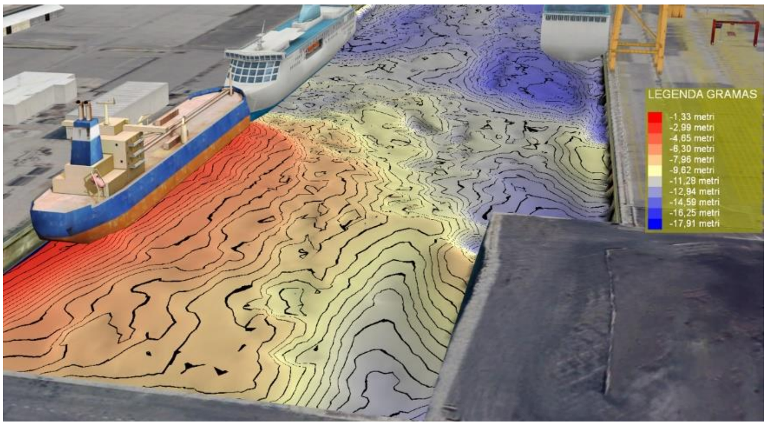

Figure 5. Bathymetric application user interface.

The second application, namely *yard vehicles management system*, allows a real-time monitoring of yard vehicles (e.g., forklifts, reach stackers, cranes, etc.) equipped with GPS trackers and supported by a low latency communication based on a private and prototyping 5G network deployed within the seaport. The application is based on general cargo management scenario at the Port of Livorno (a container terminal operator has been preliminary identified). From logistics perspective, it allows container terminal operators to monitor in real-time the status of the available forklifts within the container terminal storage area, by visualizing through a GUI (see Figure 6) the information related to each available forklift (ready or busy to perform cargo handling operations, forklift's unique identifier as well as its speed and GPS position) and the associated cargo (e.g., cargo unique identifier, width, height and length). The business logic of this application, allows to calculate the proper forklift choice according to a given algorithm in order to perform the forklift assignment (forklift-cargo association). Two parameters are taken into the account for this purpose: the distance between each forklift and the cargo to be handled, and the availability of each forklift. Finally, the third application performs trucks' and vessels' turn around time computation within the seaport of Livorno: Truck Turnaround Time (TTT) and Ship Stay Time (SST) respectively. The *Truck Turnaround Time application*, depicted in Figure 7, provides end users with information regarding the time spent by a given truck within the seaport area. Typically, when a truck arrives at the port entrance, the plate and container number (if present) is read and if the vehicle is authorized to enter the port facilities, the date and time of access are registered (gate-in event), and the barrier is lifted. After the loading/unloading operation, trucks leave the terminal and the port facilities: again, the plate and container number (if present) is read and if the vehicle is authorized to leave the port facilities, the date and time of exit are registered (gate-out event), and the barrier is lifted. The difference between the moment the truck enters the port facilities and the moment it exits the port facilities is called TTT. The knowledge of TTT can pave the way to different methods oriented to optimize the access to the port facilities and/or reduce the waiting time for vehicles at the port gate, leading to corresponding savings on direct costs for carriers.

The Ship Stay Time (SST) application, depicted in Figure 8 provides end users with information regarding the mooring time of a ship, meaning the time spent inside the port. The port information system registers the events of the ship entering and leaving the Port of Livorno, and the current infrastructure allows to seamlessly obtain and integrate data in the end-user application. Access to this kind of data allows to quickly identify inefficiencies in the current scenario, and act accordingly. Being able to spot crucial points in time when something goes wrong is a precious resource for domain experts that can take control of the situation and possibly take actions to mitigate the problem. Reducing the SST can positively affect the environmental impact of the seaport (a ship that docks for

