Towards environmental impact reduction leveraging IoT infrastructures: the PIXEL approach

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Abstract. Ports are essential nodes in the global supply chain. Usually, the port-cities experience growth and sustainability thanks to the port activities and their related stakeholders. However, it is undeniable that port operations have an impact on the environment, the city and citizens living nearby. To mitigate this impact, the ports of the future will need to count with advanced tools enabling measurement and actuation over the harmful pollution sources. Modelling the footprint and gathering information about the causes are not easy tasks, as ports are complex environments with no standard procedures established yet for these purposes. These challenges are added to another current truth: data about real-time port operations are not optimally gathered neither exploited due to, mainly, a marked lack of interoperability.

PIXEL (Port IoT for environmental leverage) aims at creating the first smart, flexible and scalable solution reducing the environmental impact while enabling optimization of operations in port ecosystems. This approach relies on the most innovative ICT technology for ports building upon an interoperable open IoT platform. PIXEL use-cases are also presented in this paper, aiming to demonstrate, through various analytic services, a valid architecture drawing from heterogeneous data collection, data handling under a common model, data storage and data visualization.

Besides that, PIXEL devotes to decouple port's size and its ability to deploy environmental impact mitigation specifying an innovative methodology and an integrated metric for the assessment of the overall environmental impact of ports.

Keywords: IoT, small and medium ports, environmental impact, PIXEL.

1 Introduction

Ports are a great example of heterogeneous information hubs. With more than 10 billion tonnes of global goods transported by sea [1], ports are logistics nodes that are essential for the development of each country. Multiple stakeholders operate inside and outside them with different motivations and businesses. Because maritime ports concentrate, in direct link to their transport activities, logistics and industrial activities and interact with urban territories, they need to engage ambitious policies and strategies to become "ports of the future" by lowering the environmental impacts of their activity and by targeting environmental excellency.

During the last few years, several actions help confirming the trend of environmental awareness reclaimed to ports by the administration and the whole society. Besides, there is a consolidated vision arguing that the environmental problem in ports will not be properly addressed and solved until a real market altogether with technological pervasiveness will not be activated. This only will be achieved by measuring. What is not identified, quantified and collected cannot be managed. This vision matches definitions of "Port of the Future" [2] and is aligned with the vision of EcoPorts, which points small ports as a priority for green ports development and sustainable growth [3].

Furthermore, the environmental impact is directly related to the operational activity of the ports [4], such as loading and unloading, berthing, docking, yard management or gate appointments, among others. In this regard, the available operational data in ports, terminals and cities is constantly increasing and technology needed to make more accurate measurements on these assets is getting inexpensive and widely available. This is why the answer to the current status must rely on application of new technologies: data acquisition via modern devices, digitalisation, optimization methods, prediction, data exploitation, monitoring and visualization. Different initiatives have tried to address this challenge, but none of them has undertaken it from an environmental impact mitigation point of view neither integrating all the available and relevant information data sources in a single component (see Section 2 of this paper).

Since the 1990s, ports have been equipped with computer tools, programs, sensors and various other technologies to optimize their logistical, industrial, environmental and societal performance ratios. The latter therefore are potentially plenty of information that is, up to now, not exploited to their highest degree. Information interchange is already in place in several port environments through Port Community Systems (PCS) or National Single-Window systems (NSW). However, it is to a large extent limited to official documentation and services of the port authorities [5], meaning a lack of pertinent communication and effective integration of operational data in essential spots such as: port-city engagements, multi-modal transport operations (trains, trucks, etc.), port quality service levels and even port-citizen interaction; redounding in a deteriorate customer, stakeholder and citizen satisfaction. In addition to all this, the digitalization does not reach equally every maritime logistic node (at European and global level). This fact is especially visible on the medium or small ones, where budget is limited and IT services usually depend on external contractors. There has been also proven the lack of guidelines and tools at national level focused on them, turning the compliance with regulations into a stern task to be carried out.

