Port Digitalization Through an Activities Scenario Model as a First Step for a Digital Twin of Port

Charles Garnier[1], Erwan Simon[1], Joao Pita Costa[2], Leonidas Pitsikas[3], Ignacio Lacalle[4], Carlos E. Palau[4]

1. Centre Aquitain Des Technologies De l'Information Et Electroniques (CATIE), France
2. Razvoj Programske Opreme In Svetovanjel (XLAB), Slovenia
3. PEOPLE, United Kingdom
4. Dpto. De Comunicaciones, Universitat Politècnica de València (UPV), Spain

Corresponding author: c.garnier@catie.fr

Keywords: *H2020 project, Digital Twin, Port of the Future, Port Management, Decision Support System, Simulation, Supply Chain, Simulation, Innovation Web Platform*

Conference Topic: *Systems and technologies for interconnected Logistics, PI Modelling and Simulation*

1 Introduction

Building on the momentum of the digitalisation of the maritime industry, the digital twin is arriving to the European ports and terminals to optimize operations and reduce costs. The technical term digital twin appears after 2010 [1] as a dynamical model which, given the current state of an observed system, is capable of a partial digital reconstruction of such a system. It got widely adopted throughout the years, especially in the context of IoT technologies and the industry 4.0 [2], as well as in healthcare to appropriately address the personalised medicine paradigm [3]. In the recent years there was a natural adoption of the approach by port authorities and container terminals [4], with the engagement of the main European ports in collaboration with the technology giants to explore several dimensions of it in this new context [5]. Though, the problems addressed by the port are much different than those in the digitalisation of a factory and, thus, need to be faced differently [6]. Data driven digital twins are still not in a general industrial practice due to the lack of AI know-how and possibly lack of relevant IoT data to reconstruct the underlying physical processes. The current marketplace for generic Digital Twin technology is not yet very mature, with key providers positioning between Bosh, IBM, Siemens, and General Electric. Most products are centred around internal businesses of the corresponding companies related to mostly IoT or manufacturing. The engineering paradigm of the Digital Twin arrives with: (i) online sensors becoming cheaper and ubiquitous; (ii) improved usefulness of Big Data analytics, processed for patterns and monitored for signals; (iii) the vast remote computing resources in the Cloud making them inexpensive and more accessible [7]. This allows businesses to reorganize organisational processes and workflows towards an improved cost-effectiveness deriving from the eminent digitalisation of the industry.

Modern ports face problems revolving around the issues of efficiency, environmental and financial sustainability. The difficulties they are facing are common with those of other nodes in the logistics chain and have to do (usually) with underutilization of resources: while there are empty warehouses and idle machinery at one given moment, at another moment there are demand peaks they cannot accommodate. One of the other challenges the ports are facing nowadays is that of the social integration. Major European cities have been developed from ancient times around ports as this eased the logistics of their time. However, in our era two issues are arising: i) high volumes of cargo entering and exiting the ports from the hinterland side, thus adding to traffic in cities, ii) usage of fossil fuels for energy production and / or machinery operations adding to atmospheric and sound pollution. An additional issue connecting the two previously mentioned problems is fluctuating employment in times of fluctuating supply and demand, which is not limited only to port workers, but also to activities related to the port industry. A great number of small and medium sized ports are not sufficiently equipped to utilize data already available or easily obtainable to face previously mentioned challenges. Examples of such data are i) vessel calls data which can assist in preparations and scheduling of energy peak demands, ii) usage of environmental sensors which can assist in normalizing emissions through better scheduling of activities, iii) usage of city traffic data which can assist in normalizing port traffic generation and iv) in the future exploitation of IoT enabled sensors in networked containers that can assist in better prioritization of port activities.

PIXEL platform allows to build a useful "what-if" scenario of the port activities which can be seen as an important contribution to the Digital Twin of the port paradigm. Thanks to an open-source tools called the Port Activity Scenario (PAS) based on vessel calls and use of handling equipment specifications and supply chain, PIXEL has allowed to establish an operational description of the port activities related to cargo handling. This description is composed of a set of data-model listing all the considered activities' time series. These PAS outputs are then use as inputs for energy model or for the quantification of pollutants emissions. PAS model has been build considering needs and constraints of small and medium ports; thus becoming adaptable in terms of data availability, i.e.,working with a minimum set of data providing results of corresponding level of confidence.