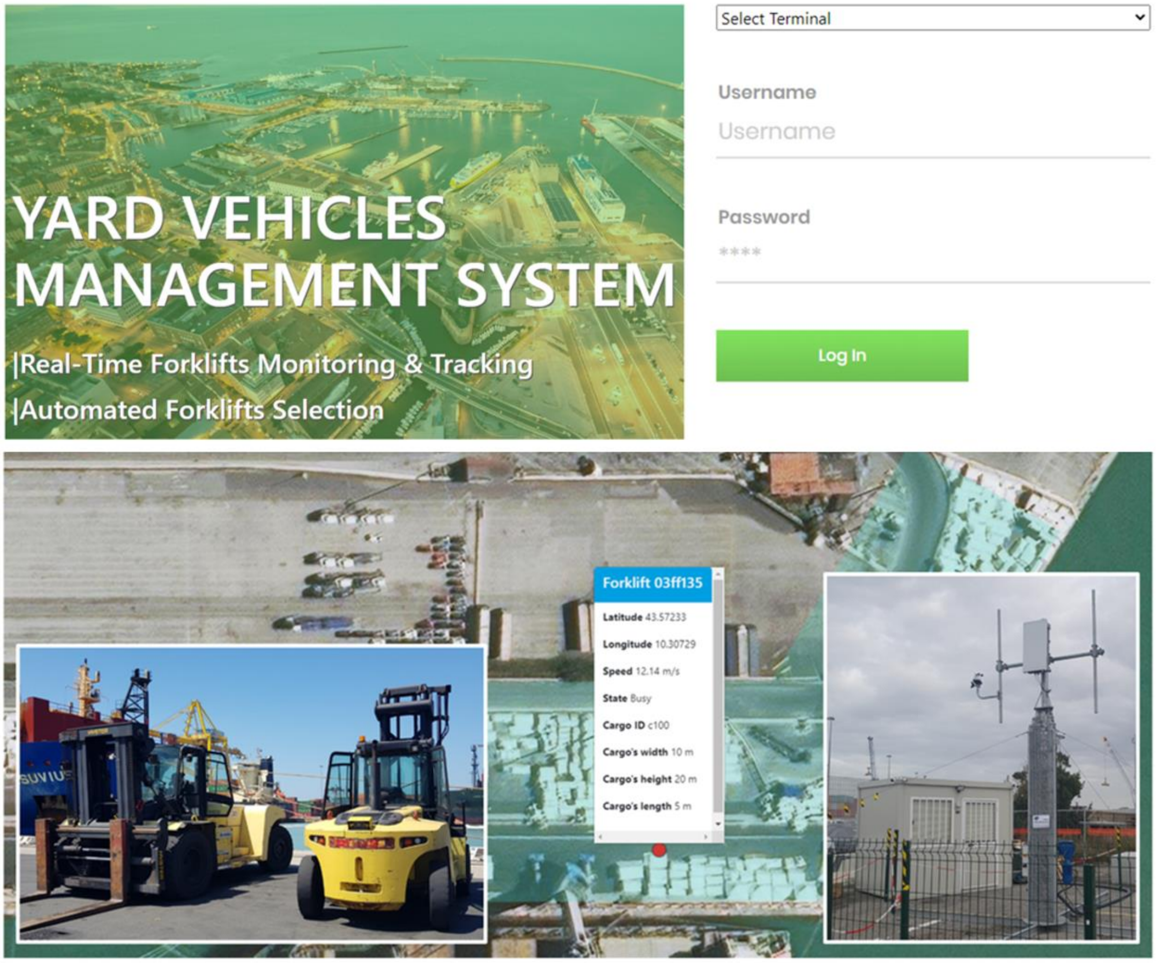

Figure 6. Yard vehicles management application and on-field equipment.

