Progress towards Federated Logistics through the Integration of TEN-T into A Global Trade Network

D2.13 Intelligent PI Nodes and PI Network services v1

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Responsible Author	Kostas Zavitsas		
Contributions from	Alfonso Molina (CITYLOGIN), Andrey Tagarev (SIR), Philippos Philippou (EBOS)		

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Table of Contents

1 Executive Summary 6
2 Introduction 7
2.1 Mapping PLANET Outputs 8
2.2 Deliverable Overview and Report Structure 9
3 Operational innovation potential in the PI 10
3.1 Current logistics practices and sources of inefficiency 10
3.2 Principles of PI enabled transport process 11
3.2.1 Integrated data structure 12
3.2.2 PI transport process workflow 13
3.2.3 PI cargo handling functionality 14
3.3 EGTN and its capabilities 14
3.3.1 Data and technology integration 15
3.4 Living Lab challenges and Generic Use Cases 15
3.4.1 Multimodal hinterland integration 16
3.4.2 Last mile collaboration 17
4 Shipping corridor and EU hinterland vertical integration 18
4.1 PI Hub choice model 19
4.1.1 Model structure 20
4.1.2 Data and services integration 20
4.1.3 Integer optimization program 21
4.2 Use Case example 22
4.3 Concluding remarks and future considerations 23
5 Last mile dynamic collaborative delivery 24
5.1 Urban delivery round design 24
5.2 Last mile uncertainty 24
5.3 Visualisation and addressing delays in practice 26
5.3.1 Delivery rounds progress simulation 27
5.4 Dynamic collaborative re-routing 27
5.4.1 Nearby delivery rounds identification 28
5.4.2 Parcel reshuffling 29
5.4.3 Meeting point and delivery round redesign 29
5.5 Collaboration and solution implementation 31
5.6 Industry perspective and way forward 31
6 PI Hub operations management 32
6.1 Manpower scheduling 32
6.2 Cargo-Carrier pairing at PI Nodes 34
7 Conclusions 35
8 References 37

List of Figures

Figure 3.1 Integrated PI data structure [11] 12
Figure 3.2: PI Services Transport Process Initiation Workflow 13
Figure 3.3 Real-time and predictive services data integration 15
Figure 3.4 Living Lab 1 collaboration sequence map [10] 16
Figure 3.5 COSCO East Asia to Mediterranean containership routes 17
Figure 4.1 Global 2017 ship density [12] 18
Figure 4.2 Ship density and Mediterranean port throughput 2019 [13] 18
Figure 4.3 COSCO's aem1 route vessel schedule for 2021-2022 [14] 19
Figure 4.4 Seaborne corridor and port cluster hinterland vertical integration model 20
Figure 4.5 PI Hub Choice model components 21
Figure 4.6 PI Hub Choice model application case study results 23
Figure 5.1 Preferred parcel delivery location [21] 25
Figure 5.2: Example of delivery rounds monitoring dashboard 26
Figure 5.3: Urban delivery rounds delay simulation 27
Figure 5.4: Example of alert of delay by the simulation 27
Figure 5.5: Nearby and available help round identification algorithm 28
Figure 5.6: Pending delivery locations for the later rounds and the five candidate help rounds 28
Figure 5.7: Area extension served by the help round after parcel reshuffling 29
Figure 5.8: Vehicle rounds redesign with meeting point using VRP with time windows 30
Figure 6.1 Inbound shipments flow diagram [26] 33
Figure 6.2 Outbound shipments flow diagram [26] 33

List of Tables

Table 2.1 Adherence to PLANET's GA Deliverable & Tasks Descriptions 8
Table 4.1 Real time and predictive data integration for PI Hub Choice model 20

Glossary of terms and abbreviations used

Abbreviation / Term	Description
AIS	Automatic Identification System
API	Application Programming Interface
DSS	Decision Support System
ETA	Estimated Time of Arrival
EGTN	EU Global Trade Logistics Network
NUTS	Nomenclature of territorial units for statistics
OLI	Open Logistics Interconnection
PI	Physical Internet
PPP	PLANET Position Paper
TEN-T	Trans-European Transport Network
VRP	Vehicle Routing Problem

1 Executive Summary

This deliverable focuses on developing algorithms, that utilise the advantages of the PI, and enable smart decision making at both network and node levels. The deliverable describes models and methods for integrating automated operations for transport and logistics planning and collaboration, in alignment with the Physical Internet principles. After introducing in brief the inefficiencies of current logistics practices, the technological features of the Physical Internet and the benefits it provides are discussed. The report builds on Physical Internet integrated data structure, network representation and workflow protocols developed in SELIS and ICONET EU research projects. Drawing inspiration from PLANETs Living Labs, three generic contexts are defined for DSS tools development capturing the:

- Vertical integration of global corridor services to PI Hub clusters and their hinterland
- PI Hubs and warehouse resource management and as-a-service functionality
- Last mile delivery dynamic collaboration

The vertical integration of seaborne services to port clusters and their hinterland, represents the integration of global trade corridors to TEN-T operations. For enabling intelligent decision making in this context, a model structure that incorporates, data requirements informed through connectivity infrastructures and predictive services, as well as an optimization based DSS are proposed. The PI Hub Choice model optimizes sea and land side collaboration, through the identification of efficient options for routing containers to their destination considering hinterland services. The tool integrates with AIS data provided by T2.2 and predictive services provided by T2.3 to analyse the routing options available for containers to reach their destination optimally. A Case Study is presented focusing on COSCO operations in Spain, and various port congestion scenarios are considered, indicating that a robust routing approach is beneficial both to liner shipping service operators and hinterland operators, while port congestion is alleviated.

When considering collaboration for last mile delivery logistics, the high uncertainty of the urban environment that arises from road traffic, limited parking availability, and handover uncertainty, are found to cause significant delays and inefficiencies to last mile operators and cities. To address this challenge, delivery status updates are circulated and stored in the cloud, from one or more operators, that are then analysed to identify collaboration options between vans or operators. The tool builds on a stochastic traffic simulation, and:

- identifies suitable help candidates from the vans operating nearby
- once the optimal help van is identified, reshuffles the parcels to assist the later running van,
- identifies a meeting point for exchanging the parcels, and
- reroutes both vans through the meeting point, and all the delivery locations.

The algorithm is applied in a case study, in central Madrid, Spain utilizing a dataset provided by CItylogin. Further real-time traffic data and delay prediction services integration is anticipated for a real-world application and model calibration.

In terms of the warehouse cargo and resources management context, operations are analysed and two value adding models are described. The models, after integration with predicted inflow/ outflow data for each warehouse enable the better planning of warehouse human and infrastructure resources. They also contribute towards enabling the as-a-service operation of warehouses as Hubs in a PI enabled context.The intelligent planning tools proposed for all three contexts, utilize T2.2 connectivity infrastructures, and T2.3 predictive services to populate the integrated data structure and undertake efficient decisions. The outputs of the planning and Decision Support tools are illustrated quantitatively. In the case of last mile logistics collaboration, the benefits extend beyond the operator specific business benefits to city congestion and air quality improvements. Furthermore, the roadmap for the further development of the tools is discussed, that includes the integration with real-data sets where available and the testing of algorithm performance in real-world conditions.

2 Introduction

The Physical Internet (PI) promises to revolutionise how transport and logistics is practiced, and to improve on critical variables such as cost, utilisation rates, and emissions through improved multi-modal integration and open accessibility to static and mobile infrastructures.

The Physical Internet (PI) is a hyper connected transport and logistics (T&L) system, whose operation follows the principles, of open and standardised interfaces, monitoring and data sharing, smart decision making and modularized encapsulation. By adopting these principles, it is possible to achieve higher efficiency and utilisation of cargo transport, including intermodal shipments that utilise greener transport modes. Despite progress in many technological and infrastructural elements of the T&L system, the PI is still in development, and it is expected to become functional over the following few decades. The ALICE roadmap, points to 2040 for PI full functionality to be operational [1].

This deliverable focuses on the integration of smart decision making in the PI in various T&L functionality contexts. Despite the power of computers ever increasing and multiple established analytic models available, there is relatively little applicability in supply chain operations. This limitation is often associated to the lack of benefit evidence, the unwillingness of operations managers to go through the hassle of changing processes that work, despite not utilizing smart decision making, as well as the sheer lack of monitoring infrastructure and equipment to enable smart decision making. The use of analytics tends to be limited to basic routing decision making, and typically not in an automated manner either, but rather as an intermediate step for informing a freight forwarder who oversees a shipment. To expand analytics and smart decision-making utilization in the PI and T&L contexts, adaptation of analytics models in context specific applications, to address real-world needs and add value to existing processes is essential.

The need for smart decision making arises due to the several stages in the development of a product, starting from one or more raw materials, going through several processing and assembly stages, before it finally reaches a retail store, and is purchased by the final customer. As specialisation increases with agglomeration economy, supply chains tend to get longer, involving more stages and stakeholders. At the same time, the products themselves become increasingly varied and complex following the ever-increasing societal needs. DTLF [2] reports on the evolving customer requirements impact on transport and logistics. For example, requirements of individuals ordering products on websites (eCommerce), differ from those of suppliers producing their products in Asia and shipping them to retail stores in Europe, or manufacturers ordering parts from first tier suppliers and shipping their finished products to their customers. In order to cope with and support this diversity, Logistics Service Providers offer a variety of services, either specialising and/or combining various activities. For instance, same-day delivery services for parcels are offered via so-called hub-spoke networks, container transport services are offered in high-volume multimodal networks, and Vendor Managed Inventory (VMI) services are offered to support on-time delivery of parts to consignees. This variety in demand and processes emphasizes the need for a dynamic and robust supply chain that can flexibly adjust to gradual or abrupt changes.

Therefore, every infrastructure operator or service provider in the T&L system, requires to manage its operations efficiently, through an integration of automation and smart decision making. Utilising data in the public domain and through the development of communal data sharing platforms it becomes increasingly possible to handle and transport goods more efficiently. Considering the variety of T&L operations, stakeholders, goods, and services provided, smart decision making requires to be sufficiently detailed but at the same time have a robust offering. The core constraints, objectives and business processes involved in planning, coordinating, and executing the transport of goods from origin to destination remain largely unaltered in a PI approach. What changes under the PI is the standardisation and interoperability of transport, logistics systems and processes. For these features of the PI to materialise, several information and decision support systems as well as standardisation and integration services require to be introduced. In this report the logistics processes focusing on smart decision making that promotes the PI approach are presented.

The proposed smart decision-making tools are based on Living Lab inspired challenges and are adjusted to align with the principles of the Physical Internet. With the assistance of PLANET partners, the decision tools are classified into three tiers in terms of their application context to:

- connecting global corridors to PI Hubs,
- PI Hubs (warehouse & terminals) operations management, and
- urban collaborative distribution.

The three smart decision use cases align with PLANETs Living Lab use cases and explore different contexts of logistics and supply chains. By designing an analytic offering that aligns with the PI principles of openness, monitoring and smart decision making for various contexts, a more complete picture of the DSS requirements is drawn as well. In the development of the solutions presented in this report, current practices have been considered, as a baseline and guideline, together with legacy and connected systems operators currently in use.

The objectives of Deliverable D2.13 is to explore the development of a Decision Support Tool that enables Transport and Logistics stakeholders to assess the impact of new developments and infrastructure components. Such a tool offers the possibility to be used for both strategic and operational decision making.

2.1 Mapping PLANET Outputs

Purpose of this section is to map PLANET's Grant Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

Table 2.1 Adherence to PLANET's GA Deliverable & Tasks Descriptions

PLANET GA Component Title	PLANET GA Component Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D2.13 Intelligent PI Nodes and PI Network services v1	Intelligent PI Nodes and PI Network services v1 using D2.3 – D2.10 as well as the DSS tools. Design and initial prototype of PI Nodes and Network services that will perform forecasting and planning, automated operations, real time reporting of operations and status of the nodes and network.	Sections 3, 4 and 5	The deliverable outlines various smart decision-making tools based on LL inspired challenges and adjusted to fit the PI principles. Applications involve global corridor decision making, urban decision making, and warehouse/ terminal operations decision making. Integration with data collection and processing tasks of WP2 is discussed for each tool individually.
TASKS			
T2.4 Group multi criteria DSS for transport and PI Networks	This task develops: 1. Multi-user and multi-criteria models that will allow stakeholders to analyse and assess the effect of new T&L developments (e.g., new trans-continental freight routes) that cross or neighbour their regions. 2. Intelligent PI Nodes and PI	Sections 3, 4 and 5	Tools for intelligent decisions at PI nodes and for the PI network are discussed, considering multiple stakeholders and improving the efficiency of the transport system through collaboration activities for global corridors, hubs and the last mile.

	Network services to optimise the efficiency of the whole transport system whilst reducing emissions		
ST2.4.2 Intelligent PI Nodes and PI Network services:	ST2.4.2 Intelligent PI Nodes and PI Network services: performing intelligent forecasting and planning, intelligent and automated operations, and real time reporting of operations and the status of the nodes, and the network utilising outputs from T2.2 and T2.3 as well as the DSS tools.	Sections 4.1.2 and 5.5	Intelligent decision models developed, are structured in an integrated way to utilize data collected in T2.2 and services developed in T2.3. The models foster collaboration and efficiency, considering the capabilities and constraints of T&L infrastructures and technologies.

