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GPICS a framework to create a digital twin for the Physical Internet

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Abstract: *The GPICS (Generic Physical Internet Case Study) framework has been developed within the ICONET (New ICT infrastructure and reference architecture to support Operations in future PI Logistics NETworks) project. It is a methodology for designing and evaluating supply networks through PI. GPICS is a conceptual framework that is generated as an abstraction of different Living Lab cases and generic industrial scenarios. It is formed based on six interrelated dimensions. GPICS modelling is designed to allow the composition of a generic PI network through reusable modelling components and rules, via appropriate configuration, these components can represent different types of supply chain flows.*

The six interrelated dimensions range from the necessary modelling components and base configuration rules (Modelling Kit) to the scenario definition/parameterization capabilities (based on operational rules, business models and vertical and horizontal collaboration strategies between the different roles in the supply chain), including Master Data Sets, that concern and are relevant for a Geographical Area within the EU. As mentioned above, the GPICS also includes a set of benchmark KPIs for the assessment of different PI scenarios, based on a different combination of the configuration capabilities of these scenarios.

The network is represented by using a virtual simulation model. A multi-agent simulation model is used to create a digital twin of the supply network, utilizing GPICS main components and integrated with ICONET's PI services. The virtual model contains a general representation of the main nodes and their interconnections. It creates a representation of the main flows of freights in a PI network. It can include transports from different companies, with different restrictions. The simulation model developed is a tool that helps companies to visualize how the movement of products over a PI network can be, including flows from other companies.

The virtual models are used to quantify the impact of the different services. Economic (transport and handling costs), operational (reducing lead time) and environmental (CO2 emissions) indicators have been obtained in different living labs. The description of two use cases developed in the project is included.

Conference Topic(s): *PI Modelling and Simulation, PI Fundamentals and Constituents.*

Keywords: *Digital Twins, Multi-agent simulation, Simulation, Showcasing, Intermodal and Synchromodal Transport*

1 Introduction

This article describes a method for modelling and analyzing different Physical Internet (PI) configurations in different use cases. A part of the content has been inspired by the implementation of the ICONET project [1] where the main parameters of GPICS (Generic PI Case Study) have been defined. The modelling components of the framework are based on the

different living labs under a common PI framework. GPICS identifies the components, parameters, rules and indicators to create a PI network within the context of the Living Labs. The design of the GPICS framework serves as the basis for simulation-based analysis of the performance of PI networks, using defined and agreed KPIs. The ICONET project also has direct connections with the SENSE project [2], but with different goals. SENSE strategic goal is to accelerate the path towards the Physical Internet (PI), so advanced pilot implementations of the PI concept will be well functioning and extended in industry practice by 2030, and hence contributing to at least 30 % reduction in congestion, emissions and energy consumption.
The design of this framework begins with a review of the existing literature on the Physical Internet. The PI literature is constantly growing. The very first publication on the PI dates from 2006 while the concept of actual PI was initially introduced in 2010 by Montreuil et al. in [3], who laid its foundations and received the attention of academics and practitioners. Most PI publications are conceptual and try to supply practical solutions for certain PI components. Similarly, there are many studies and simulations aimed at providing real-life solutions for some of the PI components (e.g., simulations for the operations of PI-hub, PI-store and PI-sorter) but there are few case studies or experiments focused on the analysis of the potential impact and benefits at the level of the PI network and the integration of the models with the specific PI services.
A Digital Twin (DT) is a virtual environment that mirrors the real physical system (a physical twin) and its processes by updating its virtual real-time status from various sources of information about weather forecasts, congestion levels, positions of assets (barges, trains, trucks) and their ongoing working conditions. There are different definitions of the Digital Twin concept. Zheng et al. [4] define the DT as ”an integrated system that can simulate, monitor calculate, regulate, and control the system status and process”. The Digital Twin could simulate multiple virtual scenarios at once. Launching virtual scenarios allows key indicators to be measured in a virtual environment, unlike pilot projects which can be expensive or risky to implement.
In the ICONET project, a methodology has been developed to combine physical and digital elements through simulation models that can be integrated with PI services that provide real-time information on the position of containers and transports. Behind the idea of the mixed Digital/Physical simulation approach is the technical perspective, that the developed models should allow the inclusion of information from both digital elements as well as and physical sources. In certain simulation models, the information of some components (i.e. the position of a truck, or the storage capacity of one facility) could be obtained from a real physical entity, through APIs available in the cloud. The work on the development of modeling and simulation around Physical Internet is currently evolving, among other projects within the PLANET project [5].