The H2020-funded project PIXEL [6] (Port IoT for Environmental Leverage), denoted as "the project", will address all of those concerns from an optimisation point of view based on new conceptual and technology development relying on information sharing and IoT (Internet of Things). Particularly, PIXEL tackles top environmental and operational concerns potentially improvable by technology. It provides a cloud-based IoT-enabled infrastructure capable to integrate operational data from sensors and devices, legacy port IT systems (PCS or PMS) and open data. With PIXEL, port-city integration and operational information issues will be supported by a common operational ICT (Information and Communications Technology) hub for clustering, harmonising and distributing information to shared management and operation of ports, cities and the hinterland transport network. Finally, the project aims at validating its technological development in for real use-cases. Four European ports (Port of Bordeaux, Port of Monfalcone, Port of Thessaloniki and Port of Piraeus) are participating in the cooperative project as partners of the consortium, therefore the assessment of the solution will be feasible in the short term at a prototype level.

The core of this paper is to describe the original approach of this project. PIXEL components, use cases and methodology are succinctly realised, while the future work and the goals of PIXEL implementation are depicted as well.

2 Related work

Several projects funded in previous years by the European Commission and other international organizations worldwide have focused on the very topics addressed by this paper: IoT for ports, digitalization and optimization of port operations, environmental impact measuring and mitigation and interoperability in this application domain.

A brief reference of those initiatives is depicted in Table 1 pointing the similarities and differences with the scope of PIXEL.

Table 1. Related works prior to PIXEL project.

Other R&D&I activities	Link to PIXEL
INTER-IoT : H2020 project devoted to achieve interoperability among (at all layers) among IoT platforms.	*Similarities*: Interoperability framework for IoT Platforms. *Differences:* PIXEL goes further about ports-specific problems while focusing in environment. Therefore it provides data representation for the IoT domain.
GreenMarine: Canadian initiative to measure (qualitatively) the environmental impact of US-Canadian ports.	*Similarities*: Measuring impact of port divided per type and other considerations. *Differences:* Qualitative approach (via surveys) versus (PIXEL) quantitative measurement (through sensors).
PORTOPIA: European initiative for monitoring environmental concerns and indicators in ports	*Similarities:* Environmental indicators identification, sustainability and impact reduction aims. European funding. *Differences:* Multi-project, not only based on technology.
iCargo aimed at extending the use of ICT towards synchronization of logistics operations to lower CO_2 emissions	*Similarities*: ICT in port field aimed at exploitation with environmental focus. *Differences:* not IoT-based, focused on infrastructure. PIXEL relies on modelling, Big Data, and predictions.
e-Freight aimed at an optimal and sustainable utilisation of freight transport resources	*Similarities*: optimization, multimodality in transport and sustainability leveraging digital technologies *Differences*: not IoT-based nor environment-focused

3 PIXEL proposition

The project has worked in four convergent aspects since its very beginning, with the aim of improving port operations and meeting the requirements of the port of the future: *(i)* enabling technologies; *(ii)* use cases for environmental leverage and process optimization; *(iii)* modelling of environmental aspects of port and city operations; and *(iv)* extendibility, benchmarking and application to other ports or transportation hubs.

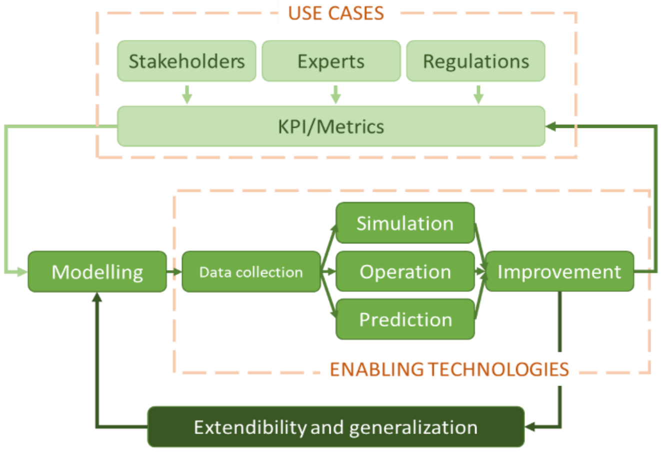

Fig. 1. PIXEL conceptual building blocks

PIXEL uses an ICT-based framework as a basis for the operational data sharing between port agents and advance analytics. Built over state of the art components, it includes new research on this area to satisfy the needs of the project. *(i)* interoperability of document-based management systems with data-centric IoT platforms, *(ii)* pattern recognition from heterogeneous data, *(iii)* prediction algorithms for heterogeneous multi-source data, *(iv)* methodology and software artefacts to allow IoT connectivity to isolated data and *(v)* annotation of environmental and logistic data.

