Sustainable port development: towards the Physical Internet concept

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Abstract: *European ports are currently facing the challenge of adapting to the current trends in global trade and efficiently handling the increasing volumes placed on them. The aim of this paper is to present an innovative framework supported by disruptive technologies for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. The innovations to be implemented within the proposed framework will contribute to the Port of the Future objectives regarding reduction of port's total environmental footprint associated with intermodal connections; the improvement of operational efficiency, and increase of data sharing and information visibility; and the promotion on the innovation in the port-urban context. Among the solutions presented, the model-driven tool for Real-time Control of port operations, the advanced Truck Appointment System and the Cargo Flow Optimization tool, aim to pave the way into interconnected port systems with information at various steps of the transportation flow. Overall, the proposed framework aims to develop models and tools which can support ports to improve their efficiency and gradually participate in a Physical Internet network.*

Keywords: *port of the future, container terminal management, sustainability, internet of things, data analytics, 5G networks*

1 Introduction

With the ongoing growth in economic activity and the trend towards increasing globalisation, transport infrastructure has to accommodate ever larger numbers of cargo flows. Extended transport capacity from building new transport infrastructure is often increasingly rapidly fully absorbed, due to ever increasing demand for freight transport. In order to sustain an efficient functioning of the economic system and preserve quality of life, new solutions for the future ports need to be found.

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In Europe, ports face the challenge of adapting to the trends in global trade and efficiently handling the increasing volumes placed on them. This challenge is further magnified by the restrictions in available land use, the environmental impact in the vicinity of the port area as well as the complexities of the hinterland connection between the port and the urban environment. These concerns increase the need for technological development and advanced logistics concepts to propose sustainable, yet economically competitive solutions for European ports (Prokopowicz and Berg-Andreassen, 2016).

The Physical Internet (PI) term has been recently used and targets sustainable logistics and supply chain management. The basic concept is an open global logistics system based on the physical, digital and operational interconnectivity enabled by smart modular containers, interfaces and protocols for increased efficiency and sustainability (Montreuil, 2011). In other words, PI intends to provide universal interconnection of logistics services, and substantially increase efficiency.

This paper presents an innovative conceptual framework supported by disruptive technologies, including internet including Internet of Things, data analytics, next generation traffic management and emerging 5G networks for cargo ports to handle upcoming and future capacity, efficiency and environmental challenges. The innovations will be implemented and tested in real operating conditions in five Living Labs (LLs), associated with five European ports: Port of Livorno, Port of Piraeus, Port of Valencia, Port of Haminakotka, and Port of Antwerp.

In this work, we present selected innovations of the proposed framework to be adopted by the ports that will serve as enablers for driving ports of the future to be ready to a PI environment, though optimisation, integration, and massive connectivity. The innovations examined in this work can be viewed as complementary to understanding the benefits of the PI. In addition, the proposed technologies exhibit innovation potential. At first, the use of predictive analytics for implementing dynamic asset management is a major step towards resource and land-use efficiency. Current asset management tools, e.g. SAP, only perform static preventive maintenance. Another novel application of predictive analytics based on rail/barge/vessel ETAs are cargo flow prognoses in order to support port operators and urban planners foresee required infrastructure changes and upgrades in the medium-/long-term so as to accommodate increased flows. Finally, truck appointment systems minimise trucks' waiting time by offering different time windows to enter the port. The Truck Appointment System presented in this work will provide a more collaborative and dynamic approach making use of an IoT environment that will link different platforms and IT sources of the logistics supply chain actors' with real time information from the urban Traffic Management Center. The system will be supported by a machine-learning module based on real-time information and traffic flows forecasting (both entering and leaving the port).

The paper is structured as follows: Section 2 provides an extensive literature review, and introduces port-driven technological innovations. Section 3 presents an approach for establishing a framework for sustainable development of the port of the future. Section 4 provides an overview of the framework implementation through the Living Labs and highlights the expected impact from the implemented technologies. Finally conclusions are drawn in Section 5.