2 PIXEL Platform a first step for a Digital Twin of Port

A Digital Twin is a digital representation of an existing physical element aimed at modelling and monitoring its behavior and status. This "digital copy" is unique and has direct communication with the actual element to remain updated, generally in a periodic fashion. The use of the Digital Twin concept offers a myriad of opportunities, focused on decision making, monitoring, predictive maintenance and others that bring clear benefits such as productivity optimization, efficiency and short-, medium- and long-term planning. When trying to characterize a Digital Twin, the main principles are: i) it is individualized, mapping 1 to 1 to a physical element, ii) it can simulate – if properly designed – the behavior of an element with high accuracy levels, but needs to be continuously maintained and updated, iii) the digital model can respond with a very low response time (latency) if and only if the proper technologies are used (IoT, 5G…) and iv) changes in one twin affect to the other, creating a closed-loop achieving physical-digital convergence.

The idea behind the concept is to allow workers (at all levels of the production chains) interact with digital copies as if they were acting over the physical elements, improving efficiency, optimizing costs and drastically reducing health risks at work. After performing a literature analysis, it is commonly accepted that the "Digital Twin" is not delivered by a single technology, nor even by a single technical domain, but rather it is an amalgam of disciplines that shall be put together on many ways and remain valid. Therefore, according to the previous, a "combination" of technologies is needed to deploy a realistic, successful Digital Twin of a physical element. In Figure 1, there is presented a summary of this multi-disciplinary view of the Digital Twin concept.

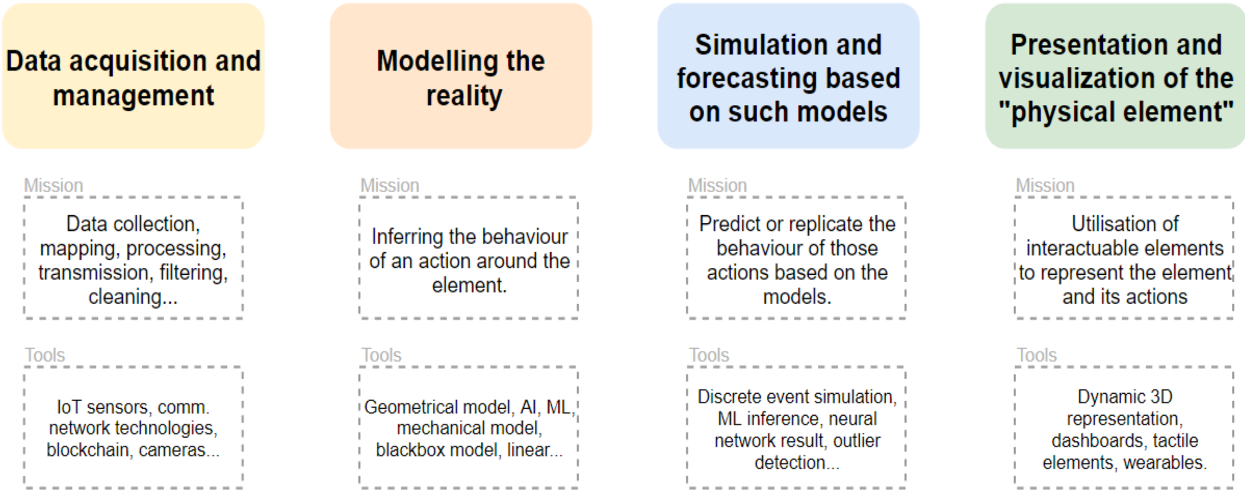

Figure 1: Digital Twin multi-disciplinary summary

Here, PIXEL comes into play. The on-going EC H2020-funded action has created the first modular platform combining strong methodologies and smart technologies for small and medium port ecosystems enabling optimization of operations through IoT while reducing environmental impact. It has been tested in four real ports (Bordeaux, Monfalcone, Thessaloniki and Piraeus) with great results in terms of digitalization and process modelling. Technologically (see Figure 2), it consists of a series of modules (services) framed within four "big blocks" (Data Acquisition Layer, Information Hub, Operational Tools and Dashboard) located at different layers (divided in three), wrapped under an ell-encompassing security framework. All the pieces of the architecture have been built using open-source technologies. The NGSI agents (in the Data Acquisition Layer) perform the actual data collection from the various sources, converting them into actionable information following a specific data format (based on the FIWARE KPI data model [8]) and sending it to an IoT Context Broker (FIWARE ORION [9]). In the case of the Port Activity Scenario (PAS) – of study in this paper –, the data collected is related to the vessel calls (announcing the ships to be operated by the port within the next few days) and the port parameters configuration. Then, these context data are stored inside the Elasticsearch database of the Information Hub for persistence. At this point, the data are ready for the simulation (using the PAS model), which is orchestrated via the Operational Tools (scheduler, controller, manager). This module manages to execute the simulation and defines the storage of the results on the proper place to be represented to the user through the Dashboard User Interface (UI).