The solution will be validated by applying the developments to improve the energy efficiency of the ports, promote the use of clean energies, improve logistics processes, increase the environmental awareness of all the stakeholders involved and, in general, contribute to reduce the carbon footprint and the environmental impact of the ports and port-related activities. The modelling building block brings simulation capabilities, as well as prediction algorithms implementations. Addressing the environmental part, models enable setting up accurate metrics and what-if cases to represent the different scenarios of the ports, as well as the impact of their operations.

As per theoretical design, the solution explained in this paper is designed to cover every small and medium port scenario. To support this, all the results are designed with the perspective of extendibility, which implies attention to the scalability of resources, architecture allowing third parties participation, excellent communication instructions and use of cutting-edge privacy, authorization and security policies.

4 Technological baseline

4.1 Reference architecture

PIXEL achieves the novelties and impacts forecasted by implementing an ICT system capable of gathering every useful data in ports to materialise an automated optimized use of internal and external resources, sustainable economic growth and environmental impact mitigation.

PIXEL challenges such as the establishment of an IoT platform valid for very heterogeneous conditions (different port sizes, different operations, different areas and KPIs (Key Performance Indicator) monitored), makes very appropriate the definition of a reference architecture to keep a common technological and functional blueprint event when the deployments vary and the requirements are in some cases uneven. Furthermore, considering scalability, flexibility and replicability aims, defining a reference architecture for IoT in ports could be fostered if PIXEL is widely adopted after the project. This, in case of achievement, will lay the foundation for a common framework to develop future systems and communications between market players in ports. Finally, the use of a reference architecture provides stability and reliability of the designed solution across multiple scenarios (as is the case in this paper) and throughout the time.

As the genuine disposition for PIXEL architecture is modular, the selection of a reference architecture endears high complexity. With, at least, five different modules to be approached separately (to be later integrated), the number of combinations are more than 1.5 million [7].

There have been a number of proposed architectures, many of them defined in specific contexts and providing solutions to a part of the "world of things". For the construction of PIXEL reference architecture, the study was focused on two of the most relevant current approaches: IIRA [8] and RAMI4.0 [9].

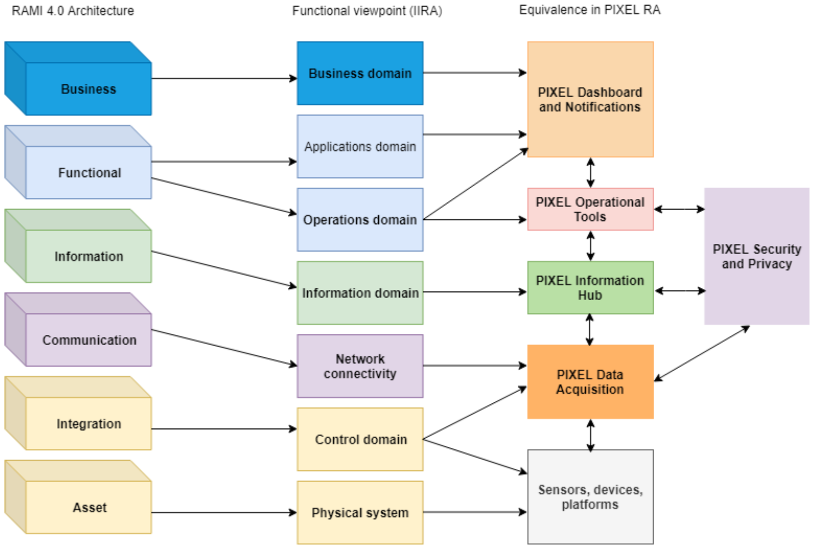

Fig. 2. PIXEL architecture and its equivalents to RAMI and IIRA references.