2 GPICS ELEMENTS

The GPICS framework consists of six dimensions that are interrelated, in fact, these six dimensions that make up the GPICS are more than interrelated, they are interdependent, in the sense that each of them is the input to the next. The GPICS framework provides not only the components needed for a case study definition but also a process or cycle to drive it.

As shown in (Fig. 1) GPICS (Generic Physical Internet Case Study) is defined on the basis of six interrelated dimensions covering from the necessary modelling components and the rules of base configuration (Modelling Kit) up to the capabilities of scenarios’ definition/parameterization (based on operational rules, business models and vertical and horizontal collaboration strategies among different roles in the supply chain) including Master Datasets, which concern and are relevant to a Geographic Area within the EU, which will allow the instantiation of the GPICS and the creation of the PI (Physical Internet) Hubs Plan. As mentioned above, the GPICS also includes a set of key performance benchmarks Baseline Key Performance Indicators for the evaluation of different PI scenarios, based in different combination of the configuration capabilities of those scenarios.

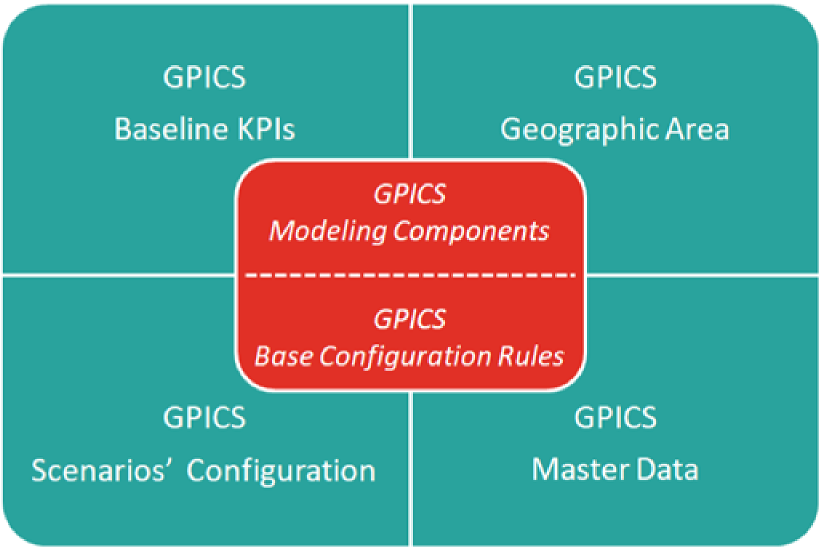

Figure 1: GPICS Framework/Dimensions

The modelling components and base configuration rules in the Modelling Kit meet the PI challenges posed by use cases as an abstraction level allow the integration of the four Key PI capabilities which correspond to each of them.

The GPICS framework is also the basis for simulation models. GPICS modelling elements and base configuration rules, which are included in the dimension "Modelling Kit", have a direct correspondence with simulation models. On the one hand, the modelling elements, such as hubs/nodes or corridors, have their representation in the simulation as objects, the so-called 'Atoms', and on the other hand these 'Atoms" have a behavior based on the basic configuration rules defined in the GPICS framework and instantiated in the GPICS definition.

The “Geographic Area” is the first dimension of the GPICS definition. The geographical area defines the regions covered by the case study and is the main GPICS parameter. The second dimension is the “Set of Master Data” associated with the geographic area selected in the previous dimension. This master data characterizes the current supply chains in the geographical area in terms of specific ports, multimodal hubs, TEN-T corridors, urban distribution centers, population coverage, cargo/freight load distribution, transport demand/flow, warehousing capacity, transport modes and frequencies, lead times, etc.
The core of the GPICS is the Modelling Kit, which consists of two dimensions. On the one hand, it includes the “Modelling Components” and, on the other hand, the “Base Configuration Rules”. The modelling components are a set of elements that represent physical elements in a PI network, such as: PI hubs/nodes, PI corridors, PI containers, etc., as well as a set of roles which interact and have an active participation in a supply chain in PI. Amongst these roles, we can highlight: PI sender, PI receiver, PI transport & logistics service provider or PI network