As it has been exposed, the whole technological provision of PIXEL could play a role towards the "Digital Twin" of a port, however this article is centered in the Port Activity Scenario (PAS). In the structure of the architecture presented, PAS is conceived as a model that aims at simulating the terminal operations of a port after a series of inputs, priorities and contextual conditions. In particular the PAS might be considered as the "meeting point" between the Physical Internet theory (see Section 4.2) and the Digital Twin concept just outlined. While it aims at representing a "physical element" (that in this case would be a maritime port terminal), it remains a node within the logistic supply chain and could be leveraged towards the optimization and standardization goals of the Physical Internet realm.

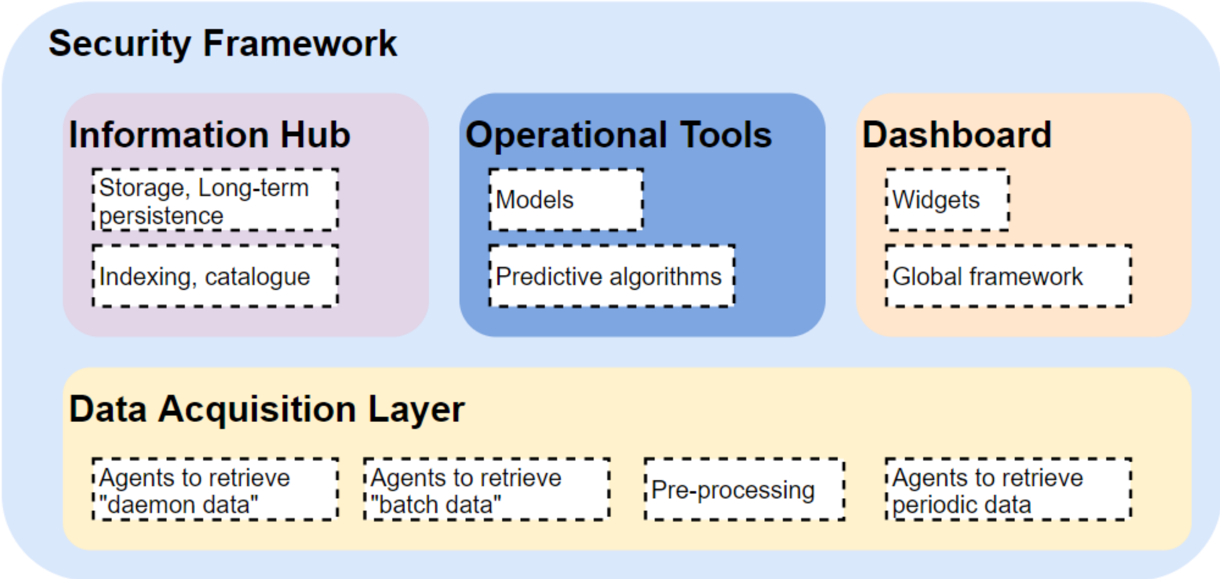

Figure 2: PIXEL modular architecture

3 The Port Activity Scenario model

3.1 Objectives of the model and context

Ports are complex ecosystems with a multitude of actors (port authority, terminal operators, carriers, citizens, legislators) producing and consuming each day huge quantities of information. These operational data are increasing, depend on different stakeholders and come from several sources: vessel operations, crane scheduling, resources tracking, container status, surface or berths available, air/water quality measurements, energy consumption and production. However, in many cases and especially in small and medium ports, the information is still exchange in a document-centric way. Today, European small and medium-sized ports are experiencing a lack of tools to calculate, estimate or predict impacts on energy consumption, transport networks and environmental pollution of port activities. To provide these tools we consider that the development and implementation of tools to model the impacts (in terms of energy, transport and pollution) of port activities is a needed step. Indeed, port activities undeniably have an impact on their environment, on the city and the citizens living nearby. To have a better understanding of these impacts, ports need tools allowing suitable modelling, simulation and data analysis. As the port activity is generated by incoming and outgoing cargoes into the port ecosystem, we have developed a model called the Port Activity Scenario, denoted as PAS, to consider cargoes' transitions and to be able to better understand the related energy consumption, pollutants emissions and organization of a port. PAS has been developed integrating constraints and need of the small and medium ports and with the objective to convert raw data into useful information about today and model port activities to predict future impact.