IIRA (Industrial Internet Reference Architecture) is an architecture based on standards designed for IIOT (Industrial-IoT) systems. However, flexibility, scalability and interoperability are not strengths in this approach so after a thorough review it was not selected for the project.

RAMI 4.0 (Referenzarchitekturnmodell Industrie 4.0) architecture reference seemed the most appropriate for the project as it defines a service-oriented architecture with high flexibility, in which each of the modules provides services to the other components via a communication protocol across a network. The idea is to divide the architecture into simpler packages easy to realise and focus on their interaction under a SOA (Service Oriented Architecture) schema.

In Fig. 2 there is a relation with the references architectures studied and the modular schema designed for PIXEL. The different modules are explained in Section 4.2.

The following reasons helped determine the choice of RAMI as the reference architecture for PIXEL as well:

- Industrial focus. The applications based on PIXEL are developed in an industrial-like environment (ports). Thus, specific requirements considered in industrial scenarios match better than generic architectures.
- Focus on interoperability: a challenge which is described as a major objective of the project and that will enable the integration of heterogeneous data sources.
- Follows a European initiative that has been implemented in other projects from other domains. This way, the reference architecture of PIXEL will accomplish one of their missions, to make the results more standardized and to be less technology dependent.

4.2 Modules implementation

After selecting a reference architecture, the project has needed a particular instantiation and design of the different modules. The technical and architectural approach is depicted in Fig. 3.:

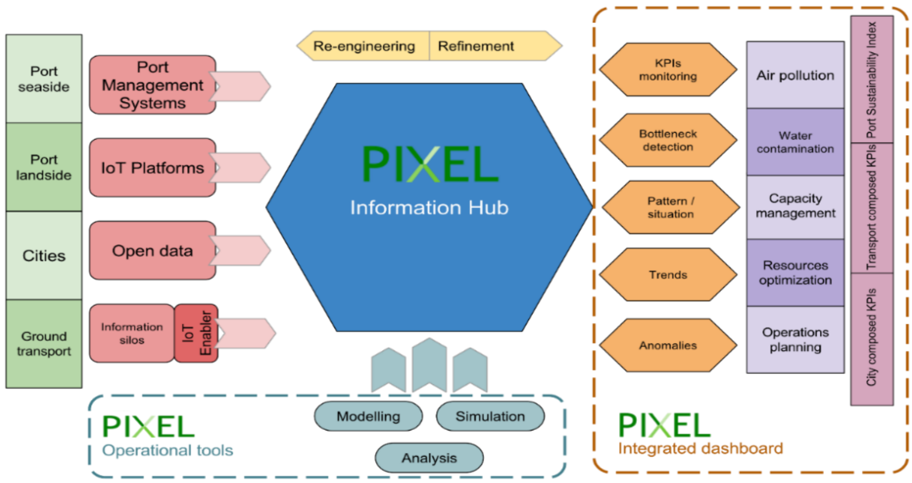

Fig. 3. PIXEL architecture and its modules.

To successfully encompass this system PIXEL leverages some existing technologies in the state of the art and aims at applying them at an innovative field with clear uncertainties. In this section the different modules are analysed: their goal, implementation hints and role within the whole PIXEL solution.

PIXEL data acquisition. This module aims at gathering every relevant data of port activities and forwarding it to upper levels of the architecture. The module has been designed and is being developed to collect data from heterogeneous sources: PCS, PMS, SCADA systems, isolated sensors, documentation generators and other different sources. Particularly, for each data source to be included in PIXEL, there is a methodology established that includes the development of an NGSI [10] agent in charge of gathering the data from the source in raw format and upstream it in a formalized data model agreed throughout all the platform. Then, the data is handled by a context broker under a publish-subscribe model. This inner component forms the foundation of data management in PIXEL.