2.2 Deliverable Overview and Report Structure

The deliverable describes models and methods for integrating automated operations for transport and logistics planning and collaboration, in alignment with the Physical Internet principles. Section 3 describes the basic principles for the transport and logistics process, identifying sources of inefficiency that the PI can address. The Section builds on findings of earlier PI related EU research projects SELIS and ICONET, for utilizing integrated data structures and versatile network representation. The EGTN capabilities and requirements are then discussed and specific use cases that arise from the PLANET living labs are presented, covering three distinct contexts:

- Vertical integration of seaborne services to port clusters and their hinterland,
- Last mile delivery collaboration,
- Warehouse and PI hub resources management.

The vertical integration of seaborne services to port clusters and their hinterland is discussed in Chapter 4, where the PI Hub Choice model is proposed for optimizing the sea and land side collaboration, to identify more efficient options for routing containers to their destination. A simplistic case study is provided to illustrate the functionality of the model. In Chapter 5 the uncertainty arising in last mile logistics is discussed, and an algorithm is proposed utilising real-time information for addressing delays and enhancing collaboration. The functionality of the algorithm is illustrated utilizing real last mile delivery data. In Chapter 6, intelligent PI node decision models are proposed for warehouse cargo processing and human resources management, utilizing historical performance data. The report findings and conclusions are summarized in Chapter 7, where future work is also discussed.

3 Operational innovation potential in the PI

The Physical Internet (PI) envisages to become a global system of freight transport across heterogenous networks and supply chains exploiting standard methods and protocols. It promises to revolutionise how transport and logistics is practiced, and to improve on critical variables such as cost, utilisation rates, and emissions through improved multi-modal integration and open accessibility to static and mobile infrastructure. Critically important for the implementation of the PI vision is the standardisation and interoperability of transport, logistics systems and processes [3].

After a brief assessment of current T&L practices and their shortcomings, the section examines PI functionality and the elements for developing an integrated workflow between the PI services and intelligent Decision Support Systems, as well as its application into various contexts.

3.1 Current logistics practices and sources of inefficiency

In principle, goods and products are transported from one location to another where they become more useful and valuable. There are several stages in the development of a product in a typical supply chain, starting from one or more raw materials, going through several processing and assembly stages, before it finally reaches a retail store, and is purchased by the final customer. T&L involves the coordinating effort of several organisations, each of them focusing on a different part of the supply chain process. A supply chain includes not only the manufacturer and the suppliers, but also transporters, warehouses, retailers, and customers themselves. Although this may include organisations that have only an indirect role such as for example banks and insurance companies, such organisations do not directly influence operational efficiency in the transport and logistics process and are therefore not considered further. Direct stakeholders in the transport and logistics processes can be due to them owning (initially or ultimately- i.e., as sellers and buyers), the goods that are transported, the equipment and other resources by which the goods will be processed and transported, or because they are integrators of the different processes and activities involved.

The functioning of a supply chain involves three key flows between the stakeholders – information, products, and funds. The goal in designing and managing a supply chain is to structure the three flows in a way that meets customer needs in a cost-effective manner. Information flow is a crucial element for achieving such efficiency, as it allows for the better planning of resources in earlier stages of the supply chain. Currently, limitations to supply chain visibility (SCV) due to the lack of information sharing, are shown to be a cause for operational inefficiencies [4].

Operational information is typically located in organizational silos, and is analysed in a post-operational setting, to inform performance metrics and educate future collaboration and contractual agreements. Although this is in contrast to the PI open accessibility paradigm, multiple transitional stages are anticipated for bridging that gap [3].

Furthermore, supply chain stakeholders' perception of performance varies with the stakeholder role, operational context (e.g., urban, or long-haul), and function in the supply chain (e.g., warehouse or transport). Therefore, the performance metrics each stakeholder utilises to measure operational efficiency do not always match, and in cases are contradicting. Through interactive discussions with stakeholders, Macharis et al. [5] establish criteria and their associated weights per stakeholder. Due to this variability, collected information and decision processes vary greatly in each T&L stakeholder setting, hindering the motivation for standardization and integration of processes that PI promotes.

Performance of freight transportation is one of the crucial elements for the sustainability of supply chains and logistics. Despite progress achieved, inefficiencies are evident by the high frequency of empty truck trips and relatively low utilisation of multimodal resources. According to Eurostat [6], one in five road freight journeys in

Europe were performed by empty vehicles. Inland freight transport modal split across Europe indicates that 76.3% of freight movements (based on tonne-kilometres) were undertaken by road in 2019, while more emission efficient modes such as rail and inland waterways only carried 17.6% and 6.1% respectively. Despite ambitious emission reduction targets, the inland road freight ratio increased (up from 75.6% in 2018). Moreover, freight transportation (in developed countries) is responsible for nearly 15% of greenhouse gas emissions. Improved transportation efficiency is therefore an important objective for environmental and financial purposes.

3.2 Principles of PI enabled transport process

To integrate current Transport & Logistics practices into the PI concept, a classification based on the Open Logistics Interconnection (OLI) layers has been proposed [7,8], with the four core layers being:

- Encapsulation: Standardises the packaging process of cargo and goods that are consolidated/deconsolidated into π-containers for transportation via the PI. It is also responsible for the consolidation/ deconsolidation of π-containers into π-movers.
- Shipping: Specifies what must be transported as well as the transportation process conditions and constraints. It is responsible to make appropriate adjustments to the shipping instructions to ensure compliance.
- 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 and links from origin to destination.

The above PI layers attempt to integrate the following four fundamental principles in the Transport and Logistics (T&L) infrastructure operation, deviating from current practices. These are:

- The ability to effectively handle **modular packaging** such as π-containers. Standardised containers have revolutionised the logistics industry, however their size range offering is limited yielding operational inefficiencies. Increasing the modularity of containers, as well as well as the number of transhipments due to the compartmentalised routing, are addressed through the development of Operations Research (OR) based decision support tools for packaging, grouping, and loading.
- The increasing **digitisation** of T&L infrastructure creates an information offering that remains largely unutilised. IoT sensors and Track and Trace capabilities are integrated into the PI workflow, enabling new functionality for cargo prioritisation, re-routing, identification, and handling of damaged goods.
- The integration of robust **decision support tools** (DSS) that enable efficient cargo and fleet routing and distribution, under uncertain and adjustable terminal, warehouse, and network conditions. Building on existing protocols [9], a toolbox comprising of established and novel Operations Research and Machine Learning (ML) models is developed, adapted for the PI context, and applied in a modular and robust way.
- The **open accessibility** to transport, terminal, and warehousing services through the “as-a-Service” paradigm improves operational efficiency. To incorporate it in the PI layers standardised collaboration protocols for the identification and formation of mutually beneficial agreements are considered.

To integrate the aforementioned functionality and rip the benefits arising from the core PI principles, a substantial change to the resources and decision-making process is required. The Physical Internet (PI) addresses logistics integration and collaboration issues and paves the way forward to deploying efficient supply chains. In a scenario in which all Physical Internet potential technological, standardization and infrastructural elements are enabled, a 300% increase in transport demand could be achieved with only 50% increase in assets [10].

3.2.1 Integrated data structure

Network information describe static infrastructure characteristics such as the length and throughput of a link, the modes that can accommodate the function of carrying cargo (e.g., truck, rail), or even more detailed information such as classification into motorway, or number of lanes. A similar concept is applied to the description of nodes, with intermodal and processing capabilities being captured. A node may also represent a warehouse that has specific capacity for storage and docking capability. Static information enables the optimisation of routing decisions; however, such decision process is prone to bias due to dynamic parameters influencing the network, such as road traffic condition, processing/handling times and costs at nodes.

Any analytic process that is based solely on static network discovery information, will inevitably yield significant inefficiencies for the operation of the PI. For example, an incapacitated link due to roadwork or traffic, if not dynamically updated, will be considered as a feasible route for cargo routing, and eventually cause delays. Similarly, for nodes, a broken-down refrigeration unit in a warehouse, if not considered by the PI, will direct cargo to a location that cannot be serviced and eventually cause product loss and operational inefficiency. It is therefore critical to accommodate network node and link operational status information as illustrated in Figure 3.1.

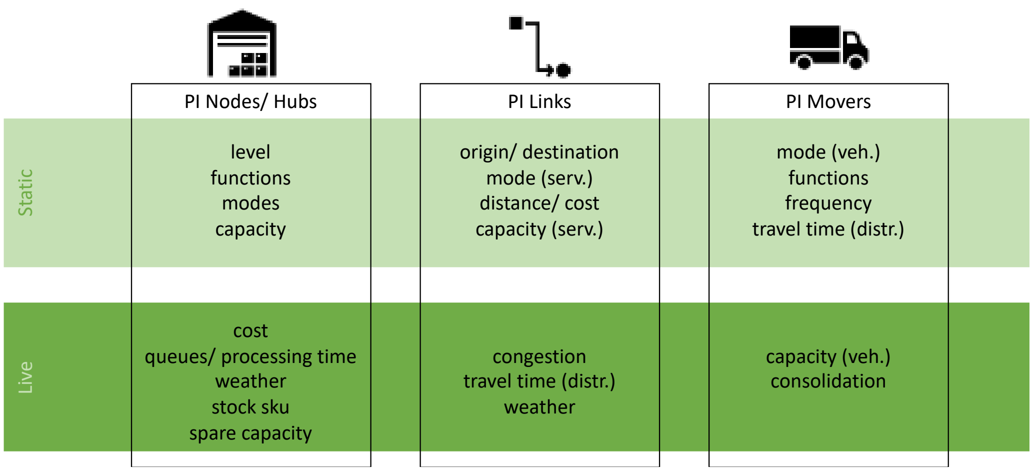

Figure 3.1 Integrated PI data structure [11]

In the context of transport links and services, an additional data layer focuses on operational services and their availability. The aim of this data layer is to account for the fact that roads and warehouses do not directly handle cargo transport, but rather indirectly. Road, air, river/sea, or rail services that operate on the T&L infrastructure are responsible for undertaking the task of physically moving cargo from one location to another. With that in mind, it is essential that network representation includes service schedules or tracks vehicles, that operate between specific locations. Such information is useful, as more enhanced freight routing and scheduling algorithms become applicable. A final layer of complexity is anticipated that accounts for live information on the capacity of en-route services and warehouses. Only at that level of detail, an optimal and reliable allocation of freight to services to routes is achieved. The first two columns of Figure 3.1 capture the standardised static and live information required to inform decision making, while the third one investigates the data collected on the services of different modes that operate in the network.

The integrated data structure allows for a detailed network representation that captures transhipment capabilities at nodes and complex PI Hubs. Transhipment operations are captured through dedicated links that connect every arrival mode (source nodes), to every departure mode (sink nodes) within a PI Hub, and each individual terminal, enabling the assignment of weights to internal PI Hub operations. This representation allows for transhipments to be associated to:

- Distances that require to be covered within the PI Hub. This weight is more relevant to large PI hubs such as containership ports, where transhipment legs are of considerable distance.
- Cost that represents average or specific cargo handling expenses.
- Travel time that may incorporate average handling time and queues
- Capacity that represents the number of such transhipments PI Hub infrastructure can accommodate.

A similar network representation can be used for capturing additional PI Hub functions that extend beyond the direct T&L functionality, such as customs and infrastructure bottlenecks. A detailed representation of a PI Hub services contributes to accurately capturing the operational limitations that often drive stakeholder decisions.

3.2.2 PI transport process workflow

Due to the increasing transhipment needs in the PI context, enhanced emphasis is paid both for process coordination between unknown to each other parties, as well as on standardisation of the exchanged information. With a standardised data structure for representing the network and contractual operations, it is possible for the PI to make informed decisions on the utilization of infrastructure, assets, and decentralized capability. This also enables the development of an integrated workflow of the transport process as illustrated in Figure 3.2. The proposed PI transport workflow aligns and builds on the OLI layers functionality [8] and the process proposed by earlier PI studies such as Sarraj et al. [9].