3.2 Definition of the model

The main purpose of the PIXEL modelling stack is to transform raw data (from sensors, various computing devices and fixed lists of data) into useful and actionable information. To do this, the approach developed makes a clear distinction between two steps, as illustrated in the figure below. The first step transforms the fed raw data into a Port's Activities Scenario (PAS) which is a list of all the upcoming port's operations with determined articulation across time. The second step calculates the outcome of the PAS on a certain period (as energies consumption, pollutants emission etc.).

Figure 3: From raw data to actionable information, the PIXEL modelling approach.

PAS focuses on cargo handling from one area to another through machines. For each cargo, there are several ways to arrange transition operations between areas. A hypothetical combination of those transition operations (for one or more cargo) is denoted thereafter as a scenario. Input data of the PAS model are mainly based on: i) vessel planning (arrival date, cargo type and tonnage, ii) activity data (details related to the transfer of cargo), iii) operational data (refer to the technical specifications of engines and equipment used) iv) emission source data (related to emissions factors of engine and equipment). The knowledge and modelling of the supply chain and port activities (machine type, duration of use, position in the port) enable the building of activity scenarios that are used to identify the energy sources and local emissions of pollutants but also to estimate the flow of cargo entering or leaving the port. Using this approach, the resulting modelling scenario might be used by the ports as a support for decision making.

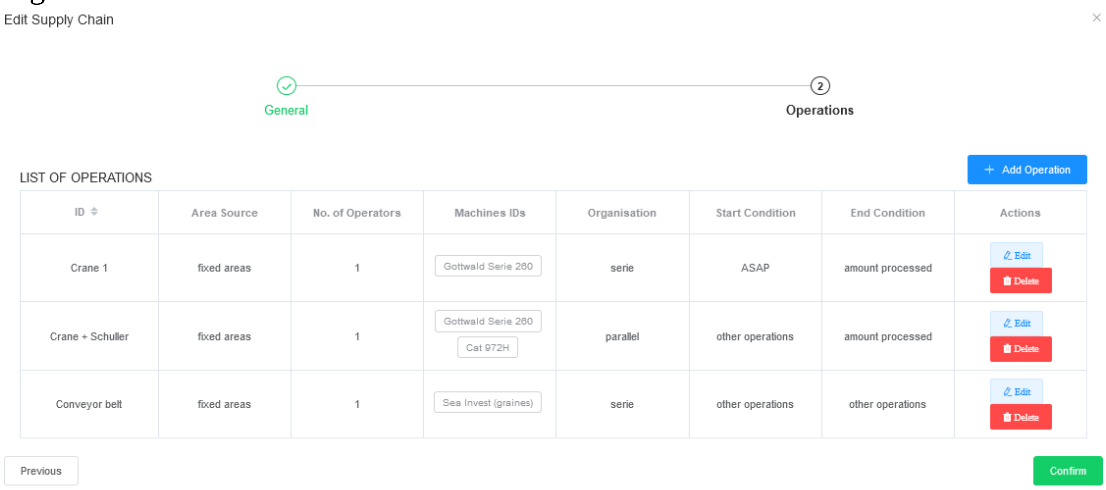

Figure 4: Supply chain definitions using the PIXEL GUI

A "PAS scenario" is a set of data describing all the activities and the equipment participating in those activities that are taking place within a timeframe for a specific amount of specified cargo. As such, it allows the calculation of energy consumption, emissions quantifications, and other externalities quantification. It consists of: a) a call for the handling of an amount of cargo starting at a specified time, b) a supply chain applied on the above-mentioned call. The supply chain contains machinery, areas, general port considerations or restrictions. PAS model can describe all operations related with a cargo transition that take place within a port. Its purpose is to establish an operational description of the port activities related to cargo handling. The produced PAS is a fulfilled data-model listing all the considered activities' time series. Because data is a key point to have useful models and because data collection is an intensive phase, PAS model can be used with different levels of details regarding input data. Depending on the purpose of modelling and the expected precision, inputs data could be less or more detailed. Thus, ports can use PIXEL models with comprehensive data (detailed model and low uncertainty), screening data (some local input and external data leading to a significant uncertainty) and scaled data (average and non-specific input data leading to great uncertainty and just giving an order of magnitude). If one port has installed enough infrastructure for collecting the data and has incorporated the needed specifications, a scheduled execution of the PAS can be set. A more detailed description of PAS model is available in [10].