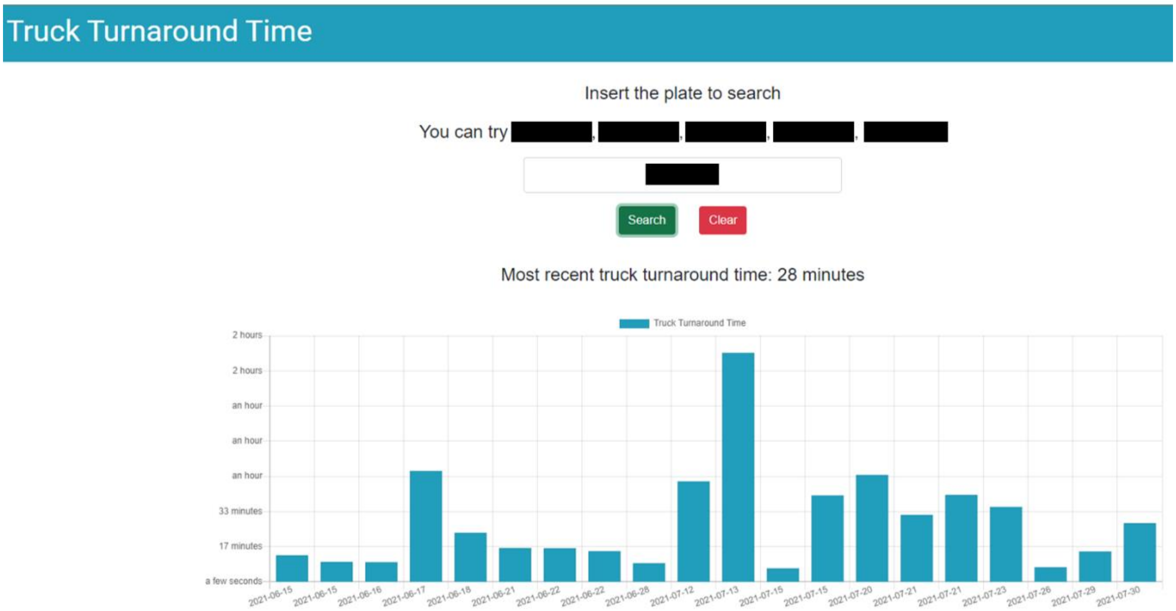

Figure 7. Trucks' turn around time computation – Graphic User Interface.