coordinator. The fifth dimension which is part of GPICS, is the “Scenarios' Configuration Capabilities”, based on What-if scenario analysis (WISA). WISA is a business planning and modelling technique used to yield various projections for some outcome based on selectively changing inputs parameters. A scenario, in this context, is a potential circumstance (i.e., parameter change) or combination of circumstances (i.e., combination of different parameters changes) that could have a significant impact -- either positive or negative -- in an organization. The last dimension of GPICs consists of a set of “Generic Key Performance Indicators”, which will allow a standard and common evaluation of the performance of the PI supply chains configured in the GPICS, between different scenarios. The GPICs Key Performance Indicators have the mission to provide a comprehensive vision of the impact of PI with respect to the current situation and to be an instrument capable of shedding light on the strengths and weaknesses of different PI scenarios.

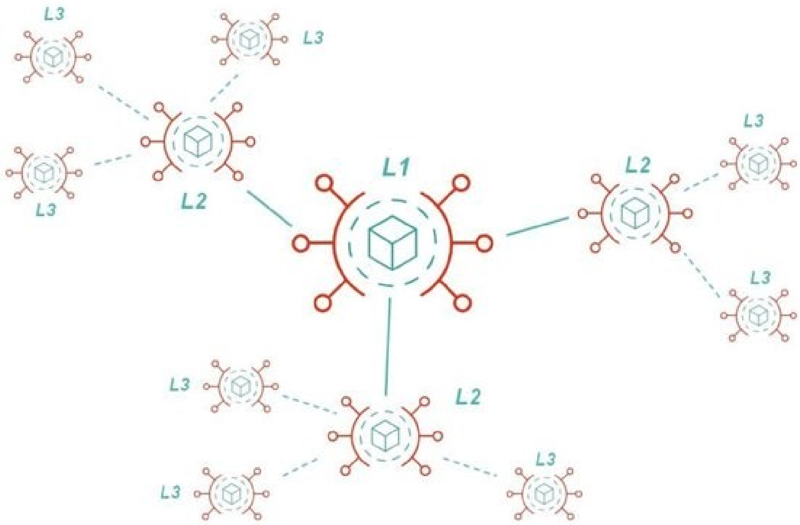

Figure 2: GPICS three-level structure of HUBS

3 SIMULATION COMPONENTS

The aim of Digital Twin model is to produce network simulation models in support of PI concepts prototyping efforts connected with the PI services designed. Simulations are used to estimate the network-wide performance associated with different routing policies and dynamic routing decisions, to find best networking for collaborating hubs, and to evaluate the efficiency of the PI-enabled services.

Regarding the design of the elements necessary to stand for a PI transport scenario, the elements defined by Montreuil, Meller and Ballot [3] have been used as a basis. They proposed three key types of physical elements as enablers of Physical Internet: the PI containers, the PI nodes and the PI movers. PI containers are described as the unit loads that are manipulated, stored, moved and routed through the systems and infrastructures of the Physical Internet. PI containers are generically moved around by PI movers. Moving in this context is used as a generic equivalent to different logistics and transport activities or processes such as transporting, conveying, handling, lifting and manipulating. PI nodes are defined as locations expressly designed to perform operations on PI containers, such as receiving, testing, moving, routing, sorting, handling, storing, picking, composing, decomposing and shipping PI containers.

