D1.6.1 MIDWAY REPORT

GLOBAL OVERVIEW OF THE RESULTS OBTAINED

Author(s)	Cassan Catherine; Finck Joris; Lemos Vitor; Michiels Philippe; Sun Shiqi; Van Bever Dries-
Contact	Joris.Finck@Imec.be
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Readers guide

The purpose of this document is to consolidate the findings of the first 18 months of the PILL project, to present the reader with a comprehensive overview of the work that has been done so far. It consolidates the main insights of the proposed deliverables or (in some cases) replaces the deliverable in question. Below you find a table overview of the links between the chapters within this document and the other deliverables.

This document should be considered as an intermediate version of D1.6 PILL practitioner end report. It is therefore not to be considered as a complete and final version of this deliverable, but as a work in progress. Where relevant, elements to be further investigated are indicated in grey.

In this document, we use “PI” to refer to the concept of the Physical Internet in the existing academia and theories and “π” for specific applications and elements we designed in PILL.

Table 1. overview of the planned deliverables and their relation to the chapters in this document

	Description deliverable	Related chapter(s)	Planned by
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1 Introduction

Freight transport today is under increasing pressure due to higher and more frequent demand. Freight transport by road is expected to increase by around 40% by 2030 and 80% by 2050 (EC, 2011b). To make this compatible with the Paris environmental agreement, a drastic reduction of emissions is needed. By 2030, the ambition of the European Commission (EC, 2011a) is to shift 30% of freight transported by road to environmentally friendlier modes that have lower societal impact, such as rail and inland waterways. This shift should increase to 50% by 2050. The conflict between increasing demand and high ambitions for sustainability can not be resolved while relying on business-as-usual methods of freight distribution.

To answer this question, Benoit Montreuil formulated the idea of the Physical Internet in 2011. In this concept, the workings of the Digital Internet are translated into the logistic network, creating a physical version of the internet. The PI is described as an open global logistics system based on interconnectivity between the different entities through the standardisation of encapsulation, interfaces and protocols. The goal is to be able to send cargo along the most optimal route, regardless of who operates the links and nodes in this route. This would increase the use rate of all assets and thereby reduce negative externalities. In addition, this would increase access to the more sustainable modes, also for smaller shipments, thus increasing their share in freight transport.

Until recently, research on this topic has been rather theoretical, mainly focusing on either standardisation of containers or the digitalising of different documents exchanged between logistic partners. Today, several research projects aim to implement elements of this concept in real life through so-called “living labs”. A living lab is “an orchestrator of open innovation processes focusing on co-creation of innovations in real-world contexts by involving multiple stakeholders with the objective to generate sustainable value for all stakeholders focusing in particular on the end users.”(Ståhlbröst, 2013). The PILL stakeholders can be subdivided into three main types according to their business roles: logistics roles, policy roles and (data)governance roles. We aim to bring together the insights of these three groups to create (1) a conceptual IT architecture data model fit to structure the future PI and (2) a pragmatic solution allowing expeditors to find and book routes in a Proof of Concept (POC) setting.

The aim of this document is to give an overview of the results obtained until today, approximately halfway through the project. Where relevant, links to more specific outputs with more detailed information are added. We start this document with a general description of the concept of PI and the relevant academic research related to the PILL project (chapter 1). Next, we give a short description of the state ‘as is’, with a focus on the processes relevant to our project and stakeholders (chapter 2). After this, we move into a more technical part. We first describe the general layout of PI as we see it (chapter 3) before diving into the details of the architecture (chapter 4). Next, we will describe the Agent-Based Model (ABM) we developed to recreate the logistic network of our stakeholders to create a safe environment for experiments (chapter 5). After this, we will describe the layout of the experiments planned for Q1 2023 (chapter 6). Finally, we give an overview of the next steps ahead (chapter 7).

2 State of the art in Physical Internet research

In this chapter, we sketch the existing theoretical background of the Physical Internet (PI) concept. We give insight into how the PI is expected to improve the current logistic system in terms of sustainability, reliability and profitability. This chapter serves as a basis for the further translation of this concept into a concrete solution in the PILL project, which is explained in the remainder of this document.