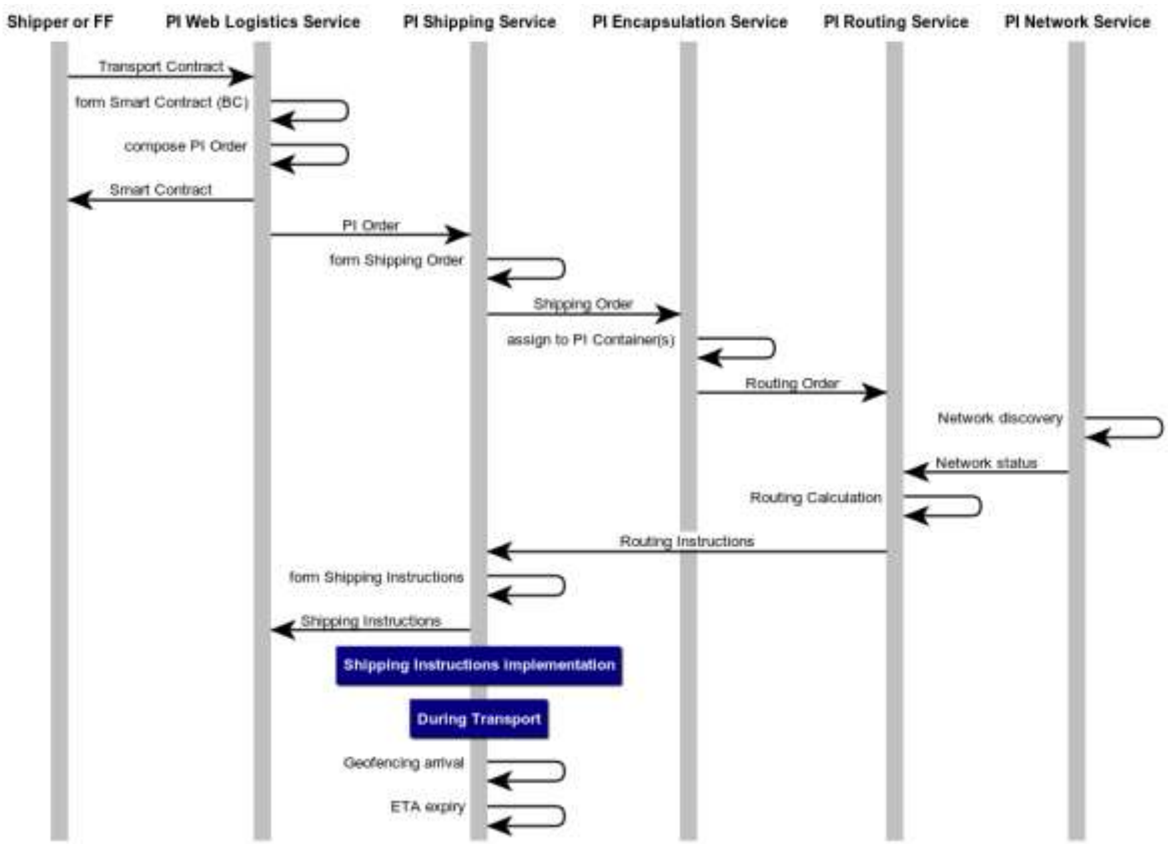

Figure 3.2: PI Services Transport Process Initiation Workflow

The Shipping Service initiates an order, capturing its core contractual characteristics. At origin, the Encapsulation Service is responsible for fitting the cargo into optimal π-boxes that start to be tracked by the PI. To initiate the transport process the Shipping Service communicates the shipment information to the Routing Service. The Routing Service collects the relevant network status from the Networking Service, and identifies an optimal shipment route considering, travel time, consolidation, emissions and cost as per the shipment instructions. It returns the Shipping Instructions to the Shipping Service, which then requests from the Encapsulation Service to fit the π-containers to the allocated π-mover(s), and finally initiates the transport process for implementation.

The progress of each shipment is tracked through frequent requests initiated by the Shipping Service. The triggers for such requests can originate from geofencing that indicates arrival at the next node, or the expiry of an ETA. In the first case the Shipping Service requests updated Shipping Instructions from the Routing and Networking Services in cases of changes in the network status, and then calls the Encapsulation Service to fit the π-containers to the allocated π-mover of the following leg. When that has been achieved, it initiates the transport process of the next leg. The process is repeated until the destination is reached. In the case of the expiry of an ETA, the Shipping Service, attempts to locate the π-container, and if needed propose better Shipping Instructions through the Routing and Networking Services.

3.2.3 PI cargo handling functionality

The proposed workflow structure allows for the integration of multiple common and novel transport process features. Some functionalities explored by the ICONET project, include:

- The expedition of a π-container if it is running behind schedule. This is achieved, by increasing the weight associated to travel time when passing the instructions to the Routing Service.
- The prioritization of π-containers with higher travel time weight (express) at PI hubs. This is achieved by considering FIFO for regular shipments, but also considering a priority queue for express ones.
- The re-routing due to updated network conditions when traffic or delays are anticipated in the Shipping Instructions route.
- The re-routing of damaged goods. The IoT connectivity of π-containers enables the identification of cargo that have been exposed to extreme conditions and require disposal. This can be handled on the go, rather than at the destination.

Such PI functions rely on the basic routing and encapsulation capabilities of the PI, however for more efficient operation, integration with optimization and intelligent Decision Support Systems is required.

3.3 EGTN and its capabilities

To advance the European Commission’s strategy to account for Smart, Green and Integrated Transport and Logistics by efficiently interconnecting infrastructure (TEN-T, Rail-Freight Corridors) with geopolitical developments (e.g. future New Silk Road and emerging trade routes), as well as optimizing the use of current & emerging transport modes and technological solutions, while ensuring equitable inclusivity of all participants, increasing the prosperity of nations, preserving the environment, and enhancing citizens quality of life. The realization of this vision is what PLANET calls the Integrated Green EU-Global T&L Network (EGTN). The main attributes of the EGTN include:

- Geo-economics aware: A European T&L network that is aware of the geo-economics aspects driving the development of new trade routes to/from Europe and their impact on the TEN-T;
- Innovation: A European T&L network that takes advantage of the potential of innovative logistics concepts (e.g., PI) and enabling technological innovations (Industry 4.0, blockchain, hyperloop, IoT, etc.) in its operation
- Impact: A T&L network that is more economically, environmentally, and socially sustainable than the existing TEN-T
- Integrated: An EU T&L network integrated with the global network both in terms of hard & soft infrastructure
- Inclusive: Accessible to disadvantaged regions; supporting the development of workforce skills & knowledge

For achieving the EGTN vision, both infrastructural and technological alternations (such as PI functionality) require to be considered. Therefore, the analytic capability for developing and managing the EGTN requires to have both predictive and decision-making features, utilizing real-time data through connectivity with existing databases and IoT infrastructure.

3.3.1 Data and technology integration

A critical dependency for developing intelligent PI functionality lies in acquiring timely and accurate data complemented by existing forecasting and optimization functionality. Performance predictions are essential for all datapoints of the integrated data structure illustrated in Figure 3.1. However, when a real-time datapoint is not available, then decision making requires an alternative that is based on prediction capability.

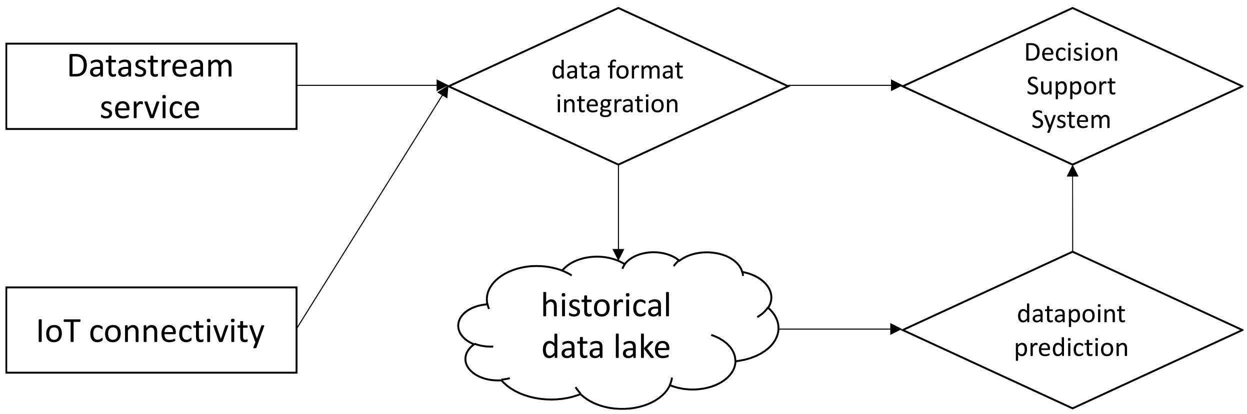

Figure 3.3 Real-time and predictive services data integration

Figure 3.3 captures the core data requirements and processing for the utilization of the decision support tools. Data are collected either via establishing connections to data-stream services, or through connected IoT devices. Those datapoints are assigned a meta-tag in terms of the integrated data structure, as well as a timestamp, that reflects the time of capture.

From the DSS perspective, data can either be real-time or reflect real-time conditions. For example, traffic congestion data might not be available in real-time, but a reliable prediction can be derived from using historical data. The same applies for all dynamic information in the integrated dataset, including utilization rates, consolidation, ETAs, travel times, etc. To address, the need for complete data, a historical data lake is populated for each network component, and upon request a datapoint prediction tool is utilized to provide a predicted datapoint to the DSS.

3.4 Living Lab challenges and Generic Use Cases

In the context of the PLANET project and its Living Labs, multiple alternative technologies, infrastructures, and policies are considered. The aim of all alternatives is to drive operational efficiency in a Physical Internet enabled supply chain. The planning impact horizon of the decisions' considered in PLANET project living labs ranges from operational to strategic levels. The three PLANET Living Labs investigate three unique aspects of technological and infrastructural development. Focusing on the connectivity of the TEN-T network to global trade corridors:

- LL1 examines how new technologies (IoT, AI and blockchain) and concepts (such as Physical Internet) can improve processes, operations and efficiency along the door-to-door transport chains linking the Maritime Silk Road with EU internal corridors.
- LL2 examines how synchro-modal dynamic management of TEN-T & intercontinental flows promoting rail transport and utilizing the Port of Rotterdam (PoR) as the principal smart EGTN Node coordinating

the rail focused transport chains linking China through Rotterdam to/from USA, and Rhine-Alpine Corridor destinations, and

- LL3 examines streamlining logistic processes in flows from China to Europe along the Silk Road by implementing IoT technologies (based on the EPCIS platform) and GS1 standards that facilitate transmission of data between the partners involved in the e-commerce operations.

All PLANET Living Labs investigate the integration of TEN-T operations as hinterland to global corridors as illustrated in Figure 3.4 for LL1. As part of this exercise, three types of use cases are defined. The first concerns the sea-side collaboration, between ocean liner operators, and port operators. In a more generic sense, this represents the operators of a global corridor, irrespective of the mode. The second concerns long-haul hinterland connections, between port and terminal operators, LSPs and warehouse operators. The third concern urban distribution and the collaboration between regional warehouse operators and last mile logistics companies.

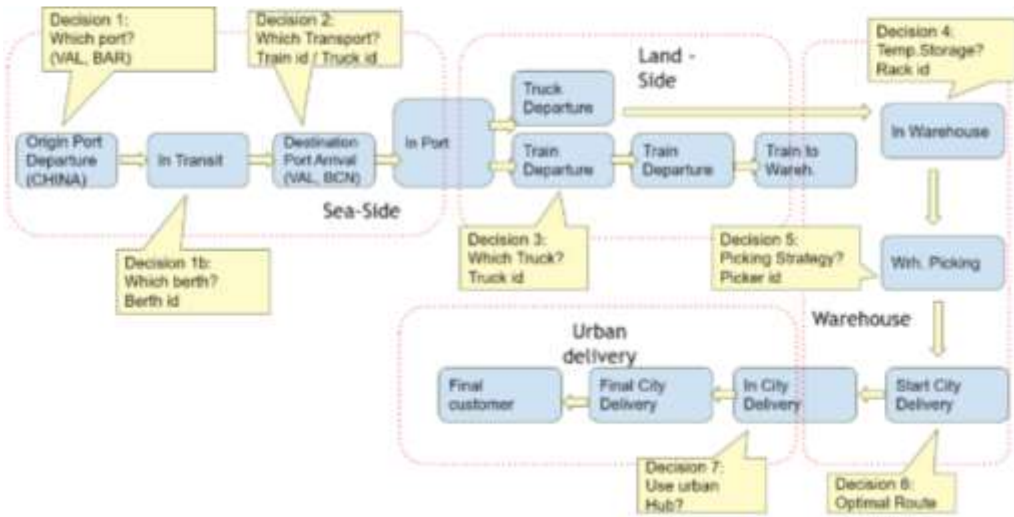

Figure 3.4 Living Lab 1 collaboration sequence map [10]

The generic use cases focus on:

1. Smart decisions at PI hubs aiming to utilise real-time synchro-modal tools to optimise container routes based on capacity, cost, and level of service.
2. Application of intelligent algorithms for assessing route changes (both arrival port, and inland transport)
3. Extension of analysis to last mile logistics considerations
4. Blockchain technology at Valencia port and hinterland
5. Worldwide tracking of containers (IoT)

This report focuses or builds on services related to the first three elements.

3.4.1 Multimodal hinterland integration

In a PI enabled transport network, capable of dynamically redistributing flows, subsequent services operators have more flexibility in optimizing their operations. Queueing and uncertainty in multimodal terminals is a significant disadvantage for freight transportation. Avoiding or bypassing long queues, when dynamic rerouting is possible, offer operators an ideal tool for addressing delays due to congestion.