Figure 5: PAS outputs and results visualize as a Gantt chart.

The sequence of actions from a vessel call to, as an example, a quantification of emissions is as follows:

1. The port agent, terminal operator or the port authority described the different supply chain with their associated machines and specifications. Figure 4 shows the GUI that have been developed to help ports fulfil these data. This work is just done once (and updated by the user as needed with the addition of new equipment procured or the deletion of obsolete machinery). Then the PAS model is configured to be run in an automatic way through the Operational Tools of the PIXEL platforms.
2. A ship approaching a port sends a vessel call and a FAL form (convention on Facilitation of International Maritime Traffic) to the port management information system. Thanks to the PIXEL platform this vessel call is automatically stored in the PIXEL Information Hub and made available as an input for the PAS model.
3. The PAS model considers the following item to create an ordered list of operations:
   a. The cargo.
   b. The estimated time of arrival.
   c. The port description.
   d. The rules and priorities set for the handling of similar cargo.

   This list of operation can then be visualize using for example a Gantt chart as shown in figure 5.
4. The energy consumption corresponding to the PAS predicted list of operations is calculated by the energy model.
5. With the use of emissions factors, the energy consumption calculated is translated to emissions quantifications by the PAS.
6. The emissions quantifications can be used by the Environmental Pollution Models and by the Port Environmental Index [11].

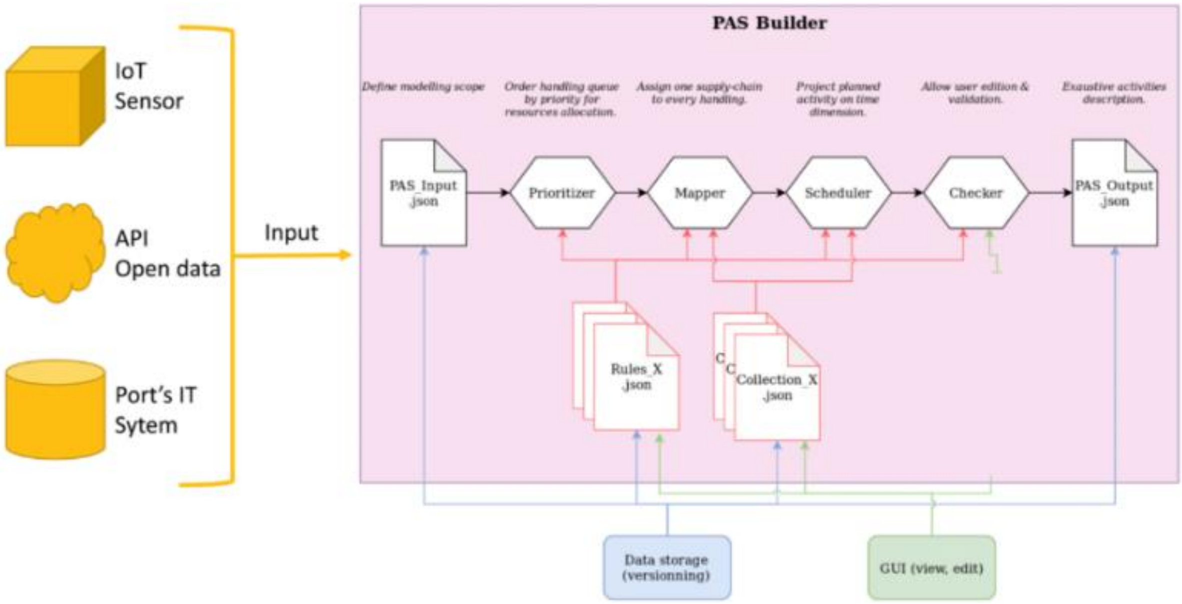

Figure 6: Schematic description of the PAS model.