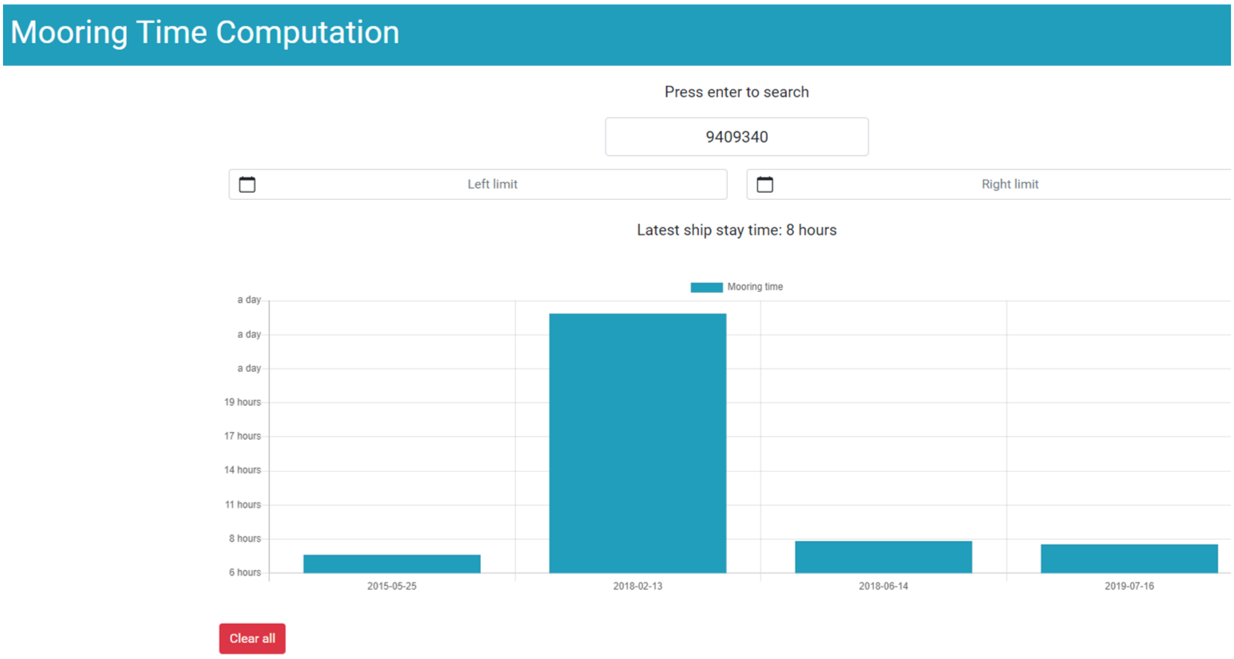

Figure 8. Vessels' turn around time computation – Graphic User Interface.

less time will likely pollute less) but also the costs (reducing the SST means being able to handle more ships). The business logic of the considered applications has been implemented in a form of a set of microservices by means of WSO2 API Gateway framework based on ASP.NET Core technology. For data access and retrieval the DVL component is used allowing the interaction with the relative data source. In case of the smart bathymetric service for seabed monitoring, raw data storage is supported by MongoDB (NoSQL and document-oriented database system [21]). As far as yard vehicles management system is concerned, we relied on Mobius [22] M2M platform (open source platform implementing ETSI OneM2M standard [23]) in order to store real-time data coming from GPS trackers. Finally, in the case of the TTT and SST computation applications, the database management systems of the existing platforms of the Livorno seaport are used as data sources (e.g., the RDBMS of the Port Community System). In all considered cases, the WSO2 API Gateway is used as the main framework for an agile microservices development while DVL is adopted as the unified interface for data lake management, data access and data retrieval. Furthermore, the communication between microservices is enabled by an open-source message broker (namely RabbitMQ [24]) that can be easily deployed in distributed and federated configurations to meet high-scale, high-availability requirements. Finally, the Authorization Server component manages the user authorization and authentication procedures, so that data access and APIs' invoking are properly handled.

5. Transferability and technological considerations

Transforming a traditional port into a smart port represents a true technological challenge in terms of increasing productivity, resource optimization and environmental and energy safeguarding.

In this respect, a significant investment in digital infrastructure is required. From an economic assessment point of view, ports of the future can achieve important impacts, or effects: firstly, in terms of microeconomic effects, since we have an increase in overall surplus (welfare) and, according to long-term growth, through the achievement of economies of scale and increased production specialization. According to the New Economic Geography Models [25], infrastructural upgrading can lead a company located in a specific area to have access to a wider market, as a result of lower transport costs. At the same time, other producers are encouraged to operate in that area, feeding an

increasingly attractive spatial concentration process and increasing the local market competitiveness [26]. In terms of macroeconomic effects, the Return on Investments in port infrastructure is expected to arise, as well as the long term GDP. This is a consequence of the high seaport infrastructures elasticity of GDP, which suggests that seaports infrastructures have an important indirect effect on economic growth. In order to validate the ports business models and to boost seaports quality of services (efficiency), any national economy must consider seaports as crucial business operating in a high competitive market, which require continuous development and specific infrastructures improvement and investments [27].
However, the seaport digital verticals can be classified into bundles, according to the C-Ports paradigm [28], which aim at offering modular and tailor-made solutions for the digitalization of port processes. C-Ports services will belong to three verticals and one horizontal, as depicted in Table 1:

- Vessel and Marine navigation (vertical);
- e-Freight & intermodal logistics (vertical);
- Passenger transport (vertical);
- Environmental sustainability (horizontal).

Table 1. R&D fields classification.