Regarding modelling Sarraj and Montreuil [6] raise that, physically, a logistic service is carried out per a transport service based on a network consisting of nodes (including distribution centers, warehousing, plants, etc.), arcs to define the means of transfer of goods by freight services (road, rail, maritime service, etc.) and the final shippers/receivers (companies, organizations, or individuals). Applying the Internet analogy, a shipper sends his merchandise to a nearby node that manages it, stores it and sends it to its destination through one of the many accessible logistics plans. For this purpose, as in the case of Internet data, the merchandise is encapsulated in the form of standardized packets: PI containers.
Based on the current state of the art of the research of modelling PI physical elements and with the valuable insights from ICONET's forums and living labs, ALICE cluster and Advisory Board of the project, an innovative approach of modelling components has been defined. GPICS makes an abstraction of a real PI world system by creating a conceptual model and such a representation must be defined by four fundamental parts: lexical, structural, procedural, and semantic. In this regard, the GPICS modelling components cover and support two of these parts of the representation. On the one hand, the lexical part of the representation, which deals with the description of the symbols allowed in the vocabulary of representation, and on the other hand the semantic aspects of the representation that establish a way of associating meaning with the descriptions. This is one of the reasons why the GPICS modelling components are considered a fundamental part of the ICONET's GPICS framework. The following image shows the components that have been designed to represent the components of a supply chain in a PI environment.

GPIC structure	
GPICS Container	Unit load manipulated, stored, moved and routed through the systems and infrastructures of the Physical Internet.
GPICS Node/Hub	Location specifically designed to carry out logistics and transport processes and activities on PI containers.
GPICS Mover/Transport	Moving element used to carry PI containers through the PI nodes/hubs.
GPICS Corridor	Connection between two PI Nodes/Hubs directly connected.
GPICS Route	Set of GPICS corridors which connect a GPICS Node origin and a GPICS Node destination.
GPICS Network	Set of containers, nodes, movers/transport, corridors, and routes.
GPICS Roles	Actors/Agents involved in the operation of the PI Network.

Figure 3: GPICS modelling components.

Throughout the virtual model, different decisions must be made, for example, if it is necessary to separate the load from the receipt of a truck, how long a pallet should be stored, if it is necessary to group different containers, or what is the best transport to advance to the next destination. The following image (Fig. 4) supports the understanding of these decisions. In fact, this figure shows the schematic representation of a Generic Hub internal process. Starting from the left side, the flow begins with the reception of the products. Subsequently, there is a classification process, in which the decision is made as to whether the container should be separated or added, with other containers. There is also the possibility of temporary storage until a new order of movement for the products arrives. The lower part represents the state of the movers (i.e., trucks, trains). Initially, the movers perform the unloading of containers. Second, they can wait some time or, finally, they can load new products into the node, and continue to the next destination.

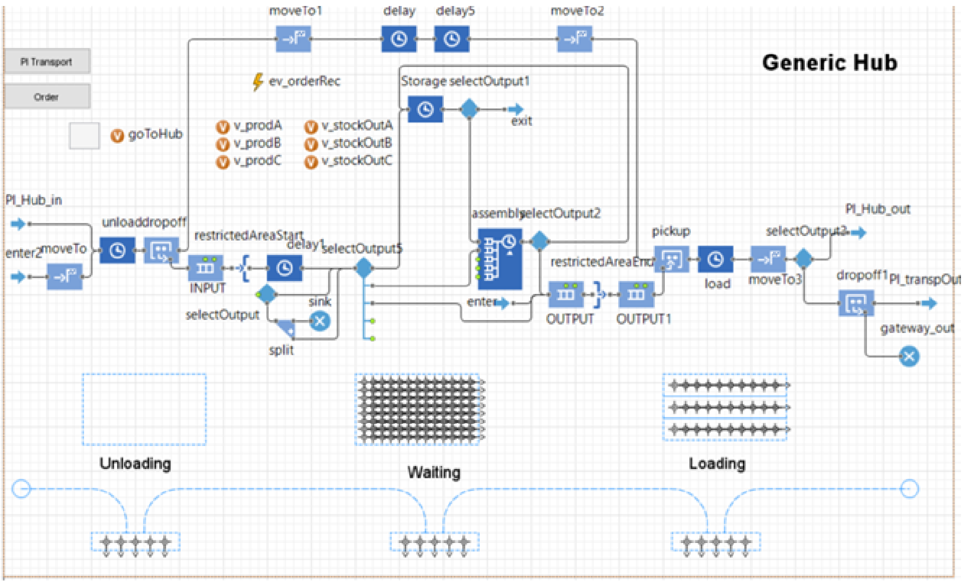

Figure 4: Generic PI Hub model

4 MODEL INTEGRATION

The designed simulation models allow to virtually represent the behavior of the different actors in the supply chain. A proposed added value is the integration with real services (e.g., networking, routing, shipping services) that supply information on the state of transports in the real world, and from this information it is possible to evaluate their evolution in different scenarios in the virtual model.