The complex interface between sea operators, ports, and hinterland LSPs, is currently difficult to manage dynamically. However, a DSS enabled network, can potentially identify commonly beneficial rerouting options, and automatically implement them.

One of the examples analysed in LL1 is that of two of COSCOs shipping lines, namely aem1 and aem2 illustrated in Figure 3.5. Both lines connect China's south-eastern territory to Europe, calling at multiple Mediterranean ports including Piraeus, Valencia, Barcelona, Genoa, etc. With port congestion being a significant cost for operators, there is scope for dynamically making rerouting choices for the vessels to avoid calling some of the ports. This immediately, transfers the responsibility to transport the cargoes to their final destinations from the containerships to the hinterland transport infrastructure and services.

Figure 3.5 COSCO East Asia to Mediterranean containership routes

Once alternative routes are identified, a DSS tool requires to be integrated to facilitate a fair and implementable decision for forwarding cargoes to their destination. Such solution is mutually beneficial, for both seaside and land-side operators.

3.4.2 Last mile collaboration

Another major challenge is that of last mile uncertainty. Last mile operators, frequently need to dynamically redesign urban delivery rounds, to alleviate delivery delays. This challenge is highly relevant to the concept of the Physical Internet and EGTN as it utilises the benefits associated to dynamic tracking of parcel deliveries and vehicle fleet. The problem focuses on decision-making at an operational level. Delivery rounds are typically fully designed prior to initiating their implementation every day. The design of delivery rounds considers, the fleet (i.e., the number and capacity of delivery vehicles available) and local accessibility constraints such as Low Emissions Zones (LEZs) or Zero Emissions Zones. LEZs that are increasingly popular in European cities as they are one of the most effective measures towns and cities can take to improve air pollution, as they reduce emissions of fine particles, nitrogen dioxide and (indirectly) ozone. In practice this means that vehicles with higher emissions cannot enter the area, complicating last mile delivery logistics.

To expedite a late delivery round completion time, operators sent assistance vehicles, that share the delivery load. This involves undertaking the following actions:

- Identify which vans can be sent for assistance without inflicting severe delays in their delivery obligations,
- Identify how many and which parcels require to be transferred from the late vehicle to the helping vehicle,
- Identify a common meeting point, and
- Dynamically redesign the delivery round for both vehicles featuring the common meeting point.

A critical factor for effectively addressing delivery delays, is the availability of helping vans, which is typically limited as operators aim to utilise all their resources in the planning phase. Offering fair and balanced criteria for determining helping rounds contributes to promoting collaboration between otherwise competing operators. However, operators tend to seek solutions internally, rather than handing over their deliveries to other operators. A collaborative DSS is therefore required to offer fair and balanced alternatives for collaboration to last mile operators.

4 Shipping corridor and EU hinterland vertical integration

Seaborne trade handles nearly 80% of the international merchandise trade, and therefore ports are essential network components for facilitating it. Seaborne trade uses either liner routes or ad-hoc charters, that when aggregated form seaborne corridors as illustrated in Figure 4.1 for global and in Figure 4.2 for Mediterranean vessel and port traffic. For vessels that follow a schedule, timetables are typically designed on annual basis, well ahead of voyage, with little or no awareness of the weather and congestion conditions the vessel will face. To alleviate the uncertainty that arises in seaborne trade, major containership operators, expand their operation to port terminals and the hinterland, seeking better integration of terminal and transport services.

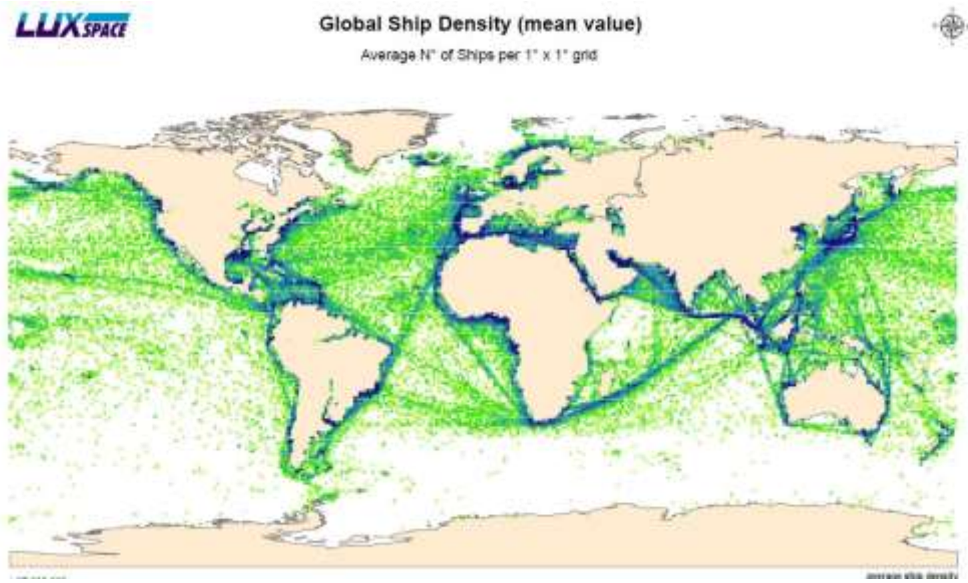

Figure 4.1 Global 2017 ship density [12]

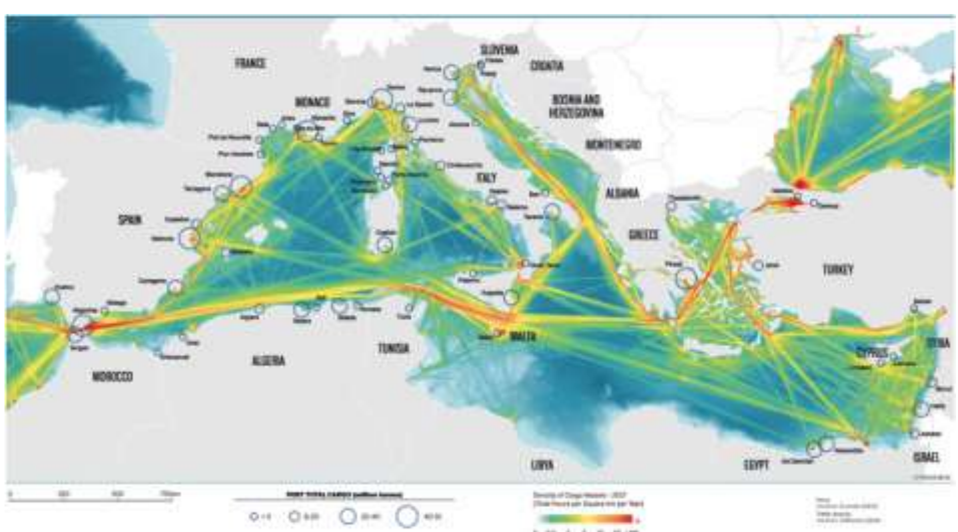

Figure 4.2 Ship density and Mediterranean port throughput 2019 [13]

UNCTAD [24] reports that ports are showing more interest in strengthening connections with the hinterland to get closer to the shippers and tap the cargo volumes that could be committed. Providing intermodal access, warehousing and other logistics services illustrates the type of actions that may help ports capture local market volumes.

From 2010–2020, container shipping companies sought to expand their services offer to include shipping, terminal operations, and inland logistics to reduce exposure to volatile freight rates and generate alternative revenue streams providing end-to-end logistic solutions. Several of the largest terminal operator companies, such as PM Terminals/Maersk; Terminal Investment Limited/Mediterranean Shipping Company; COSCO; etc., are part of or are closely linked to shipping lines. Similarly, terminal operators are engaging in vertical integration by taking greater control of inland logistics and aiming to provide integrated service offerings and generate more value [24].

Worker shortages at ports and port closures resulting from the pandemic in 2020, affected the ability of ports and terminal operators to complete vessel-related operations in a timely fashion and to provide key services associated with the port–hinterland interface. This situation led to interrupted cargo movements in and out of ports, inducing port congestion, additional costs for shippers and container shortages [24].

The aim of this use case is to establish intelligent decision making through technological innovation and data integration, to enable making network status aware decisions for vessel and cargo routing. Such a capability enhances the integration of global seaborne corridors to multimodal terminals and hinterland transport infrastructure.

4.1 PI Hub choice model

Major containership operators develop detailed vessel schedules for each route served well in advance of the voyage time. Figure 4.3 illustrates vessel departures for COSCO's Asia to Europe Mediterranean (aem1) route, that stretch to March 2022. Those schedules do not account for weather and congestion conditions at ports, canals, and other bottlenecks of the seaborn network, which can cause delays in the vessel voyage. Delays range from a few hours to several days, and are of cumulative nature, having a domino effect to the rest of the schedule. Operators can speed up vessels, or prioritize them at the ports they operate, however, with increasing competition and vertical integration, there is an increasing risk of facing queues for entering and unloading/loading at ports. As illustrated in Figure 4.3 (shown with yellow colour), some ports along the aem1 route are omitted, indicating locations of the network being unprofitable to call, either due to port congestion or the availability of alternatives, such as the EUROFOS port near Marseille, France (column is indicated by an arrow). Improved vertical integration between shipping corridors, port terminals and hinterland transport services, is anticipated to enable the identification of alternative routing options, offering increased flexibility to operators, increasing profitability, and reducing delay uncertainty.

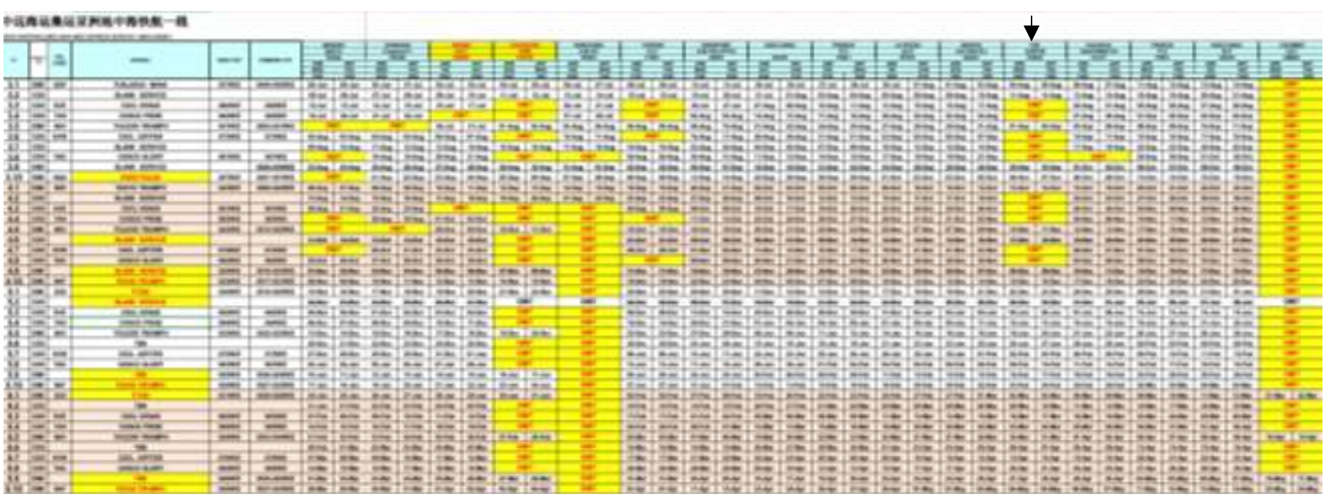

Figure 4.3 COSCO's aem1 route vessel schedule for 2021-2022 [14]

4.1.1 Model structure

The PI hub choice model aims to determine the optimal port calls for a specific vessel on a global corridor route, considering port conditions and hinterland connectivity. Neighbouring ports are identified, which in the case of LL1 UC1 are the port of Algeciras, Valencia, and Barcelona in Spain, that form a continental entry point cluster. A few more examples for COSCO's aem1 route, are the ports of EuroFos, France, Genoa and La Spezia, Italy, which also form a neighbouring cluster based on their proximity. Similar clusters can be formed for Northern European ports. Then, for each vessel calling multiple ports within each cluster, the container final destination data are gathered. A subnetwork is constructed using service-detail network representation, and the network discovery PI tools are used to determine port infrastructure availability, port real-time entry and processing serviceability data, as well as hinterland infrastructure connectivity and operating services data.