Table 2. Data acquisition module implementation detail

Functions	Technologies and concepts used
• To provide a standard way to acquire different data types and protocols • To persist context data • To store short-term historical data	– FIWARE ORION (Context Broker) – Custom data-models inspired on FIWARE data-models – OAuth2 security

PIXEL Information Hub. It is the core element of the architecture, as it constitutes the sink where the different information siloes discharge and store their real-time data. A key innovation potential of this component is underpinned by the fast development of the Internet of Things (IoT) in logistics, environmental and wellbeing sectors. The basic concept behind the Information Hub is its capacity for long-term storage and its role of centralizing element: serving the data to whichever other module needing it.

Table 3. Information Hub module implementation detail

Functions	Technologies used
• To push data toward database of long-term storage (downstream) • To prepare the data and serve it through an API for retrieval and further processing (upstream) • To configure and monitor services for scalability and flexibility of the whole platform	– REST API Gateway – Zookeper – ElasticSearch

PIXEL Operational Tools. In PIXEL, several models are elaborated shaping ports' typical processes and applying simulations within the technological infrastructure to be released. To materialise this appliance some Operational Tools are created and executed extracting data from the Information Hub Thus, the role of this module is to bring closer to the user the predictive algorithms and simulation models laying behind the transport-related innovation developed in the project.

Table 4. Operational Tools module implementation detail

Functions	Technologies used
• To provide the tools for the UIs associated to each model or predictive algorithm • To execute the models or predictive algorithms • To bring the intelligence to the system • To set the analytics capabilities to the user	– Complex Event Processor (CEP) for managing rules, alarms, thresholds – Containerization (Docker) – Custom developments based on microservices and REST APIs

PIXEL Integrated Dashboard. The top modular component of the PIXEL platform contains user-oriented tools. The result of the previous acquisition, modelling, processing and preparation redounds in comprehensible displays for humans to help their decision making. These are composed by monitoring features, KPIs tracking, time evolution of parameters, historic data, reports, forecasting and the rest of capabilities provided by previous layers of the architecture.

Table 5. Integrated Dashboard module implementation detail

Functions	Technologies used
• To apply predictive algorithms and models and provide the information to the final user • To calculate a Port Environmental Index • To provide push notifications coming from CEP • Selectable options of visualization for the different agents in the port	– Widget-like interface options – Grafana – Kibana – ElasticSearch – Vue.js

PIXEL Security. Transversally to the other modules, there is a crucial action implemented in the project for ensuring security and sovereignty of the data throughout all the layers. Despite introduced in all components (OAuth), security in PIXEL has its own relevance leveraging top state-of-the art solutions.

Table 6. Security module implementation detail

Functions	Technologies used
• Resource access negotiation • Access policies repository • Access policies management	– OAuth 2 – FIWARE KeyRock – FIWARE Vilma

5 Validation scenarios

The work exposed in this paper is intended to be validated in relevant scenarios with real data. To assess the success of the architecture and its modules and to validate the final product it has to be tested and properly refined. Thus, as it has been mentioned before, the action of the project includes the deployment of several use-cases in four European ports.

The ports selected for this validation fit the required criteria: *(i)* preferred size of ports small-medium (4-15 Mt/year of cargo), *(ii)* ports confronting varying issues related either with data interchange between several agents, city-port questions, environmental impact or any other improvable port operation and *(iii)* providing at least one testbed with greater volume of devices, passengers and operations.

The reader shall realise the need, benefit and assessment traits of every use-case out of the following validation tables created for each scenario that will be undertaken. Besides, respective figures are provided to illustrate the data flow and purpose of the deployments.

5.1 Energy demand prediction: Grand Port Maritime de Bordeaux

The Grand Port Maritime de Bordeaux (GPMB) is located on the Atlantic coast, in the city of Bordeaux (France) where the urban-port integration is crucial. It is a focal point of a dense network of communication by river and sea, by air, by rail and by road being a core port of the TEN-T Atlantic Corridor.