R&D field	Type	Regulator	Services
Vessel and Marine navigation	Vertical	ISO and IMO (mainly)	Vessel traffic management, vessel maneuvering in port waters, accident at sea, suspicious vessel/maneuver, berth allocation and docking.
E-freight and intermodal logistics	Vertical	UN/EDIFACT and not-standard proprietary solutions	Freight management and control, gates automation, in-port smart navigation, freight routing, accident at landside.
Passenger transport	Vertical	ISO, IEEE, MaaS Alliance	Infomobility and journey monitoring, integration with the traffic control centre (TCC), in-port smart and autonomous mobility (including safety).
Environmental sustainability	Horizontal	UN protocols	Pollution level (including COx and noise) reduction, road traffic level monitoring and control, dynamic pricing (all services) to vessels, terminals.

Services and product requirements are defined by the needs of the specific user-personas, representing port stakeholders. Thus, it is important to analyze the users' expectations and needs, to make them part of the process of development, by collecting feedback, deriving from their experience, with a continuous improvement approach. The level of involvement of the port communities can in fact be assessed through the definition of ad-hoc Key Performance Indicators (KPIs), as these indicators can provide important information about the validity of models and prototypes. Every smart port offers tailor-made services to its port community. This is achievable by using standard data interchange protocols and standard digital platforms, in order to let the systems interoperate with each other. The digital port services must follow a commercial exploitation plan, in order to extend the smart port concept to the other logistics hubs, which are part of the maritime network. In this sense, a feasibility study must be investigated, with the purpose to understand the services time-to-market depending on the specific business case. User requirements must be defined, in this sense a strategic partnership with the major ICT players is needed. Users adoption rate must be investigated, as well as the compliance to the standards and law requirements. Most specifically, according to the SWOT Analysis paradigm (Strengths, Weaknesses, Opportunities and Threats), the factors to keep in mind are both internal and external, as there are several aspects which can may have a positive or negative influence on the business strategy. While developing the new smart port features, the innovation lab has taken into account the most competitive and innovative business in the ICT and logistics sector, as well as telcos, insurance and shipping companies. As already mentioned, the transferability issue should be also assessed from a technological perspective. Technology is transforming maritime business models and value chains. Ships are becoming smarter and increasingly connected. Ports around the world are becoming more automated in the face of growing labour constraints. Maritime companies are leveraging developments in both hardware (e.g., advanced sensor systems, sea-to-shore connectivity, robotics, etc.) and software (e.g. data analytics, artificial intelligence, machine learning, etc.) to better optimize their operations. In this sense, seaports are at different starting positions and will adopt different degrees of digitalization. Some ports have taken pioneering steps to become first-movers in the adoption of advanced technologies for collaboration, synchronization, automation, and analytics. But, at many smaller ports, much of the information is not managed by digital means. Despite the user's needs and requirements are slightly different between the two considered seaports, a common and similar ICT infrastructure guarantees a certain level of freedom in development and testing of innovative services without additional costs. Moreover, the availability of digital platforms and monitoring applications (including legacy systems) in the Port of Singapore fulfils the minimum requirements as far as data availability is concerned. Moreover, an open and scalable ICT stack for data storage, access and retrieval as well as for smart services and applications business logic development is easily applicable in other maritime domains such as the one characterizing the Port of Singapore. The existing digital infrastructure, including the underlying communication technologies as well as the computational resources, enables the deployment of the proposed solution by providing an efficient and agile tool for the development of the innovative services driven by the Port of Singapore needs, requirements and challenges.

6. Conclusions

The potential offered by commercial ICT solutions is often limited by the lack of a standardized way to build new services on it.

We proposed and discussed a reference architecture, with the aim to provide a straightforward, easy-to-adopt solution to all the actors of the Port Community interested in the rapid development of service prototypes. In order to validate the proposed framework, we developed and presented some example applications to demonstrate how the considered approach can support an agile development as well as integration of new or already existing services at the Port of Livorno. Finally, we provided and discussed some considerations related to the ICT stack transferability with special focus to more challenging context such as the one of the Port of Singapore. Additionally, to motivate our approach, we expect to conduct a survey with some relevant members from the Port Community of Singapore, so that user needs and requirements can be used for the consolidation of the proposed solution.

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