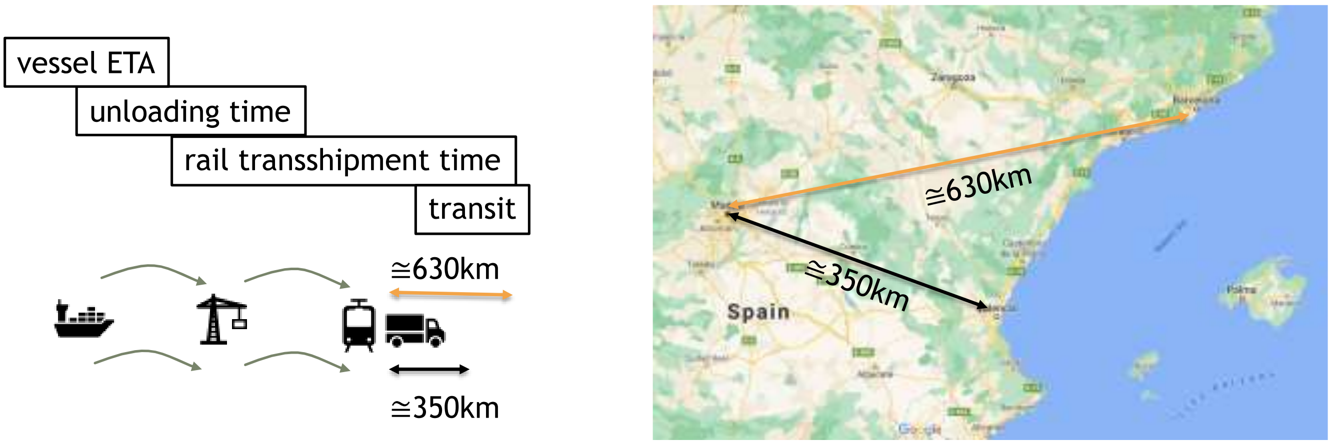

Figure 4.4 Seaborne corridor and port cluster hinterland vertical integration model

Figure 4.4 captures model functionality in relation to LL1 UC1, assuming that containers loaded on a vessel are either destined for the ports of Valencia and Barcelona, or to be transhipped to Madrid. The model requires vessel ETA based on each port congestion, loading/ unloading duration data, rail transhipment services time and costs, to determine if the vessel should call both ports (as originally scheduled) or if it should omit one of the two ports and if so which one.

4.1.2 Data and services integration

For operationalising the PI Hub Choice model, appropriate data require to be provided either through real-time updates (connectivity established in T2.2 [28]) or by applying appropriate predictive services (provided by T2.3 [29]). The model's data requirements are summarized in Table 4.1.

Table 4.1 Real time and predictive data integration for PI Hub Choice model

	Predictive model	**Real-time source**
Loaded containers and their final destinations	N/A	Vessel/ Port operator
Vessel ETA – port congestion	Vessel/ Port operator/ AIS data	N/A
Unloading/ loading duration	Historical data	Port operator short-term plan
Multimodal terminal handling duration	Historical data	Port operator short-term plan
Transit services	Historical data	Service operator

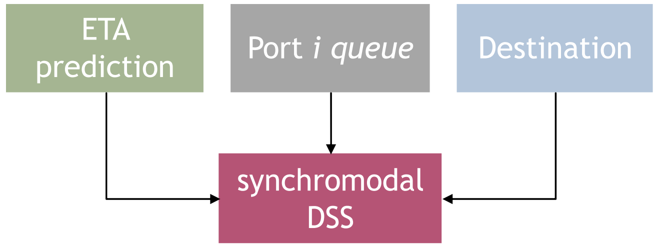

Figure 4.5 PI Hub Choice model components

The list of container loaded on the vessel information that are planned to be discharged at any of the cluster ports requires to be provided either by the port or the vessel operator. The seaborne voyage duration from Asia to Europe's Mediterranean lasts typically more than 14 days, which is sufficient for communicating the final destination and planned discharge location of the containers on board. A prediction can potentially be made on the final destinations of the containers based on historical data, but even small inaccuracies in the planning face might cause significant inefficiencies at implementation.

The vessel ETA is published well ahead of time by vessel operators; however, this often does not reflect the actual arrival time. This can be more accurately estimated using AIS data, capturing the location of the vessel, as well as for estimating port congestion. The connectivity to AIS data provider services is being developed by T2.2 [28]. As discussed in D2.7, an API with AIS data provider MarineTraffic is examined for ship tracking and container ETA. MarineTraffic offers an interactive real-time User Interface (UI) map and several available APIs for paid subscriptions. All the APIs and can be used both for a single vessel and/or for a fleet (group of ships). It is possible to manage fleets (add, remove, or add terrestrial/satellite tracking for a vessel) via an API called "Change Fleet API". It is also possible to see all vessels of a fleet. The AIS data, as well the data on the anticipated arrival times at each port API, can then be passed to a prediction model to estimate port congestion.

The hinterland infrastructure status and services timetables and conditions also require to be collected. The data are typically consolidated by national rail and barge alliances into platforms and can be accessed through APIs such as the Port of Antwerp (PoA) digital community platform that provides a Barge Traffic System (BTS) and a Rail Traffic System (RTS). RTS has been designed and developed by the Antwerp Port Authority in close cooperation with the railway actors such as railway undertakings and terminal operators. RTS is a real-time data hub for all the railway stakeholders to facilitate enhanced data sharing bringing together multiple diverse data sources.

Weather data can be also accessed through APIs and integrated with the other datasets to inform probabilistic prediction models, on weather impact to transport congestion and delays. Vessel running and operating costs are also required to inform the decision, and therefore the dataset might be unique to each operator. A dashboard interface that allows operators to enter the necessary figures for each vessel might assist in overcoming this difficulty. Alternatively, the use of a rough estimate based on vessel size, can be collected from the AIS database.

4.1.3 Integer optimization program

A mixed-integer linear program has been developed for determining the route of a vessel through appropriate PI Hubs. In the formulation presented below, the ports of Valencia and Barcelona are considered, however the model is extendable to accommodate more ports, without loss of functionality and computational efficiency. The program determines if the vessel should call all ports, or a smaller subset of the ports available, aiming to optimize the operational costs of getting all containers currently on board, to their individual destination. A binary decision variable y_p is defined for every port p in the cluster $p \in C$, that represents the decision to call or not to call port p. For $p \in \{B, V\}$, the PI Hub Choice model determines whether to call both ports, or one of the two, and if so which one.

$$y_V = \begin{cases} 0 & if\ vesel\ goes\ to\ Valencia \\ 1 & otherwise \end{cases}$$

$$y_B = \begin{cases} 0 & if\ vesel\ goes\ to\ Barcelona \\ 1 & otherwise \end{cases}$$

$$y_V + y_B \leq 2$$

The latter constraint is not limiting. It ensures that the decision variables can both be equal to 1, and the vessel calls both Valencia and Barcelona ports. Further decision variables are defined that capture if a specific cargo shipment is discharged in Valencia or Barcelona. To this end, x_{pc} where $p \in \{B, V\}$ resembles the port of discharge and $c \in \{1, \dots, n\}$ is the container identification defined for n containers on board to be discharged at any of the ports in cluster, which is further tied to a specific destination. Therefore, for any container c, $x_{Bc} + x_{Vc} = 1$. Then the binary variable indicating whether a port will be called, y_p is equal to 1 if at least one container is discharged there. The point of having a y decision variable is to allow for additional costs of calling an additional ports to be represented. Then, the problem can be formulated as follows:

Assuming a set of candidate discharge ports $p \in C$ and a set of containers to be delivered $c \in \{1, \dots, n\}$ at specific customers location j, a binary decision variable x_{pc} is equal to 1 if container c is discharged at port p, and 0 otherwise. A matrix m_{cj} captures the relationship between containers and final destinations. An additional binary variable y_p is equal to 1 if at least one container c is discharged at port p, in which case a fixed port calling cost f_p applies. A logistic cost proportional to the distance d_{pj} from port p to customer location j is also considered. A sufficiently large number M is considered. Then, a cost minimizing problem can be defined with the following objective function.

$$\min_{x,f} \sum_p \sum_j (d_{pj} x_{pc} m_{cj} + y_p f_p)$$

Subject to constraints:

$$\sum_p x_{pc} = 1$$

$$y_p M \geq \sum_c x_{pc}$$

$$x_{pc}, y_p \in \{0,1\}$$

The first constraint ensures that each container on-board will reach its final destination. The second constraint ensures that even if the optimizer decides to discharge at least one container at port p, the decision variable for calling port p, y_p will be equal to 1, and the corresponding costs for calling the port will be considered in the cost function. Finally, the binary nature of the container and port call decision variables is defined.

4.2 Use Case example

Considering data connectivity is in development, an indicative application of the PI Hub Choice model is presented utilizing artificial data. The Use Case applies the DSS model, in the context of the Barcelona, Valencia port cluster, for an arriving vessel. The vessel is assumed to discharge 1000 containers at both ports, that are destined for Zaragoza (300 containers), Madrid (300 containers), Albacete (100 containers), Murcia (100 containers), Valencia (100 containers) and Barcelona (100 containers). The hinterland connectivity costs have been calculated based on the distance and frequency of services metrics for all links originating from the two ports to the final destination locations. No data have been collected on port congestion and serviceability times at each port, and no data on the vessel operating costs have been provided, therefore three scenarios have been developed to monitor various cases. Scenario 1 assumes no congestion, Scenario 2 assumes extreme congestion at both ports, and scenario 3 assumes small congestion in the port of Barcelona and extreme congestion at the port of Valencia. The results from running the PI Hub Choice model are illustrated in Figure 4.6.

	discharge port, x	
final destination	Barcelona	Valencia
Zaragoza	1	0
Madrid	0	1
Albacete	0	1
Zaragoza	1	0
Zaragoza	1	0
Madrid	0	1
Madrid	0	1
Valencia	0	1
Murcia	0	1
Barcelona	1	0
Call port, y	1	1
Call, LHS	100	100
Call, RHS	4	6
M	100	100
Call cost	0	0

	discharge port, x	
final destination	Barcelona	Valencia
Zaragoza	0	1
Madrid	0	1
Albacete	0	1
Zaragoza	0	1
Zaragoza	0	1
Madrid	0	1
Madrid	0	1
Valencia	0	1
Murcia	0	1
Barcelona	0	1
Call port, y	0	1
Call, LHS	0	100
Call, RHS	0	10
M	100	100
Call cost	2000	2000

	discharge port, x	
final destination	Barcelona	Valencia
Zaragoza	1	0
Madrid	1	0
Albacete	1	0
Zaragoza	1	0
Zaragoza	1	0
Madrid	1	0
Madrid	1	0
Valencia	1	0
Murcia	1	0
Barcelona	1	0
Call port, y	1	0
Call, LHS	100	0
Call, RHS	10	0
M	100	100
Call cost	100	5000

Figure 4.6 PI Hub Choice model application case study results

The PI Hub Choice model yields three different solutions for each of the scenarios. In scenario 1, when port call costs are minimal, the solver suggests the vessel calls both ports and discharges the containers heading to Zaragoza and Barcelona, at the Barcelona port, while the containers heading to Madrid, Albacete, Valencia, and Murcia are discharged at Valencia port. In scenario 2 where, port congestion is set to extremely high levels for both ports, the optimizer suggests, the vessel calls only Valencia, and discharges all the containers there, that are transshipped to hinterland rail services to reach their destination. In the final scenario, where the cost of calling Barcelona is low, while the cost of calling Valencia is extremely high, the optimizer suggests, the vessel only calls Barcelona, and discharges all containers there, which are then transshipped to rail services to reach their final destination.

4.3 Concluding remarks and future considerations

The PI Hub Choice model offers novel vertical integration between sea trade routes, port clusters and hinterland transport and logistics services. The case study presented in Section 4.2, illustrates the optimizer's capability to adjust its decision making depending on network and serviceability criteria, and to optimize transport operations, yielding a benefit to the vessel operator, the hinterland services, while at the same time contributes to managing port congestion intelligently. The offering increases network robustness and enables the better utilization of resources.

Appropriate data and services connectivity is required to fully automate the model . Furthermore, an integration with port and hinterland connectivity indexes [25] for estimating the costs of hinterland options is anticipated to add value and simplicity to the analytic aspect of the model. A dashboard integration is also anticipated for communicating the optimized container routing to global corridor (vessel or train) and PI terminal operators.

5 Last mile dynamic collaborative delivery

A challenge proposed by Living Lab 1 partner, CITYlogin, concerns the ability to dynamically redesign urban delivery rounds, to alleviate delivery delays. Delays in the last mile are typically accumulative in nature causing second delivery attempts, increasing cost and emissions. This challenge is highly relevant to the concept of the Physical Internet and EGTN as it utilises the benefits associated to dynamic tracking of parcel deliveries and vehicle fleet, as well as open collaboration between operators.

The problem is operational and dynamic due to its real-time nature. Delivery rounds are typically fully designed prior to initiating their implementation every day at 9am local time. The design of delivery rounds considers, the fleet (i.e., the number and capacity of delivery vehicles available) and local accessibility constraints such as Low Emissions Zones (LEZs) or Zero Emissions Zones. LEZs that are increasingly popular in European cities [15] restrict vehicles with higher emissions from entering the area, complicating last mile delivery logistics.