The concept of physical simulation in the PI framework refers to the simulation of models that can be performed with real data/events fed from the physical world. The physical simulation will materialize with sources of information that come from data sources available in the living laboratories.

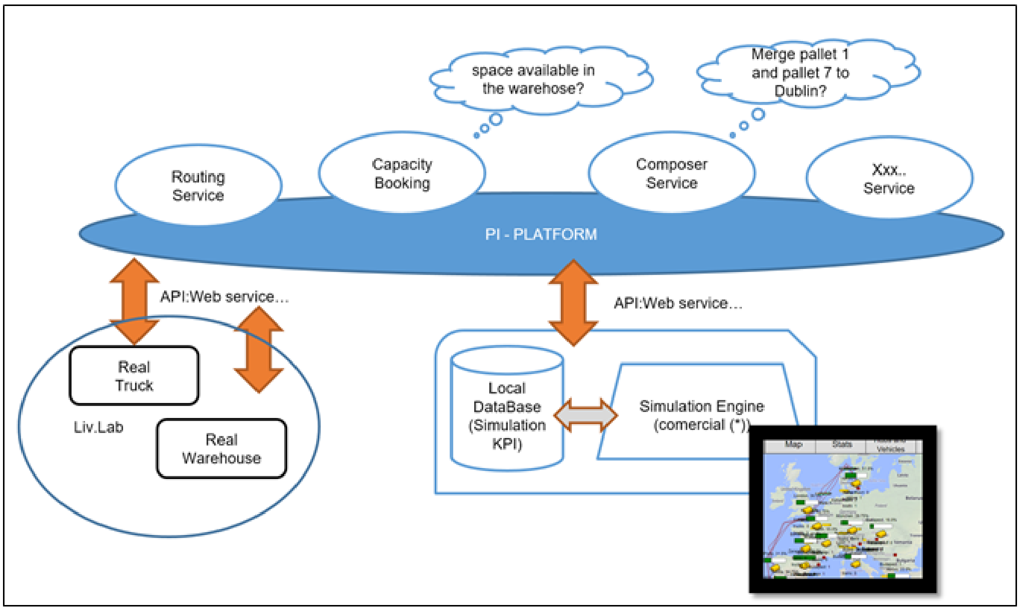

Figure 5: Simulation model integration.

The information of the physical world will be connected to the simulation models through data exchange interfaces. (i.e., from a common information management platform). In the information platform, the different physical elements, such as a truck or a container, can give information about their arrival at the destination, their departure from the port or their GPS position at a certain time through the IoT devices in the PI containers. The digital simulation can receive this information and, consequently, apply the management rules of physical internet management to evaluate the possible evolution of the network considering the real data that has just received. The following image describes the connection between the simulation (virtual model) and the different PI services developed in the ICONET project.

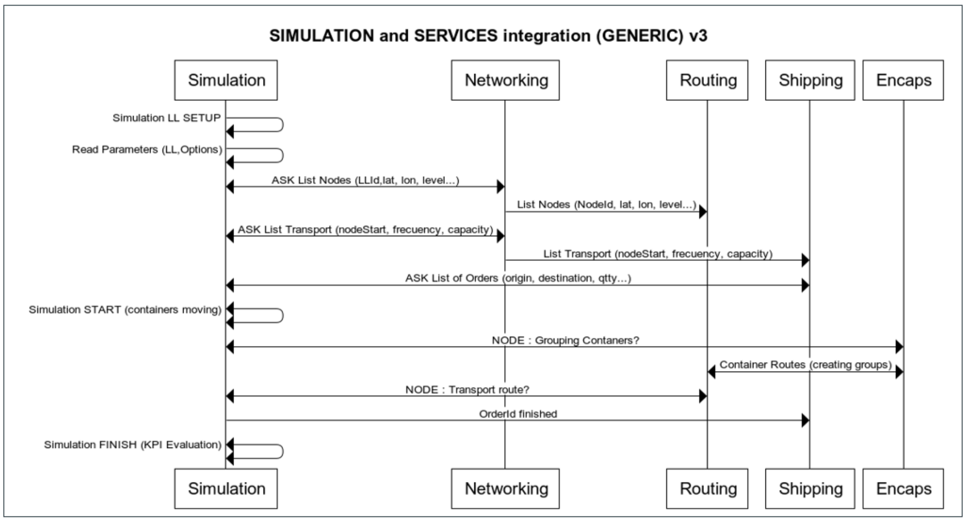

Figure 6: Simulation model and service integration.