2 Physical Internet and sustainable port development

2.1 Literature review

Very recently, the concept of the Port of the Future has been introduced, as the one that has 'no negative impact on the ecosystem and recognises environmental systems as a mix of elements that interact with each other' in the maritime environment (Schipper et al., 2017). However, as this 'no-impact port' term refers to an ideal situation in practice, the Port of the Future can be better described as the port which has achieved and is maintaining a balance in economic, environmental and social extent for the surrounding local region[1,2]. Moving to such a definition and considering that ports are strong catalysts for regional development, their optimisation, integration and seamless connectivity with the surrounding socio-economic area are key requirements.

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To this end, and according to Deloitte Port services (2017), the Port of the Future has three considerable characteristics, which can provide the port of the future with the level of adaptability required to the increasingly changed (physical, economic and social) environment, namely the cooperation in both horizontal and vertical level, the innovation and digitalization and the sustainability. Having embraced the above, the vision of the Port of the Future ecosystem is twofold: on the one hand it is substantially increasing and extending the range of innovation possibilities and it is providing opportunities across the entire value chain (from seaside to port and landside) and on the other hand the desirable seamless infrastructure, port ecosystem connectivity and data handling can be more proactively come true toward a more sustainable and interoperable future.

Whilst ports are ripping for disruption in optimization processes, seamless connectivity and data handling and although disruptive technologies (such as IoT, 5G networks etc.) are considered as major driving forces, some of the already matured technologies and processes are not fully-fledged drive towards the Port of the Future vision, according to Trelleborg Marine systems (2017). For achieving a step closer to this vision, the PI is a newly introduced concept in port logistics, with the aim to provide the principles for making disruptive and emerging models more dynamic, towards improving the transportation of goods both environmentally, economically and socially speaking. The paradigm of the PI intends to substantially increase the flow of physical goods through open networks, protocols and the encapsulation of goods (Montreuil et al., 2012).

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Under the PI vision, a large scale optimization process along with the development, customization, and deployment of proper emerging technologies can radically replace the deficit of efficiency in networks interoperability and operations with tangible positive effects on prices, time, urban congestion, pollution etc. (Crainic and Montreuil, 2016). To this end, PI can be considered a mean to improve the sustainability of logistics by fostering the seamless movements of goods in and out of ports and across the cities towards the Port of the Future vision[3].

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2.2 Port-driven technological innovations

A challenging task for port operators, is to make decisions regarding freight movement and other related matters such as asset management, without having information on how their choices may affect the entire transport system. There have been numerous efforts in the past to enhance information sharing and collaboration on vertical as well as on horizontal level, in order to increase operations efficiency. Today, collaboration enabled by new technological solutions, new logistics paradigm as provided by the PI as well as new business models, are creating a new business reality paving the way for well-coordinated and networked port logistics operations (Montreuil B., 2011).

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[1] Port of the future: Explanatory Study, Deltares & WWF (2015) https://www.deltares.nl/app/uploads/2015/12/Port-of-the-Future-report.pdf

[2] PIANC - IAPH EnviCom WG150, Sustainable Ports, A Guide for Port Authorities (2014)

[3] https://www.port-montreal.com/en/physical-internet-aut2015.html

The proposed framework comprises a set of port-driven technological innovations, which are expected to lead to an increased understanding of port and terminal requirements in order to be able to move towards a physically connected world. These innovations include:

i. The Truck Appointment System: This system aims to enhance the hinterland connectivity of the port with the surrounding urban space as well as optimise the use of trucks within the container terminal area. The aims are achieved by using developed solutions to increase data sharing and visibility between supply chain actors, which is one prerequisite in PI.
ii. The PORTMOD Module: This is a modelling tool focusing on operational efficiency. It will help port operations to plan container yard layouts such as optimal length of container rows and stacking heights. The tool uses historical data of container movements, and when the port operates with intelligent PI containers, the simulation model will benefit from accurate data.
iii. The RTPORT Module: It is a model-driven tool for real time control of port operations, and it uses emerging technologies in mobile communications (4G/5G) and Internet of Things. The module relies on availability of supply chain data of intelligent PI-containers and fast data processing, which enables improvements in container ground handling and helps to avoid inefficiencies.
iv. The Cargo Flow Optimiser Module: This module aims to minimise containers' waiting times at the port and improve current land infrastructure use by multiplexing vessels' estimated time arrival with data from the rail operators. This data sharing of different actors is a step towards open supply chain data in port, where PI relies.
v. The Predictor – Asset Management Module: This module will realise a powerful predictive analytics task by analysing the monitored data of port handling equipment. It will enable cost-efficient maintenance models for the handling equipment and prevent disturbances of operations.

3 Methodology

The proposed methodology will be implemented in three distinctive yet complementary phases. A stakeholder driven approach will be initially followed, considering the ports' and port-cities' main challenges.

3.1 Scenarios and requirements phase

The first phase of the approach will produce a classification of the port of the future stakeholders through a two-staged iterative participatory method: in the first stage, the 'Tier 1' stakeholders will be identified and classified, comprising the core port personnel, city authorities and logistics organisations immediately collaborating with the port. Next, the 'Tier 2' stakeholder list will be identified, namely an extended and comprehensive list of people and organisations involved and influencing the smart port-city ecosystem. By mapping and prioritising the stakeholder list, a set of personas will be identified, representing persons/roles that have a direct impact to or from the port-city operations within the surrounding urban space. Around those representative personas, the scenarios describing the implementation of the proposed modules in the LLs will be created via a two-stage process of scenario co-creation and description a) a hands-on, scenario co-design iteration implemented during local focus groups, organised in each LL, and b) a second iteration, that aims to enhance, refine and consolidate/document the co-designed scenarios produced during the first iteration. Phase I will conclude with deriving port requirements (technical, operational, societal, environmental, legal, security and other relevant) that will stem from the defined scenarios.

3.2 Technical design and development phase

This phase will cover the technical design and development and will implement the technical and societal innovations piloted and assessed in the LLs. Phase II will start with producing detailed technical specifications. The mapping will be reflected in a requirements-specifications traceability matrix that will clearly demonstrate the priority level for each specification and the components involved. The design and development of the components/innovations will be done in two iterations: i) The first iteration involves the implementation of proof-of-concept alpha versions of the technical components in a protected environment (the definition of alpha version per component will be included in the scoping documents). In parallel, this phase will produce a set of KPIs/metrics to be measured and assessed within each LL. ii). During this iteration, any tools, devices or components that are necessary for the final testing of the innovations in each LL will be deployed and full integration with existing IT infrastructure in each port will be implemented in real-life operating conditions.

3.3 Full-scale implementation phase

During this phase, real-life implementations will take place in each local LL setting described in section 3.1. Initially, a full set of solutions will be ready to be deployed, allowing complete testing, demonstration and results evaluation in the target operational environment.

The proposed methodology, follows a stakeholder driven approach, considering the ports' and port-cities' main challenges, in view of the major changes brought by ocean carriers and the shift to Industry 4.0 era. Within this approach, the innovations will be co-created with the ports after prioritising the port requirements and needs. The three complementary phases are expected to create better systems, taking into account the specific challenges faced in each local setting, related objectives of each port and the port's anticipated benefits.

4 Implementation approach

4.1 Living Labs

4.1.1 Port of Livorno

The Port of Livorno is a mid-size port, which is an ideal reference for implementing ICT solutions oriented to sustainable growth. It is taking part in the digital revolution around the maritime transport. The Port of Livorno, with CNIT of Pisa, is leading a deep digital revolution, making port industrial activities more efficient and safer. The main goal is to achieve a complete digitalization of port operations, through R&D and technology transfer.