5.1 Urban delivery round design

The delivery rounds design process involves, the pairing of each delivery location with a delivery vehicle, while the time and operational constraints are respected. This is typically achieved using a Vehicle Routing Problem (VRP), a popular operations research problem with wide applicability, that has been extensively researched and documented in the literature since 1960s. The VRP is a well-known NP-hard problem because it includes the Traveling Salesman Problem (TSP) as a special case [16]. The largest VRP instances that can be consistently solved by the most effective exact algorithms proposed so far contain about 50 customers, whereas larger instances may be solved to optimality only in particular cases. Heuristics and approximate methods are typically used for solving larger instances to near optimality, however, solving the VRP remains challenging even for reasonable sized real-world problems. Indicatively, according to the data on the delivery rounds provided by CITYlogin, there were more than 1800 customer locations that required to be serviced on a single day (16th July 2021).

To address larger instances a commonly used algorithmic approach, involves using unsupervised Machine Learning clustering algorithms to break down the parcel delivery jobs into smaller regional groups. Then, the resulting subdivisions of the parcel jobs, are solved as separate cases of the TSP. In the context of Machine Learning, clustering refers to a very broad set of techniques for finding subgroups, or clusters, in a data set. When we cluster the observations of a data set, we seek to partition them into distinct groups so that the observations within each group are quite similar to each other, while observations in different groups are quite different. In the context of urban parcel deliveries, the classification criterion typically used is a measure of distance or time between any two coordinates. The algorithms consider the straight-line distance (alternative distance metrics can be also used) between all delivery locations and compute the centroid of each cluster. Machine Learning offers multiple data clustering methods, that perform differently and use different hyper-parameters, such K-mean and DBSCAN. However, the main limitation of vehicle capacity is not considered in the process of separating the clusters, unlike with the VRP. To overcome this problem, unsupervised Machine Learning algorithms allow for an upper limit in the size of each cluster to be set, which is typically used as a proxy for vehicle capacity.

5.2 Last mile uncertainty

Last mile of urban parcel deliveries is typically associated to high uncertainty due to the busy city environment. DfT argues that the last mile accounts for around 30% of operators' costs [17]. This includes fuel, space rental for consolidation centres, staff employment, vehicle purchase, and other logistics' fixed costs such as insurance and maintenance. Furthermore, for urban parcel delivery rounds, about 50% of the time of a delivery tour, is not spent while driving, but while the vehicle is parked and the handover to the customer takes place [18]. Allen et al. [19] study 25 vehicle rounds in the busy "West End" of Central London and identify that 62% of the total round time was spent with the vehicle parked while the driver sorted, unloaded, and delivered parcels. Therefore, urban delivery uncertainty arises from urban road traffic, parking spot availability as well as during the handover process.

Aljohani and Thompson [20] survey participants to measure the influence of operational issues on the efficiency of the carrier operations in the inner-city area. They find that parking availability received the highest rating (29%) while regulations of on-street loading zones (OLZ) are ranked as the 3rd most negative issue (13%). This high rating highlights the negative effects of the improper planning and unavailability of on-street loading infrastructure. Issues related to traffic congestion and physical design of the city centre, were viewed as the second most negative aspects, as traffic congestion received a rating of 24%, whereas street design received a modest rating of 5%.

Analysis of delivery round data obtained from the GLA 2017 report [18], indicate large variety in the duration of vehicle dwell time per stopping location. The set of dwell time per stop values, has mean of 5 mins 10 sec, median of 4 mins, standard deviation of 4 mins 30 sec, minimum 1 min and maximum 21 min per stop. A similar observation is done by Allen et al. [19]. Furthermore, failed first time delivery rate for household deliveries associated with increasing e-commerce has been recognized as a significant challenge by many studies. It is estimated that 13–14% of all online shopping deliveries in the UK arrive either late or when the customer is not at home. This caused retailers and carriers £771 million cost in 2014 [21].

Allen et al. [19] report that online retailers are beginning to make greater use of delivery services that do not involve delivering to the residential address and thereby reducing the extent of failed deliveries. However, Mintel [22] data suggest that household delivery is largely favoured by online retailers. There is a consistently upward trend for click and collect, and alternative delivery locations (e.g., convenience store, petrol station, locker box) (see Figure 5.1). Mintel [22] survey had 55% of responding households reporting that there will not or may not be someone at home to accept a delivery.

The ‘click and collect’ strategy and the increasing use of local collection point, are trying to address the high rate of failed first time deliveries as well to allow for better cargo consolidation. Additional methods to address efficiency and emission challenges, include introducing collection points for customers. To address uncertainty at handover parcel delivery rounds are typically designed with a 6-minute interval for every parcel handover (once the vehicle is parked). Despite, this figure representing the average, it may still be the case that for a specific round multiple handovers are longer causing accumulating delay.

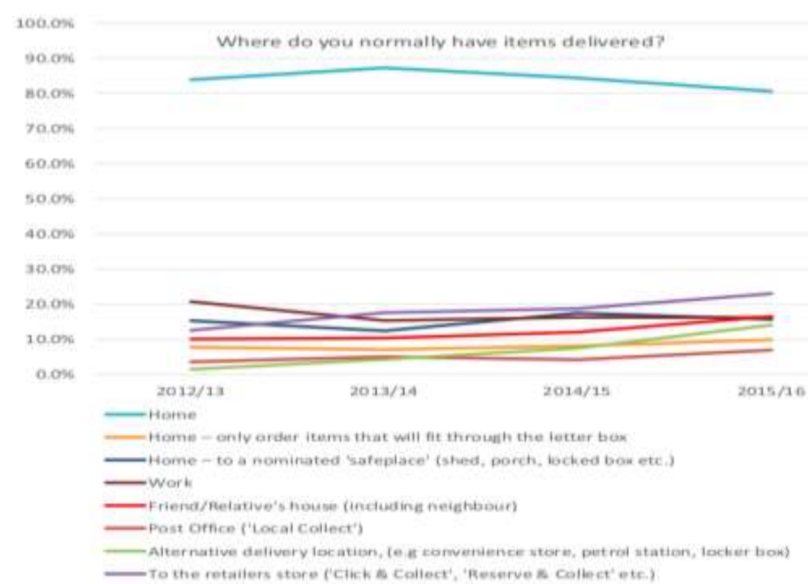

Figure 5.1 Preferred parcel delivery location [21]

Road traffic conditions worsen in high congestion hours, typically between 6–10 AM and 3–7 PM. During peak traffic periods traffic speed may reduce up to 40%. The average traffic speed (including out-of-peak hours) has been consistently declining in the inner-city areas. This adversely impacts the travel time and the reliability of deliveries. This figure may vary from country to country, city to city, from region to region, and seasonally. For example, Allen et al. [19] reported that vehicle delays have increased by 31% in central London.

With respect to parking availability, a study performed in Seattle, USA, revealed that couriers had used the kerbside to park their vehicles during deliveries to about 87% of all buildings in the downtown area [23]. Similarly, Allen et al. (2018) reported that couriers had to use the kerbside for about 95% of deliveries in central London. Couriers need to park their vehicles very close to the retailers and businesses. Their productivity decreases with longer walking distances, as they become less able to carry multiple parcels in each walking trip.

5.3 Visualisation and addressing delays in practice

The implementation of the originally designed delivery rounds is monitored through vehicle GPS sensors, and the software that track the delivery progress (through barcode scanning). The delivery rounds progress is typically visualised on dashboards as shown in Figure 5.2, where each row represents a delivery round. Its progress is captured through a series of delivery timestamps that represent the planned delivery time of a specific parcel, spanning from 9AM to 9PM. Green vertical lines represent successfully completed deliveries, orange lines represent pending deliveries, while red line represent unsuccessful deliveries.

Figure 5.2: Example of delivery rounds monitoring dashboard

The visualisation of the delivery rounds enables the manual tracking of delivery progress, and the identification of severe delays, when a round is considerably behind schedule. The red vertical line at 3pm in Figure 5.2, captures the current time, and enables progress inspection. For example, route C17 (first row) seems to be roughly on-time, while round C24 (last row) seems to be running slightly late. It is also worth noticing that the sequence at which van drivers choose to implement the delivery round does not always align with the delivery planned route, as experienced delivery drivers have tacit knowledge about the complex operational environment in which they serve customers daily. They know which roads are hard to navigate, when traffic is bad, when and where they can easily find parking, which stops can be conveniently served together, and many other things that are hard, if not impossible to formalize in an optimization model. This tacit information is therefore not contained in most route planning tools used in the industry, causing drivers to frequently deviate from originally planned route sequences. Taking into account their tacit knowledge, drivers follow a deviated actual route sequence instead, which is potentially more convenient under real-life operational conditions.

As round delays arise, the original planning and design of the rounds might require to be updated. This is because delivery operational constraints, such as delivery time windows (no deliveries past 9PM) and driver shift hours, cannot be violated. In such cases, a fleet operator tries to identify delivery rounds that might finish early or be ahead of schedule and dispatch them for helping the round running late. The process of identifying van availability, van suitability and then redesigning the delivery rounds, that involves identifying which parcels will be moved from the original van to the helping van, and where the two should meet for the parcel exchange will take place is currently undertaken manually. Automating this process can potentially remove human related constraints and costs and enable the faster identification of considerably more efficient solutions.

5.3.1 Delivery rounds progress simulation

To enable the development of solution strategies to the last mile delivery rounds delays, a dynamic modelling approach is required. Therefore, a simulation model has been developed that starting at 9AM, records the progress of all delivery rounds at one-minute intervals. The simulation terminates at 9PM when all rounds require to be completed. Furthermore, the simulation applies stochastic delays to the vehicle rounds based on data collected from Open Street Maps (OSM).

An API is set up, that communicates the route information (origin, destination, and current time) for each van that travels towards its next stop. The API returns the route duration considering traffic, and any delays are recorded in the delivery round timestamps and Estimated Time of Completion (ETC). Furthermore, a stochastic parking and handover duration is assumed using a normal distribution with mean of 6 minutes and standard deviation of 3 minutes. The allocated time, is also reflected in the calculation of ETC. The simulation does not consider deviations from the round sequence as there is no way of telling what kind of impact such deviation might have in the route design process. Furthermore, in the simulation the ETC calculation only considers delays up the current timestamp and does not have the ability to predict and account for future delays.

If any delivery round ETC is found to be later than 9PM, then an alert is triggered providing the information on the vehicle round that appears to be running late, and its current location. The original round sequences provided by CityLogin, rarely created delay alerts which may partially be attributed to the fact that the rounds were run in the summer months where city congestion diminishes. To account for this limitation, a stochastic traffic delay model has been integrated and calibrated to yield higher traffic congestion delays during rush hours.

Figure 5.3, is a graphic representation of the simulation sequence, and Figure 5.4 illustrates alert example, created when a delivery round is found to be running late and beyond 9PM.

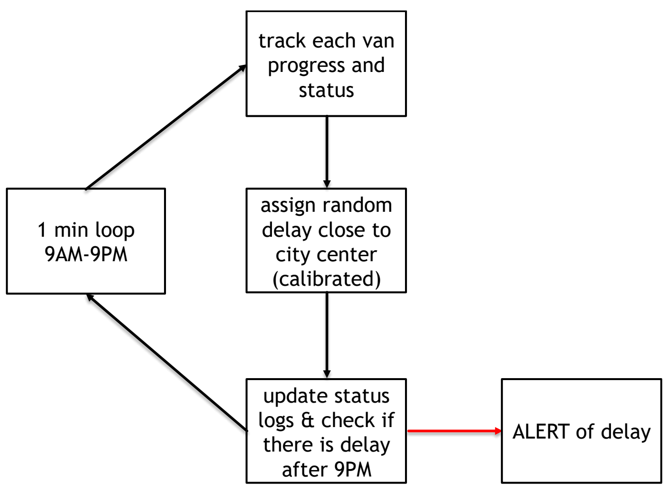

Figure 5.3: Urban delivery rounds delay simulation

```
> time now:  2021-08-17 10:37:00
     the earliest ETC is:  2021-08-17 17:12:00  for round D21
     the latest ETC is:  2021-08-17 20:57:00  for round E27
> time now:  2021-08-17 10:38:00
     the earliest ETC is:  2021-08-17 17:12:00  for round D21
     the latest ETC is:  2021-08-17 21:02:00  for round E27
ALERT: assistance required for  E27  that is scheduled to complete its round at  2021-08-17 21:02:00
```

Figure 5.4: Example of alert of delay by the simulation

5.4 Dynamic collaborative re-routing

As an alert for a late running round is raised by the simulation, the dynamic re-routing model for delayed rounds is called to assess possible options for assisting the van that is running late and optimise the process. The process is designed to run in two stages, with the first stage identifying the nearest available help rounds, and the second stage dealing with the redistribution of parcels, and redesign of the delivery routes.

5.4.1 Nearby delivery rounds identification

As illustrated in Figure 5.5, the first step of the process involves identifying all the delivery rounds operating in proximity. Following the openness principles of the Physical Internet, the proposed algorithm can consider the delivery rounds of one or more operators as candidates for helping the delivery round running late. The process firstly filters the rounds in terms of ETC, to identify the ones with higher availability, and then undertakes the more computationally intensive process of identifying the centroid for each round. The round centroid calculation considers all pending delivery locations for each round separately.