Table 7. Validation table for Grand Port Maritime de Bordeaux's deployment of PIXEL

Operational and environmental objectives	PIXEL assessment traits targeted
• To adequately dimension the renewable energy networks (especially storage) • To optimize the resources based on the management centered in the self-production • To propose new green policies of energy consumption inside the port • To develop services with over-produced energy • To reduce the carbon footprint impact over the city • To propose innovative strategies for the development of ports through to Big Data analysis	– Development of standard interfaces between PIXEL and PCSs – Interoperability of already existing and new sensors – Implementation of open data exchange mechanisms – Design and execution of predictive algorithms for port traffic evolution – Design and execution of predictive algorithms to estimate the real-time quantity of energy consumed and produced by the port

The Use Case of Grand Port Maritime de Bordeaux shall demonstrate that Port Community Systems are not only regulatory tools: they are communication tools enabling people working in a port to share information and data in order to improve port operations efficiency in a collaborative way

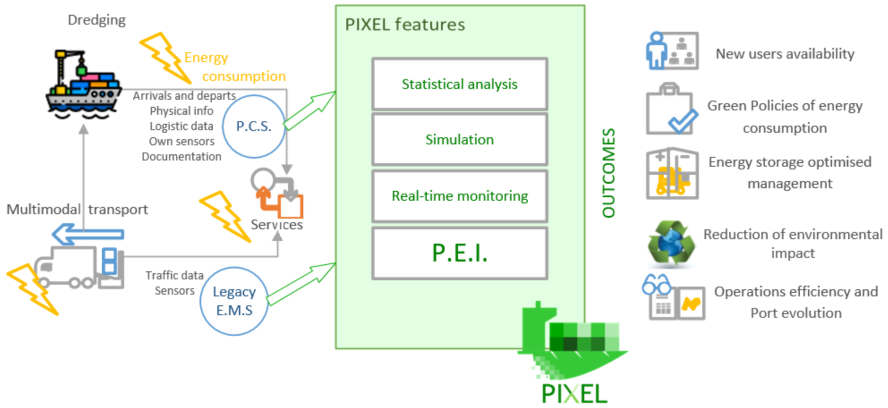

Fig. 4. Grand Port Maritime de Bordeaux deployment illustration

5.2 Hinterland intermodal exchange: Port of Monfalcone

The port of Monfalcone, the authorities of the Friuli Venezia Giulia region, the truck terminal of Gorizia in association with the regional Environment and Health Observatory will use the PIXEL framework to integrate data available in the existing system SILI (Integrated Logistic Information System) in order to share data and cooperate with other stakeholders for operational and planning activities.

Table 8. Validation table for Port of Monfalcone's deployment of PIXEL

Operational and environmental objectives	PIXEL assessment traits targeted
• Better road planning to reduce urban and extra urban traffic • Providing a better distribution of the waste costs • Monitoring and re-routing of dangerous goods • Reduction of CO_2 emissions and acoustic pollution in port surrounding areas • Disposition of tools to improve the correlation between air pollution and specific diseases • Creating synergies with the other players of the surrounding areas	– Multi-agent inter-modality integration – Integration with SILI system – Algorithms calculating impact and predictive algorithms – Data gathering coming from video-surveillance cameras – Dangerous goods and other environmental hazardous aspects dealt with