The focus of the Livorno LL is represented by the implementation of a general cargo management system called RTPORT (Model Driven Real Time Control Module), based on the usage of disruptive and pervasive technologies (5G). This innovation proposes a complete and optimized system for managing the general cargo in relation to the vehicles available on the yard. The optimization that will be achieved, will concern: 1) loading/unloading phases of the general cargo, 2) distribution of the cargo into the storage area and its handling during loading phases on the ship, and 3) the choice of the most appropriate forklift for handling the cargo.

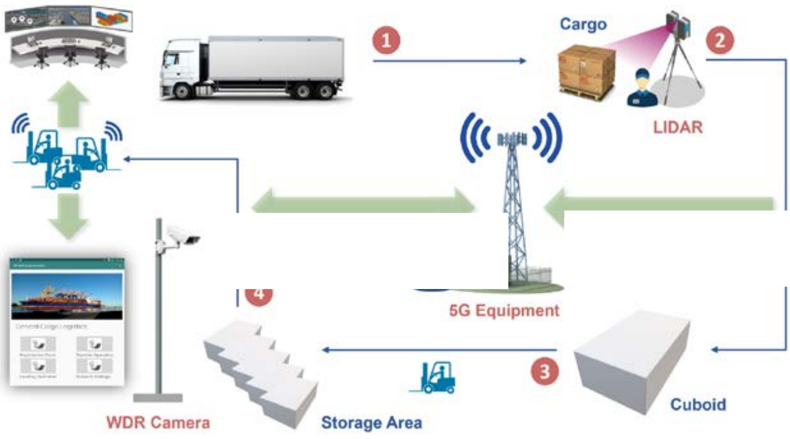

Figure 1: Flow Diagram.

The RTPORT tool, consists of a mobile network (5G), connecting smart sensors with cloud resources for optimized handling of general cargo compared to traditional human-driven communication. IoT devices such as HDR cameras and LIDARs will be used for cargo size measurement as well as goods localisation. In particular, the area where goods are stocked will be monitored by a set of cameras. Specific software will then be used to identify each object and its position. Local processing will be applied to run the distributed applications needed for image processing and pattern and context recognition while Artificial Intelligence processing, will support workers' activities to guide drivers and workers with real time Augmented Reality info.

The implementation of RTPORT provides a high level of automation for the general cargo management process that is an indispensable requirement to increase the visibility of the cargo in the intra-terminal operations. This is expected to be a fundamental part of the full visibility concept throughout the supply chain.

4.1.2 Port of Piraeus

Piraeus Container Terminal (PCT S.A.), is managing Piers II & III of the container terminal in Piraeus. The Company's main activities are the provision of loading/unloading and storage services for import and export containers handled via the Port of Piraeus, including cargos which use Piraeus only as an intermediary station of transport (transhipment cargo). The strategic location of Piraeus makes it an ideal port to be used as a hub for destinations in the Central and Eastern Mediterranean, as well as the Black Sea. The Piraeus container terminal is currently ranked 6th in terms of annual throughput among European container terminals.

The focus of the Piraeus LL will be on the Predictor tool which focuses on the development of a predictive maintenance tool for yard equipment in order to achieve Just in time (JIT) spare parts inventory. The Predictor tool will dynamically predict anomalies in port operations and reduce the total life-cycle cost of port assets, increasing its accuracy over time. To do this, an Artificial Intelligence model will be developed for predictive maintenance of the ports' assets. The model will aggregate similar data from different assets to determine recurring phenomena; calculate the impact of asset state changes on port inventory and compare events with patterns to detect anomalies. This learning approach helps to comprehend interactions of port agents and accurately estimates control measures' impact to operations. Coupled with advanced heuristic optimization algorithms to calculate nearly optimal control measures in quasi-real time, it will enable a Just-In-Time inventory and longer (re)use of port assets. At first, pre-processing of data and training of the AI model takes place. Then, using the network infrastructure, this data is transmitted and utilized to predict assets' breakdowns.