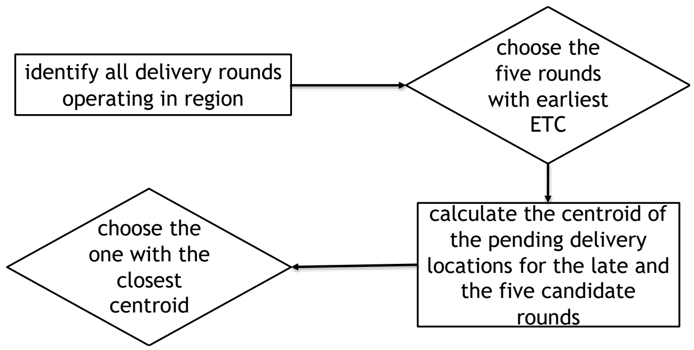

Figure 5.5: Nearby and available help round identification algorithm

Figure 5.6 illustrates all the delivery locations that are used for the round centroid calculation for the late running round (leftmost light blue) and the five candidate help rounds. The figure confirms quantitatively that the round depicted in pink is operating at proximity to the late running round (light blue) and is therefore considered as the ideal assistance option.

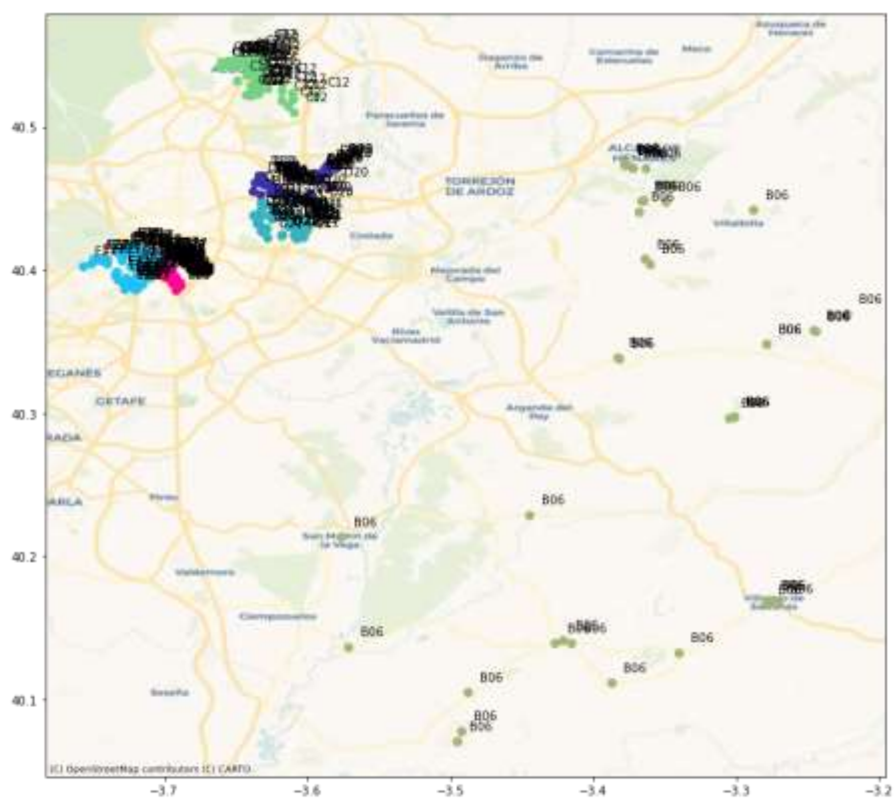

Figure 5.6: Pending delivery locations for the later rounds and the five candidate help rounds

5.4.2 Parcel reshuffling

Once the optimal help round has been identified, and it is confirmed that it is operating in proximity to the late running round, as well as that it has sufficient spare time for handling additional parcel deliveries, the task of reshuffling the pending parcels is initiated. The aim of this task, is to identify which of the pending parcels of the two rounds, should be delivered by which vehicle, to alleviate overall delivery delays. The late running round requires to share some of its load with the helping round, however up to this point it is not clear which ones should be transferred.

Utilising the dataset provided by CityLogin, a Machine Learning K-means clustering algorithm is applied to the dataset. The number of clusters parameter of the K-means algorithm is set to two to represent each of the two vehicles. The K-means algorithm utilises a calculation based on the moving centroid of its cluster to determine to which cluster a node will belong. The K-means algorithm compulsorily assigns all nodes to one of the two clusters, leaving no nodes unassigned. The algorithm has been applied using the straight-line distance as the criterion of vector separation of a node to the cluster centroid.

The output of the clustering algorithm is a new tag for each node of the population, that corresponds to a unique delivery round. Each tag is then associated to each of the two delivery rounds, by considering the original assignments, which ensures that the correct delivery round tag is set on each cluster. The parcels can then be classified into the ones remaining in the late running round, the ones remaining in the help round, and the ones moving from the late running round to the help round.

Figure 5.7 illustrates how the boarder for the delivery locations of the late running and helping delivery rounds changes before (dashed line) and after (continuous line) the parcel reshuffling. The delivery locations boarder for the help round, which is operating at the bottom right of Figure 5.7, moves further north claiming the shaded area that after the parcel reshuffling is served by the help round.

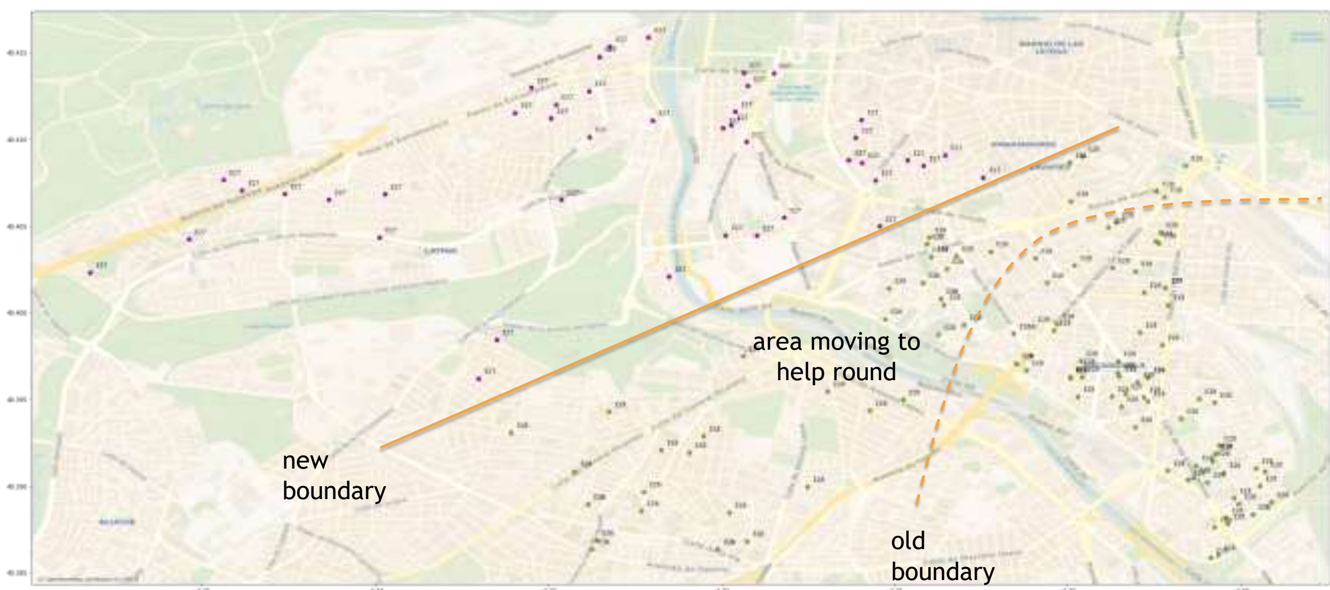

Figure 5.7: Area extension served by the help round after parcel reshuffling

5.4.3 Meeting point and delivery round redesign

After reshuffling the parcel delivery locations, and establishing the area moving to the help round, it is required to convert that information to instructions for the two vans and drivers. In effect, this includes the new routes for both vehicles, that incorporate a meeting point, and the information on which parcels require to be transferred from the one van to the other.

The meeting point can be determined prior to addressing the vehicle routing decision. The meeting point necessitates proximity of the two vans, as well as limiting the waiting time involved in the process. To identify two locations with proximity that are suitable for serving as the meeting point, the locations of the parcels remaining on the late running round, and the location of the parcels remaining on the help round are considered. The locations of the parcels moving from the late running round to the help round are excluded from this process, as prior to the exchange at the meeting point, they are loaded on the incorrect van. The distances between all locations are calculated and the two points with the closest distance are identified. From the pair, the meeting point is set to be location originally included in the late round as illustrated in Figure 5.8. This location is then added to the locations the help round requires to visit.

An alternative method considered for identifying the meeting point, included considering both the timestamps and the locations for the original delivery rounds. The method examined the application of weights on the two parameters, to determine location pairs that are both close in proximity and time, with the aim of skipping the redesign of the delivery rounds. The location pairs identified through this method, were not satisfactory, as the two rounds were found to visit regions in proximity at distant time periods during the day that involved long waiting times. This approach was not considered further.

The meeting point represents a proximity location suitable for the two vans to visit, however there is no guarantee up to this point that the two vans arrive there simultaneously. To address this, a common time window is set on both vans for reaching the meeting point. The time window is set to start in 30 minutes from the current time, and last for 30 minutes. Depending on the position of the vehicles in comparison to the meeting point and the time available until the 9pm cut-off, the time window start time and duration can be appropriately adjusted. If no solution can be found the meeting point time window is relaxed, by either delaying its start time, or expanding it, or both.

A Travelling Salesman Problem with time-windows is then solved, including a common time window for reaching the meeting point, while no time window constraints are considered for all other locations. As illustrated in Figure 5.8, the two rounds meet simultaneously (at 12:18 which is the start of the time-window), to exchange the parcels, and then the help round (shown as blue) delivers the additional parcels.

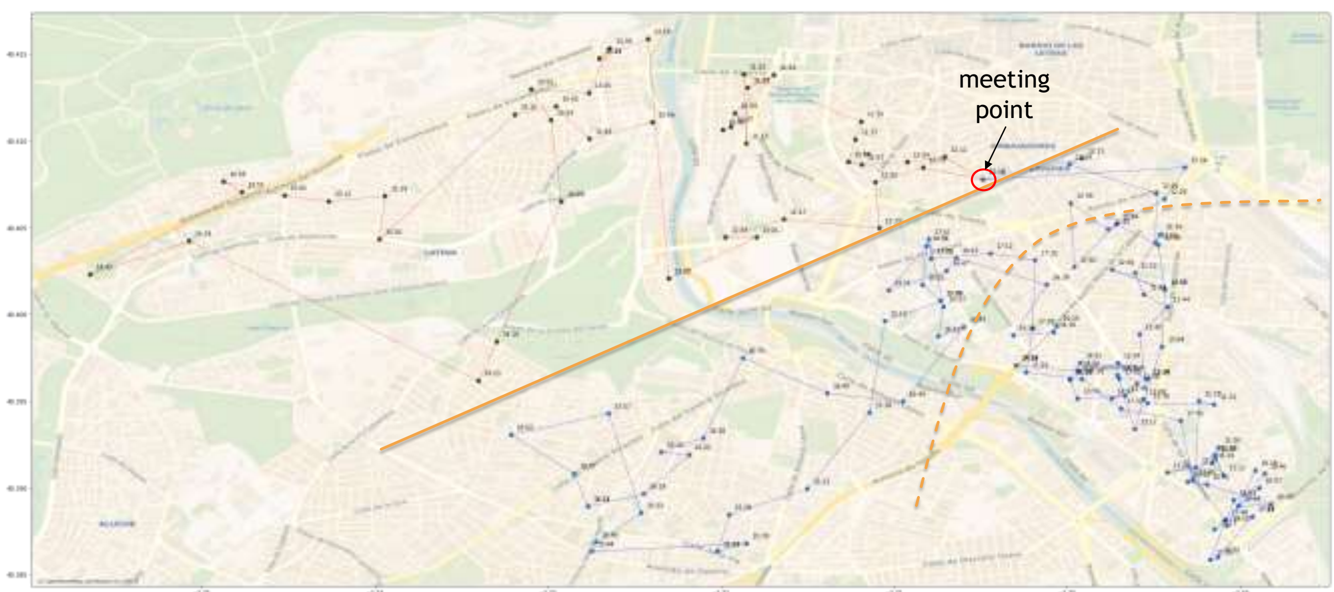

Figure 5.8: Vehicle rounds redesign with meeting point using VRP with time windows

The help round ETC changes from 21:03 to 16:56, reducing its duration by a significant four hours. This allows plenty of time to deliver the parcels, even with adverse traffic conditions that are not yet accounted for. The help delivery round ETC is also updated to 18:19, costing an additional two hours to the termination time of the round.

5.5 Collaboration and solution implementation

The dynamic algorithm developed offers a solution to the last mile delivery rounds delays in the urban context. The tool is useful for last mile operators addressing delivery delays, but it also offers an opportunity for collaborative last mile logistics, as it creates fair criteria for assessing the helping rounds available in a region. The algorithm is end-to-end in determining, and identifying optimal help rounds, as well as dealing with parcel reshuffling and delivery round redesign through a meeting point. As multiple last mile operators run delivery rounds in proximity, integrating this methodology in an EGTN-type platform, enables collaborative logistics to be applied in a fair manner, increasing substantially the collaboration opportunities and benefits between operators.