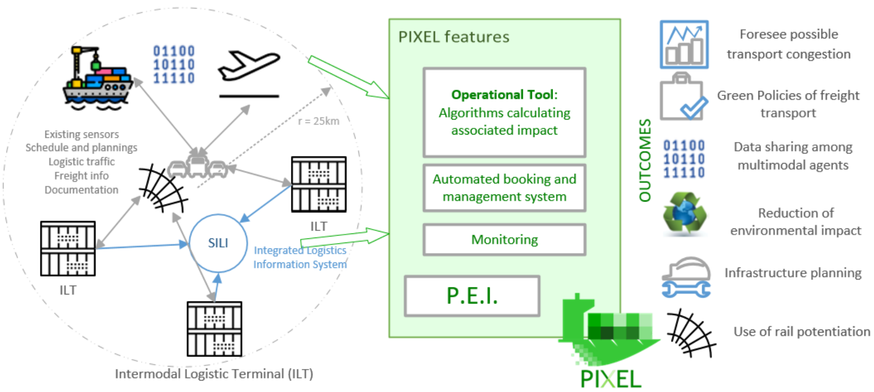

Fig. 5. Port of Monfalcone deployment illustration

5.3 Port-city integration: the ports of Piraeus and Thessaloniki

The port city integration validation scenario will be tested in two Greek ports (Thessaloniki and Piraeus), the rationale behind using two ports for the pilots is that in the first the deployment is focused on goods/containers and in the second in passengers. Additionally, Piraeus pilot will be used to evaluate and measure scalability. Both ports are key in the traffic in the area and in the corresponding TEN-T corridors.

Table 9. Validation table for Port of Thessaloniki's and Piraeus' deployment of PIXEL

Operational and environmental objectives	PIXEL assessment traits targeted
• Improvement of the access to the seaport • Mitigation of traffic-related impacts on the environment • Facilitate transport intramodality in passenger traffic • Incorporate innovative approaches to overcome bottlenecks in the transportation net-work creation of a positive awareness of sustainable transportation methods	– Integration of PCS, PMS, TOS and new installed sensors both environmental and traffic-related – Design and execution of models for air and noise pollution calculation and prediction – Design and execution of predictive algorithms about traffic congestion

To incorporate technological components and harmonise the Greek Ports use-case with the global PIXEL system an effort will be made to homogeneise and integrate data from several software sources.

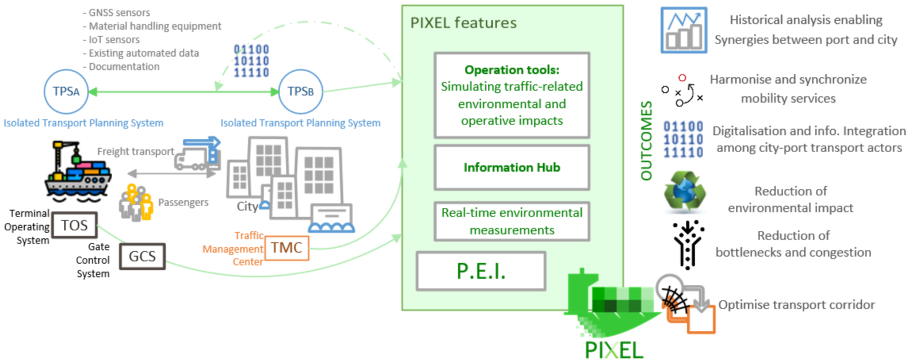

Fig. 6. Port of Piraeus and Port of Thessaloniki deployment illustration

6 Conclusions and Future Work

In order to mitigate the environmental impact of the ports activities it is necessary to measure. To measure, ports (especially those of small and medium size) need actionable tools, methodologies and technology specifically designed with this aim.

PIXEL has realised an architecture to collect, aggregate, store, process and monitor operational and environmental data to provide additional value to port agents.

The project has scheduled the deployment of that architecture in four European ports for the next months. Therefore, the near future work will be focused on evolving the developments from a laboratory prototype into a relevant environment demonstrated product. These actions will allow evaluating the performance and appropriateness of the solution.

Furthermore, the ICT solution will be explored to be deployed in new small, medium and big European ports. A robust assessment of its technical and business-related performance is also planned to be conducted in the middle term. The rationale behind the forthcoming actions is to bring innovation and useful ICT equipment to ports aiming at digitalization and environmental impact reduction. With aims of European market validation, a sound strategy will be followed, as well, targeting real impact of PIXEL to the port community. Different entities and experts will be addressed for achieving this validation.

Regarding new research lines drawing from PIXEL, they are diverse. The Consortium of the project is conducting a specific task devoted to envisioning how PIXEL developments can be continued and which other technologies and methodologies can be integrated in the future in the solution. For the moment, technologies such as: 5G, advanced cloud processing, edge computing and blockchain for security are thought to be feasibly embeddable. About logistics theory and optimisation purposes, PIXEL might be extended to investigate on mobility management, soil environmental models, synchro-modality and deeper traffic prediction, among others.

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