4 Outcomes and results linked with the PAS model

4.1 PAS as an element for logistics innovation

The Port Activities Scenarios is used to link different models and guarantee interoperability as described in the figure below. Depending on the available data via the PIXEL Information Hub, a scenario can be completed with models related to energy, environmental pollution, area occupancy. In the following some examples are provided on how PAS and the modelling approach previously described can be used to improve logistics and the environmental port management.

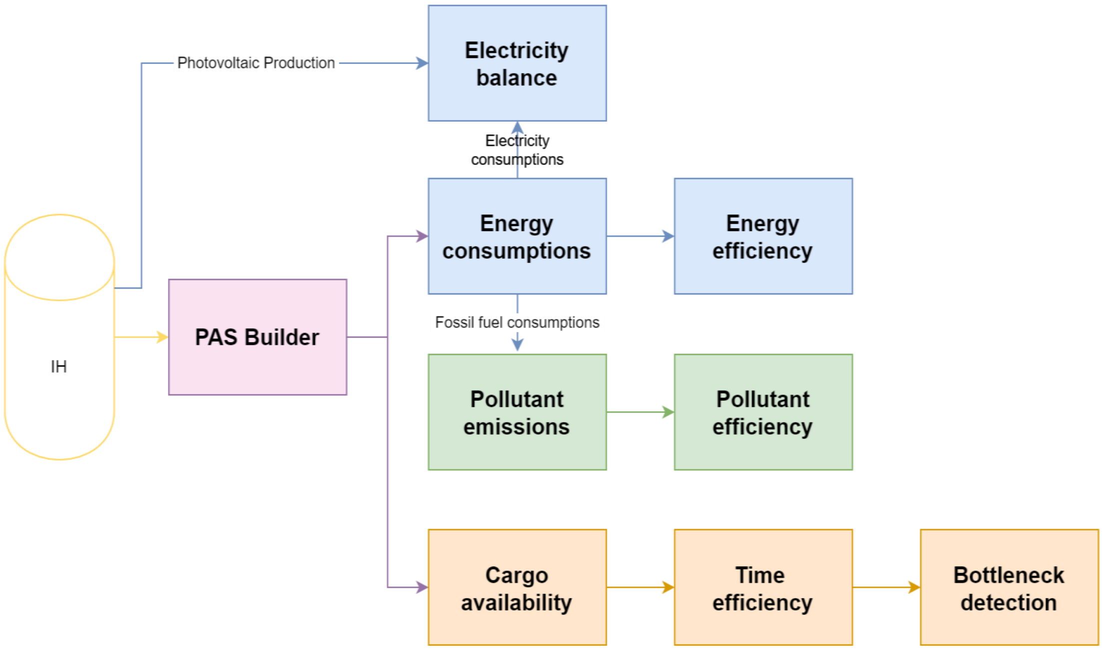

Figure 7: PAS and example of models' interoperability

PIXEL proposes a model that enables ports to calculate their energy consumption relating to their activities. For every considered cargo that is transiting inside the port, the corresponding sequence of operations across time is provided through the Port Activity Scenario described in the previous section. For each operation, the duration, the machine's energy type and its unit consumption values are available (from input and parameters combination). For each operation, the energy cost is calculated as the product of atomic operation's duration multiplied by its machine's unit consumption. Note that the energy consumption independent to the PAS (e.g., buildings with thermal regulation) could also be considered and add to the energy's consumption time-series. Then for every energy's type, all the consumptions occurring during the same timeframe can be summed to get the corresponding total consumption. The sequence of all those timeframes constitutes the energies consumption time-series. This functionality is directly included as a module of the PAS.

Figure 8: Example of results of the energy model (via the PIXEL platform GUI). Results can be filtered by energy type and be displayed as instant or cumulative consumption.

The Port Activities Scenario (PAS), combined with the energy model and emission factors, is a transferable and applicable tool for small and medium European ports that allows to model port supply chains. The output of this model can be used as an input for evaluating the energy consumption and with the use of emissions factors to provide an estimation of pollutants emissions. Following the previous, the usefulness of the PAS for the Port Environmental Index [11] can be understood two-fold: i) Providing information on the berthing time. Ideally, a port will provide the values of the time a vessel is being berthed, hoteling and manoeuvring within port maritime area. The PAS outputs can be used to obtain a (approximated) value of how much time is a vessel operated (loaded/unloaded), which can be considered a basis for the berthing/manoeuvring ratio. ii) Providing information of energy consumption of the terminal to calculate air emissions. Energy consumption is, usually, a complex metric to quantify, in contrast of what logical thinking would indicate. PAS output allows to know, with a simulation perspective, the total amount of energy consumed by the machinery needed to operate one vessel. Using that information, altogether with the type of fuel/power used, can be leveraged by the PEI to estimate the air emissions attributable to the terminal activity in a period of time. This functionality is directly included as a module of the PAS.