The virtual simulation model is integrated with the different ICONET services to interact with the real elements of the physical network. Through these services the simulation models are dynamically configured, the number and position of the nodes are defined, the dynamic route for the containers is calculated, the necessary container groupings are created, and the best mode of transport is specified through the following services.

- *Networking*: Networking defines the interconnected infrastructure of available processing, storage and transporting facilities (transport services, terminals, distribution centres, warehouses) through which the goods will be transported from their origins (manufacturing, distribution and other locations) towards their customer(s) locations.
- *Routing*: Routing is a process that creates a plan that describes the stage by stage detailed visiting and usage of networking nodes from origin to destination.
- *Encapsulation*: How products to be shipped are encapsulated in modular packets that are then consolidated/deconsolidated into containers for transportation via the PI.
- *Shipping*: The shipping service specifies the cargo that is transported, the limitations and restrictions on its transport.

5 USE CASE EXAMPLES

The GPICS methodology and the described simulation models have been applied in various living labs to validate the PI modelling concepts and operating rules on real business scenarios. This article describes two use cases and how the virtual models have been applied.

The simulation of the first use case is focused on the evaluation of the performance of the IoT and the Cloud-based ICT Infrastructure for PoC Integration to foster the intermodal transportation. The goal of the Living Lab is the selection of the best route for containers in the Antwerp - Milano corridor, using intermodal transportation and considering the current position of the container and network status.

In this case, the virtual model is used to compare the impact of different transport options: direct road transport with intermodal transport, several steps are taken, in addition to the loading, road and unloading, there are terminal movements for the container and the rail transportation.

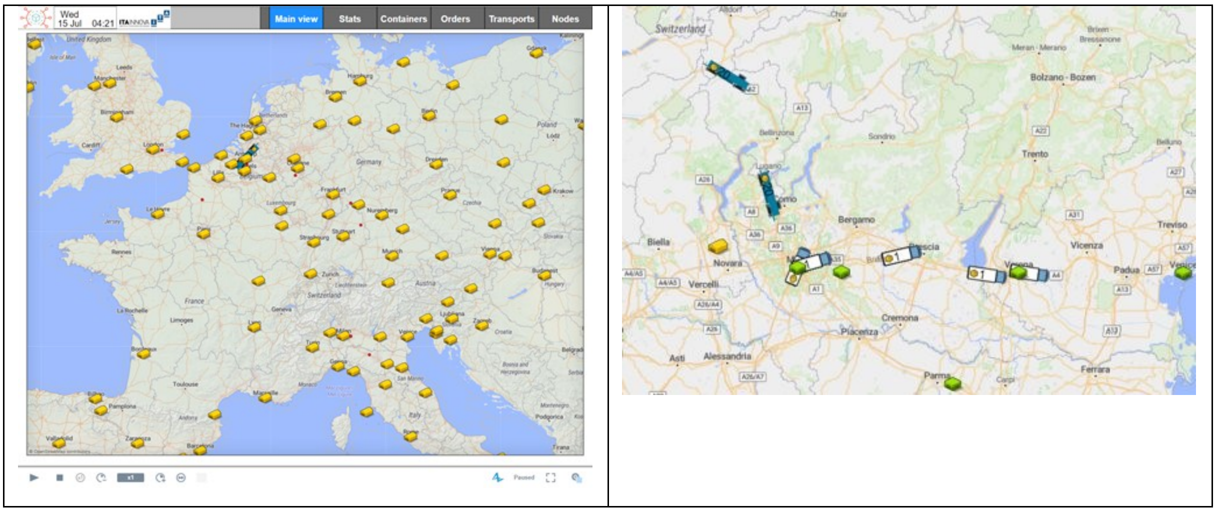

Figure 6: Virtual model representation in a European corridor.