5.6 Industry perspective and way forward

Higher first attempt delivery success is key for all the stakeholders involved. Each package returned to the warehouse due to a failed or out of time delivery, generates economic, social, and ecological costs. It is, therefore, key for Last Mile delivery companies to save the costs associated to a second try. Currently, second delivery attempts represent around 20% daily extra cost for operations due to the additional amount of kilometres needed to either come back and try delivery on the same day or to return to base and plan the delivery for the next or a later date. It is also key for the cities to avoid additional runs by delivery vehicles operating, as they contribute to road occupation and pollution emissions. From a busines perspective, customer satisfaction is key, and it is therefore important, for consumers to receive deliveries successfully without additional contact or disturbance.

Solutions may consider convenience delivery points but also utilise better monitoring and daily management based on AI applications. Such applications allow operators to predict the impact of real-life non planned events and anticipate corrective actions to resolve them using optimization methods, which yield savings in personnel cost, fuel consumption and road and vehicle wear and tear. The solution presented here, enables a field of tools to work on minimizing these problems that affect the entire last mile industry. With the support of the public sector and such new disruptive technologies, private sector collaborative operations can be promoted and prioritised.

The proposed last mile delivery collaborative logistics DSS, requires further data integration of real-time traffic data through connectivity established in T2.2 [28]. The round progress and barcode scanned data require to be integrated with the EGTN platform, as well as traffic and delay predictive capability through utilisation of T2.3 services [29]. A dashboard integration is also anticipated for communicating the new delivery rounds to late and help delivery rounds operators. This will enable the calibration of the Machine Learning and optimization parameters of the algorithm to improve its performance.

6 PI Hub operations management

In a PI Hub context, multiple terminals and warehouses operate, that facilitate processes, typically starting with shipment arrivals and ending with shipment departures. All warehouse and terminal processes are constrained by space, infrastructure, and workforce capacity. Ganbold et al. [26], study the workforce planning that represents a major component of the warehouse operational cost. The inefficient assignment of staff to workstations is identified as a major bottleneck for warehouse operational efficiency and increase of service level. This is reflected in the key operational objectives of a warehouse that include customer satisfaction via effective resource utilization, and the shipment of the right product in good condition and within the target shipment time. In effect, warehouses address the differences in time and space between suppliers and customers, while adapting to the fluctuating market conditions. The processes facilitated in warehouses are:

- Temporary storage
- Protecting goods
- Service support in customer order fulfilment
- Goods packaging
- After sales service support
- Quality inspections
- Testing
- Assembly
- Repairs

Furthermore, Edwards et al. [27] distinguish three phases of manpower planning, which include the:

- prediction of manpower demand,
- prediction of the future supply of manpower, and
- reconciliation of the discrepancies between supply and demand via workforce scheduling and staffing.

6.1 Manpower scheduling

In the context of PLANET, DHL warehouse operations are investigated through the development of inflow and outflow traffic prediction models, that can then be used to optimize manpower scheduling and staffing. Optimal staffing, or allocation of workers to tasks, is key to tackling the challenges of high demand fluctuations daily. In the warehouse, this problem is dependent on workers qualifications, i.e., skill sets, which are very specific to each employee. Features to influence operational efficiency and cycle time include:

- Product types: We chose to consider all product types, i.e., franchises, that the warehouse handles (other than DHL) or product categories the warehouse handles (e.g., regular, express, e-commerce).
- Inbound activities: Inbound activities start with the arrival of shipments at the warehouse. Immediately after the dock-in, the products in pallets are unloaded at the inbound staging area and later moved to the sorting workstation. After manual counting and checking for defects and damage, the products are moved to the goods receipt (GR) workstation. At the GR station, workers scan the barcode on each item and register the items in the warehouse management system (WMS), while put-away slips with storage bins are generated for each pallet load. After the GR, they are ready for put-away to the storage area(s). The put-away worker puts away the pallet in its designated storage area following the storage bin information printed on the put-away slip. Put-away activity is denoted as the terminal inbound activity. Figure 6.1 shows the flow diagram for inbound shipments.

Figure 6.1 Inbound shipments flow diagram [26]

- Outbound activities: Outbound activities start when order information arrives at the WMS and a pick slip is generated. One order is assigned to one picker. After the order picking is completed, depending on the labeling requirements, the items need to be labeled before scanning starts. Otherwise, the picked items are sent to the scanning station. There are two types of scanning, each for a certain type of product, i.e., manual scanning and scanning via auto-scanning tunnel (AST). The scanning activity makes sure that all the items are picked against the order lists, and it generates slips that denote items which need to be packed together based on pallet or case dimension constraints. Then the items are packed into pallets and cases accordingly. A release worker moves the order to the outbound staging, from where the order is shipped out with an outbound truck. Figure 2 describes the outbound entity flow diagram.

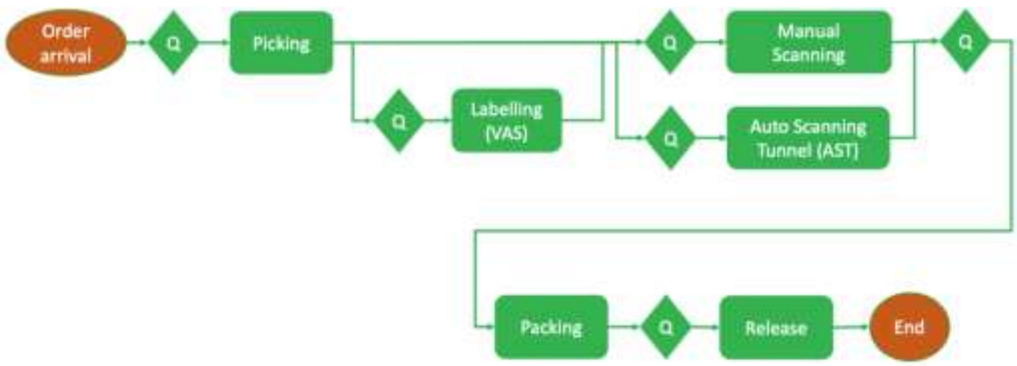

Figure 6.2 Outbound shipments flow diagram [26]

- Types of storage areas: There are three storage areas in the warehouse, i.e., racking, long-span shelving (LSS), and vertical lift modules (VLMs). Racking is designed to store SKUs in full pallets, LSS contains SKUs in loose boxes, and VLMs are for loose boxes. Each storage type is dedicated to one or more product types.
- Shift configuration and working days: There are two shifts operating during business days (excluding weekends and holidays): the morning shift operates from 8:00 a.m. to 6:00 p.m. with a one-hour break during 12:00–1:00 p.m., and the night shift operates from 9:00 p.m. to 7:00 a.m. (next day) with a one-hour break during 1:00–2:00 a.m.
- Worker numbers and shift assignment: The total number of workers is fixed. Worker numbers assigned to each shift are pre-fixed; 21 workers are assigned to the morning shift and 5 workers are assigned to the night shift. Additionally, 5 outsourced workers are assigned to value-added service (VAS) activity for labeling upon request.
- Worker skill set matrix: We assume that each worker has his/her own unique skill set. If the worker is trained to conduct an activity, “yes” is put in the respective activity cell.
- Workload demand for one-week period is known upfront.

Based on this modelling approach a warehouse inbound and outbound services are simulated, and the manpower scheduling and staffing can be determined, using an optimization algorithm. The service is connected to T2.3 predictive model for inbound and outbound flow volumes. The tool aims to plan human (and other) resources required in the warehouse to handle the estimated flow reliably and at a minimum cost. The method can be extended to identify the utilization rate of various in-warehouse processes, and to act as a proxy for predicting spare warehouse storage and processing capacity. This sort of as-a-service warehouse operational information is essential for route planning decisions in a multi-hub PI enabled context.

6.2 Cargo-Carrier pairing at PI Nodes

Another PI functionality associated to PI Nodes, is the automated assignment of cargoes to shipments. Transport networks offer multiple routes between an origin and a destination, and routing algorithms are available by T2.3 services for calculating the shortest or fastest paths. However, in freight supply chains more complex requests arise, and additional factors require to be considered in path finding decisions. Although multi-criteria path finding algorithms are available, their usability is limited. In practice, freight forwarders are responsible for cargo orchestration decisions, and consider only a limited number of routing options based on personal contacts and simplicity of carriage. Multiple modes and transhipments are avoided as they may be more time consuming to oversee and manage, in-particular in case of delays. The routing decision is a one-off decision, rather than a recursive one, as the PI paradigm dictates, that is also restricted by limited established contract relationships, and where only essential carriage preferences are considered. Specialized equipment requirements are being considered (e.g., refrigeration) while there is limited variability in the transport offering which the only parameter typically being voyage speed.

Utilising the multi-criteria routing services provided by T2.3, an algorithm is in development which in addition to the routing options and carriers available and the special carriage requirements, also considers, the storage options analysing the accessibility to the entire network, as well as more refined shipper and consignee preferences in terms of, time and budget limitations, cost, travel time limits/ delivery windows, emissions goals, and safety/ punctuality/ accuracy.

The proposed algorithm provides the means for pairing the unique needs of each shipment/ consignee with ideal carriers running in optimal routes. The algorithm simultaneously adapts the transport offering for custom shipment preferences, carriage requirements and performance KPIs for all shipments. It incorporates a comprehensive shipper/ consignee preference in balancing shipment needs to the infrastructure and services offering.

7 Conclusions

This deliverable focuses on developing algorithms, that utilise the advantages of the PI, and enable smart decision making at both network and node levels. The intelligent decision-making algorithms described in this report align with the PI principles of openness, monitoring, digitization, modularization, and smart decision making.

In the development of the solutions presented in this report, current practices have been considered, as a baseline and guideline, together with legacy and connected systems operators currently use. The use of analytics in current T&L practices tends to be limited to basic routing decision making, and typically not automated, but rather used as an intermediate step for informing freight forwarder decisions. The deliverable describes models and methods for integrating automated operations for transport and logistics planning and collaboration applied for both to PI Hubs and transport legs. After introducing in brief, the inefficiencies of current logistics practices, the technological features of the Physical Internet and the benefits they provide are discussed. An integrated data structure, process workflow and robust network representation proposed in earlier PI related EU research projects, SELIS and ICONET is presented as the basis for introducing real-time decision making in the EGTN. Three application contexts are defined, inspired by PLANETs Living Labs:

- Vertical integration of global corridor services to port clusters and their hinterland
- PI Hub (warehouse and terminal) resource management and as-a-service operation
- Last mile delivery dynamic collaboration

The vertical integration of seaborne services to port clusters and their hinterland is discussed in Chapter 4, where the PI Hub Choice model is proposed for optimizing the sea and land side collaboration. The model enables the identification of more efficient options for routing containers to their destination. The tool integrates with data provided by T2.2 and predictive services provided by T2.3 to analyse the routing options available for containers to reach their destination optimally. A simple Case Study is presented focusing on COSCO operations in Spain, and various port congestion scenarios, indicating that a robust routing approach is beneficial both to liner shipping service operators and hinterland operators, while port congestion is alleviated.

The uncertainty of the urban environment that arises from road traffic, limited parking availability, and handover uncertainty, cause significant delays to last mile operators. To address this challenge, delivery status updates are circulated and stored in a data platform, from one or more operators, that are then analysed to identify collaboration options between vans or operators. The tool builds on predictive traffic modelling tools, and:

- identifies suitable help candidates from the vans operating nearby
- once the optimal help van is identified, reshuffles the parcels to assist the later running van,
- identifies a meeting point for exchanging the parcels, and
- reroutes both vans through the meeting point, and all the delivery locations.

The algorithm is applied in a case study, in central Madrid, Spain utilizing a stochastic traffic simulator and a dataset provided by PLANET partner, CItylogin. Focusing on warehouse and hub operations, two value adding models are proposed. The models, after integration with inflow/ outflow data for each warehouse enable the better planning of warehouse human and infrastructure resources.

The intelligent planning tools proposed for all three contexts, utilize T2.2 connectivity infrastructures, and T2.3 predictive services to populate the integrated data structure and undertake efficient decisions. The outputs of the planning and Decision Support tools are illustrated through case studies and quantitative examples. In the case of last mile logistics collaboration, the benefits extend beyond the operator specific business benefits to city congestion and air quality improvements. A comprehensive quantification of all models' performance in terms of transport and logistics KPIs will be included in the second version of this report. The roadmap for the further development of the tools, includes the integration with real-data sets where available and the testing of algorithm performance in real-world conditions. The interface of the tools for the various operators will be further analysed, through specialized workshops, that will investigate the stakeholders associated to each, and offer unique dashboard interfaces for each user. Connectivity infrastructures and predictive services integration is necessary through functional workflows, and dashboard interactions, serving as blueprints for EGTN platform functionality.

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