4.2 PAS as a node of the physical internet

The Physical Internet (PI, pi or π) is a concept that models logistics chains as an interconnected network of intermodal hubs that manage unified, standardised elements (pi-containers), encapsulating merchandise within them. The basic idea is to conceive the logistics network as a Digital Internet landscape, with a series of nodes (pi-nodes, representing logistic hubs) interacting among them to forward such elements behaving like a TCP/IP network. PI relies on collaborative protocols, and standardized, modular, and smart containers [12]. This change of paradigm relies on collaborative protocols, effective data sharing and the use of standardized, modular, traceable smart containers. PI, if successfully achieved, will improve overarching efficiency, reducing the impact of logistic chains on the environment and the time-to-distribution perspective. The PI requires the interconnection and intervention of a huge number of informational elements, which entails the co-operation of innovative technology applications for tracking pi-containers, managing the pi-protocols and sharing information among involved actors (from both horizontal and vertical sectors). In this sense, a major technology that comes to play here is Internet of Things. IoT can hugely benefit PI as it encompasses most requirements about containers tracking, end-to-end visibility of the objects, allowing operations over that digitalized data and facilitating ubiquitous information exchange [13].

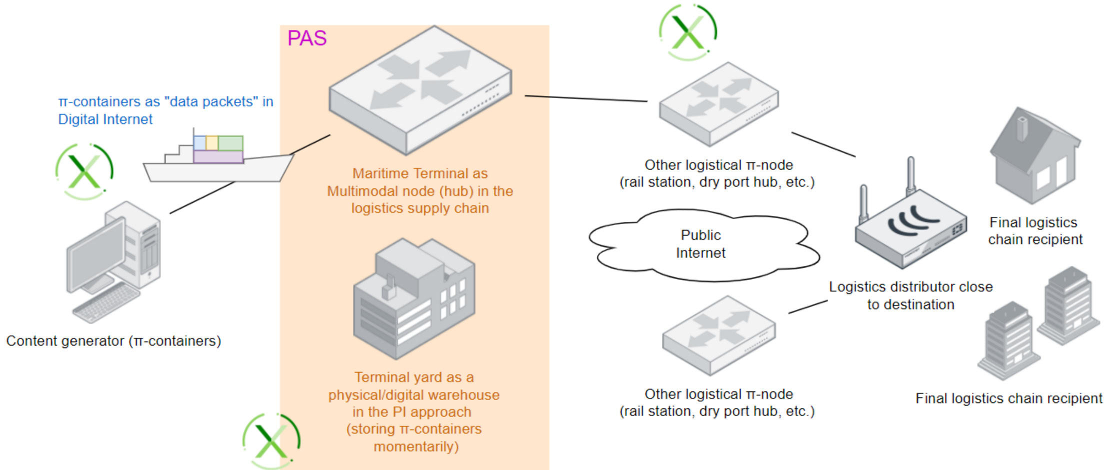

Figure 9: PIXEL and PAS as Digital Twin to represent a pi-node in the Physical Internet approach

Figure 9 aims at illustrating the fit of PIXEL (X logo) and PAS (orange rectangle) within the Physical Internet. On the one hand, PIXEL can be understood as the (aforementioned) IoT framework to achieve end-to-end communication and sharing of data/processes between diverse entities and actors of the logistics supply chain. PIXEL is prepared to bundle the components of the PI (pi-containers, pi-trucks, pi-trailers, pi-conveyors, etc.) as data pieces to be managed by the Context Brokers and Information Hubs (single-instance per each deployment in a node). In addition, PIXEL would allow their tracking (via GPS, RFID or others), allowing the logical operation of that data in each logistic node. Due to the multi-actor approach of the platform, they could share information (easy-to-connect APIs) in real time, letting various profiles of port managers to analyze and visualize the information.