The simulation of the second model is focused on the evaluation of the efficiency of the PI concepts in an eCommerce distribution network. It compares multiple locations (stores and warehouses) to assess best option to fulfil an order in terms of cost, lead time and stock out, considering different distribution networks, from different companies.

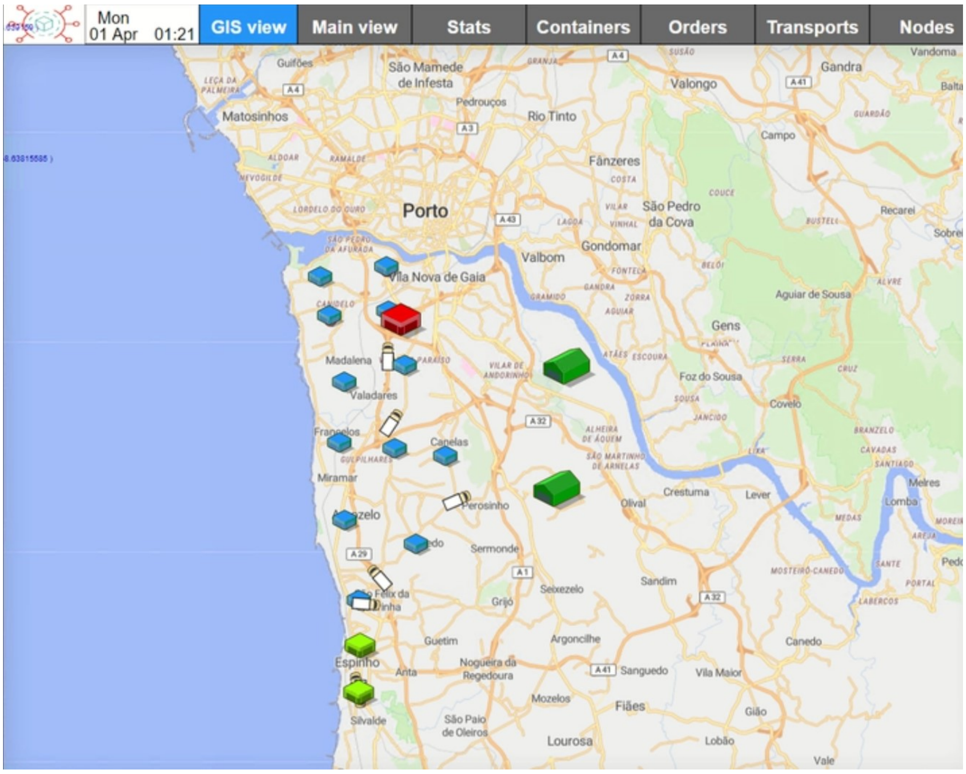

Figure 7: Virtual model representation in a urban environment

The simulation developed is a tool that helps companies to visualize how the movement of products over a PI network can be, including flows from other companies. The simulation helps to confirm the value generated by PI Services developed for the operation of Physical Internet. The virtual model helps with the quantitative assessment of the impact that PI services introduce on companies' supply chains. The visualization and sharing models between different users to evaluate the effect of PI on their own network considering economic, operational and environmental indicators.

6 CONCLUSIONS

This paper presents a methodology to create a digital twin of a transport network under the Physical Internet framework. It is based on the work developed in the ICONET project and will be continued in the PLANET project. The GPICS Framework enables the comprehensive representation of a real PI world system by creating a conceptual model that can be virtual simulated and connected with real PI services to generate accurate digital twins of the transport network. The GPICS Framework enables the comprehensive representation of a real PI world system by creating a conceptual model that can be virtually simulated. Companies need to have a better understanding of how they can take part in PI, how to benefit from PI, how to integrate in the network and what data they need to share. The simulation with virtual model is a powerful tool to visualize how the movement of products over a PI network can be, including the impact of the flows from other companies.

This report is the result of a dedicated effort in a relatively short period of time. The authors are very grateful to amongst others Makis Kouloumbis, Philippos Philippou, John Farren, Kieran Flynn and Kostas Zavitsas. Their input and feedback, direct or indirect, has been of great value to this report. Furthermore, we would like to thank all members of the ICONET consortium for having fruitful discussion and providing a productive atmosphere for applied research.

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