JIT inventory is one of the main methodologies used to enhance competitiveness through yard equipment availability, life-cycle extension and lead time reduction. However, implementing JIT has some challenges, e.g. lack of required information sharing or communication between stakeholders, insufficient sound action or planning system etc. Achieving JIT will enable the port to take advantage of Internet of Things (IoT) technology which has the potential to be used for acquiring data and information in real time to facilitate dynamic yard equipment planning and repairs. In addition, by better estimating the resources and the maintenance time the module will contribute to a fully interconnected system with better estimations between the relevant logistic entities, closer to the vision of PI.

4.1.3 Port of Valencia

The Port of Valencia, is the first port of the Mediterranean Sea in container cargo with an annual throughput in 2018 of 5.18M TEU. The Port of Valencia is considered as a mixed hub with balanced transshipment and gateway traffics and it is the first port for import/export container cargo in Spain with more than 2.35M TEU[4]. This figure of gateway traffic is translated into a huge pressure for its hinterland, which is mainly connected by road transport (approximately 93% of the container cargo) while the rail transport represents only the remaining 7%. To tackle this unbalanced hinterland connectivity, the LL of the Port of Valencia will focus on the implementation of new solutions to improve the efficiency of the road transport as well as boosting the railway transport for inland cargo.

The implementation of an advanced Truck Appointment System (TAS) to increase the efficiency of the delivery and pick-up container operations in the port terminals will be assessed in the Valencia LL. This Advanced TAS will count with predefined slots to perform operations at the container terminals but will also calculate in real time the Estimated Time of Arrival of the trucks to the port premises, increasing the information available for the stakeholders of the container supply chain. The ETA component relies on a machine learning model that learns the patterns in the recent location data from the trucks (e.g. peak hours, congestion, weather impact) and infers the arrival time at the port with a high accuracy.

In addition to the Estimated Time of Arrival of the trucks is computed dynamically offering a rescheduling capability to the system. By sharing information about available capacity for the port in real time it can improve the load rate of the trucks, reduce the waiting time and contribute to an interconnected system. The utilization of the system promotes multimodal solutions on one hand while on the other hand the efficiency of operations is increased. The system brings one step closer the vision of PI for an interconnected system with information about the capacity at various steps of the transportation flow.

[4] https://www.valenciaport.com/wp-content/uploads/Bolet%C3%ADn-Estad%C3%ADstico-Diciembre-2018-PBI-1.pdf

4.1.4 Port of Haminakotka

Kotka Container Terminal (KCT) handles about 650.000 TEUs a year, one half of which are export containers (paper, pulp, sawn timber). Outbound products are transported mostly by rail to the stuffing warehouses located at the port, but significant share of cargo comes also by trucks from paper, pulp or sawn timber mills. In the stuffing warehouses, the products are stuffed to containers and shipped with feeder container ships to the main ports of North Sea. Therefore, in addition to moving containers, modularity questions of containerized cargo are integral parts of operations..

The aim of HaminaKotka LL is to define a roadmap to increase automation in a medium-sized port. Important part of this aim is to increase data sharing between different stakeholders and improve the use of the data. To achieve this aim, the PORTMOD simulation tool will streamline container handling operations in the container field. The tool is expected to evaluate the benefits of different container yard layout alternatives, especially for the cases where the port has major changes in its cargo flows.

The purpose of TAS tests is to link physical transports with information flows by increasing cargo data sharing between transport company and port operator. Adoption of TAS will improve visibility of pulp, sawn timber and paper transports between mills and stuffing warehouses, which simplifies port operator's ability to balance work force needs between different warehouses. This supply chain data sharing is also one step towards PI supply chain and hub in HaminaKotka LL.

4.1.5 Port of Antwerp

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As the second largest port in Europe, the Port of Antwerp is an important transit port in Europe handling great volumes of international maritime freight. Antwerp is the biggest port area in the world. The central position of Antwerp provides its customers a vital link among biggest maritime and to Europe's centers of production and consumption. The Antwerp Port Authority seeks to achieve a better balance among the various modes of transport by switching to more sustainable options: rail and inland shipping, where further growth is anticipated. Main problems/weaknesses existing in the port-city context include i) sub-optimal organization of pickup and delivery of containers due to schedule changes or delays of both ocean vessels or inland means of transport, ii) road congestion around the port and city area and at the CT gates, and iii) delays regarding discharging cargo and late booking of necessary equipment.