5 Conclusion

In this whitepaper, we have described the Port Activity Scenario that has been developed during the PIXEL project. Based on an open-source IoT platform that allows to gather and store data coming from heterogeneous sources, the PAS model is able to simulate and predict the port activities and can be seen as a first step towards a Digital Twin of a port. The Port Activity Scenario (to be used as a model within PIXEL or outside the platform as a standalone tool) can be utilized to i) model and ii) simulate (two of the Digital Twin domains) a maritime port terminal as a pi-node in the logistic chain of a classic maritime transport picture. The fact of wrapping PAS as a pi-node provides various interesting traits towards optimization and efficiency: the PAS allows to i) “predict” the behavior of the pi-node (terminal) with regards to packet (pi-container) throughput, ii) forecasting how time it will take to operate each unit, and iii) how much energy will be used to do so and the internal operations required. The previous will allow port operators (and actually upcoming elements in the supply chain) to plan ahead and minimize round-trip-time of the pi-container (packet). Additionally, PAS is providing information that can be distributed in the internet regarding the expected timing of ports operations (such as loading and unloading of vessels) that can impact the logistics chain as well as their surrounding communities, through Port Community Systems. Thus, it can then be used to normalize a logistics chain, minimize storage times, warn about upcoming traffic, etc. The modularity of PIXEL allows PAS to connect and provide data to multiple models (calculation modules). Future research can focus on addition of models related to intramodality of transportations (selection of transport mode in relation with the expected cargo) and on integration of data available by pi containers in order to automate decision making regarding storage and shipment.

Acknowledgements

PIXEL project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº769355.

References

[1] Elisa Negri (2017). "A review of the roles of Digital Twin in CPS-based production systems". Procedia Manufacturing. 11: 939–948.
[2] T. H. J. Uhlemann, C. Lehmann and R.Steinhilper (2017). The digital twin: Realizing the cyber-physical production system for industry 4.0. Procedia Cirp, 61, 335-340.
[3] C. Angulo Bahón, J.A. Ortega Ramírez, L. Gonzalez Abril (2019). Towards a healthcare digital twin. In Artificial Intelligence Research and Development vol. 319 (pp. 312-315). IOS Press
[4] W. Hofmann and F. Branding (2019). Implementation of an IoT-and Cloud-based Digital Twin for Real-Time Decision Support in Port Operations. IFAC-PapersOnLine, 52(13), 2104-2109.
[5] R. Boyles, "How the Port of Rotterdam is using IBM digital twin technology to transform itself from the biggest to the smartest," 29 8 2019. Online, https://www.ibm.com/blogs/internet-of-things/iot-digital-twin-rotterdam/. Accessed on: 9 Mar, 2021.
[6] E. Rademaker, "The Digital Twin of Port of Rotterdam," 17 10 2018. Online, https://youtu.be/nUbgHGJXj5c. Accessed on: 9 Mar, 2021.
[7] Maggie Mae Armstrong (2020) Cheat sheet: What is Digital Twin? https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/
[8] Smart Data Models: Key Performance Indicator." https://github.com/smart-data-models/dataModel.KeyPerformanceIndicator (accessed Apr. 15, 2021)
[9] "FIWARE Orion Context Broker." https://fiware-orion.readthedocs.io/en/master/ (accessed Apr. 15, 2021), "pyngsi framework." https://pypi.org/project/pyngsi/ (accessed Apr. 15, 2021).
[10] E. Simon, C. Garnier, I. Lacalle, J. P. Costa and C. E. P. Salvador, "Small and medium ports' activities: introduction to the PIXEL approach.," WIT Transactions on the Built Environment , vol. 187, pp. 149-163, 2019.
[11] A novel approach for assessing the ports' environmental impacts in real time – The IoT based port environmental index, Matija Široka, StjepanPiličić, Teodora Milošević, Ignacio Lacalle, Luka Traven, in Ecological Indicators, Volume 120, January 2021, https://doi.org/10.1016/j.ecolind.2020.106949, (Available online 19 September 2020)
[12] E. Ballot, B. Montreuil, and R. Meller, The Physical Internet: The Network of Logistics Networks, L. D. Française, Ed. Paris, France: La Documentation Française, 2014
[13] H. Tran-Dang, N. Krommenacker, P. Charpentier and D. Kim, "Toward the Internet of Things for Physical Internet: Perspectives and Challenges," in *IEEE Internet of Things Journal*, vol. 7, no. 6, pp. 4711-4736, June 2020, doi: 10.1109/JIOT.2020.2971736