The Antwerp LL will be focused on demonstrating the advantages of the Cargo flow optimizer. Automatic Identification System (AIS) data from the Port of Antwerp management system, data from barges schedules at national level, data from railway operators in Belgium and the Netherlands, and contextual information, e.g. weather, will apply Big Data based advanced predictive and descriptive analytics coupled with optimization techniques, in order to perform cargo flow optimization and prognoses. The AIS data will be multiplexed with (big) data from an Automatic Number Plate Recognition (ANPR) network, the rail operators and barges ETAs so that cargo flows are streamlined aiming to minimize containers' waiting time at the port. Cargo flow prognoses for short-, mid- and long-term will be implemented for urban planners to optimize their infrastructure investment planning.

4.2 Expected impact

In terms of sustainable port development, the proposed framework aims to improve the terminal operations efficiency, maximize the use of the infrastructure and equipment and decrease operational costs as well as external costs derived from congestion, waiting and idle time. This will be primarily achieved via the Cargo Flow Optimization module, the TAS and a high-capacity mobile network, following forthcoming 5G standards. A significant increase up to 15% in service times for shipping companies as well as an increase of 10-15% in operational efficiency is expected. Furthermore, the PORTMOD and RTPORT modules, are expected to lead to a 5% reduction in the empty container runs, 10-20% reduction of operational and maintenance costs of the port spare parts as well as 30% reduction in the trucks and yard equipment idling. Regarding the data-driven opportunistic replacements of assets proposed by the Predictor module, more than 10% cost-rate improvements can be achieved compared to the classical failure-based or naïve age-based equipment replacement methods. In addition, the proposed framework aims for a lower environmental impact of port operations. In particular, a decrease of 15% in CO_2 emissions is expected as well as up to 10% reduction in the noise generated by trucks calling in the port to pick up or deliver containers. This will be achieved via the advanced TAS that is expected to improve links with the road traffic in the port vicinity by scheduling truck arrivals and reduce trucks' dwelling time before entering the port.

Furthermore, the innovations examined in this work can be viewed as complementary to understanding the benefits of the PI. The framework primarily aims to lead to an increased understanding of port and terminal requirements in order to be able to move towards a physically connected world. The framework is expected to raise awareness of the types of possibilities that PI may have on future transport logistics, and further assist port operators into understanding the potential benefits of PI applications for their business.

5 Conclusions and further research

The proposed framework aims to improve the terminal operations efficiency, maximize the use of the infrastructure and equipment and decrease operational and external costs derived from congestion, waiting and idle times. A lower environmental impact of port operations is also expected to be achieved. Finally, the framework aims to improve links with the road traffic in the port vicinity as well as increase the modal split to greener transport modes, such as rail and inland waterways.

The innovations to be implemented within the proposed framework will contribute to the Port of the Future objectives regarding reduction of port's total environmental footprint associated with intermodal connections; the improvement of operational efficiency, optimization of yard capacity and increase of data sharing and information visibility; and the promotion on the innovation in the port-urban context. Some of these technologies, and in particular the RTPORT tool, the advanced TAS and the Cargo Flow Optimiser tool, aim to pave the way into interconnected port systems with information at various steps of the transportation flow. The interoperability between networks and IT applications for logistics represents the first step to follow in order to achieve the ambition of the PI concept: set up an open global logistic system founded on physical, digital and operational interconnectivity, enabled through encapsulation of goods, standard interfaces and protocols. The adoption and integration of smart infrastructures such as IoT devices and new disruptive technologies (5G) in supply chains will allow increasing the efficiency, effectiveness and control of supply networks.

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