This chapter starts with a general explanation of some of the key concepts used in this document. The following paragraphs of this chapter are based on academic papers by the PILL team members, which can be consulted for a more in-depth view.

2.1 Concept and definitions

2.1.1 Definition of Basic Ideas

Multimodal, intermodal and co-modal transport

Steadieseifi *et al.* (2014) give the definition of these concepts.

Multimodal transport is:

> “the transportation of goods by a sequence of at least two different modes of transportation (UNECE, 2009). The unit of transportation can be a box, a container, a swap body, a road/rail vehicle, or a vessel. As such, the regular and express delivery system on a regional or national scale, and long-distance pickup and delivery services are also examples of multimodal transportation.”

Intermodal transport is:

> “a particular type of multimodal transportation where the load is transported from an origin to a destination in one and the same intermodal transportation unit (e.g. a TEU1 container) without handling of the goods themselves when changing modes (Crainic & Kim, 2007).”

And co-modal transport is:

> “the use of two or more modes of transportation, but with two particular differences from multimodality: (i) it is used by a group or consortium of shippers in the chain, and (ii) transportation modes are used in a smarter way to maximize the benefits of all modes, in terms of overall sustainability (Verweij, 2011).”

Synchromodal transport

According to Giusti *et al.* (2019), synchromodality is:

> “the provision of efficient, reliable, flexible, and sustainable services through the coordination and cooperation of stakeholders and the synchronization of operations within one or more supply chains driven by information and communication technologies (ICT) and intelligent transportation system (ITS) technologies”

The four characteristics of synchromodality are (Pfoser *et al.*, 2022):

- Real-time switching
- Integrated network planning
- Horizontal collaboration
- Mode-free booking

Disruptions

According to the definition adopted by Yang *et al.* (2017b), disruption is:

> “unplanned events that hamper the SC system.”

Generally, there are two types of disruptions: facilities disruptions that make facilities unserviceable and transportation disruptions that interrupt the flow of material.

Robustness

Supply chain robustness is (Brandon-Jones et al., 2014)

> the ability of a supply chain to withstand disruptions and continue operating.

It stresses the ability to cope with disruptions and to maintain the continuity of operations during the disruption. The disruptions are usually unexpected but trivial, e.g. order cancellation, late arrival of trains, etc.

Resilience

Supply chain resilience is (Brandon-Jones et al., 2014)

> the ability of a supply chain to return to normal operating performance within an acceptable period of time.

This term stresses the recovery ability because normal functionality is interrupted because of the severity of the disruption, e.g. crisis, breakdown, strike, etc.

2.1.2 *What is the Physical Internet?*

More detailed information can be found in D1.1. PILL Literature Review.

The concept of PI (also known as π) has been promoted based on the deficiency of sustainability and the breakthrough of the technologies. Montreuil (2011) points out the 13 unsustainability symptoms in the logistic sector, introduces the components PI system and initially justifies the superiority of the notion behind PI.

Montreuil *et al.* (2010) propose the various PI-related components (Figure), which still remain the main concept of PI, including π-containers, π-movers and π-nodes as the main categories. The size of π-containers can be variable, which can either be as big as the standard ISO container or small but be able to compose to a standard container for the easiness of transportation. They envision each π-container, as the standard transport unit in PI, is equipped with technologies like RFID so that the π-containers are moved like the packets in Digital Internet (DI). The π-containers will be handled and transported by π-movers, which refers to PI-transformed tools for moving the π-containers, such as π-vehicle, π-carrier, π-conveyor etc. While some of the π-movers are operating within a PI node, most are creating links between nodes. Although π-node can also refer to other PI structures, like π-bridges and π-transits, π-hub is the most prominent and the research focus as PI transportation networks are often considered to be composed by PI hubs and infrastructure sections between the PI hubs. Note that we use “π” here because this is how it is named in the paper. In this document, we use “PI” to refer to the concept of the Physical Internet in the existing academia and theories and “π” for what we designed in PILL.

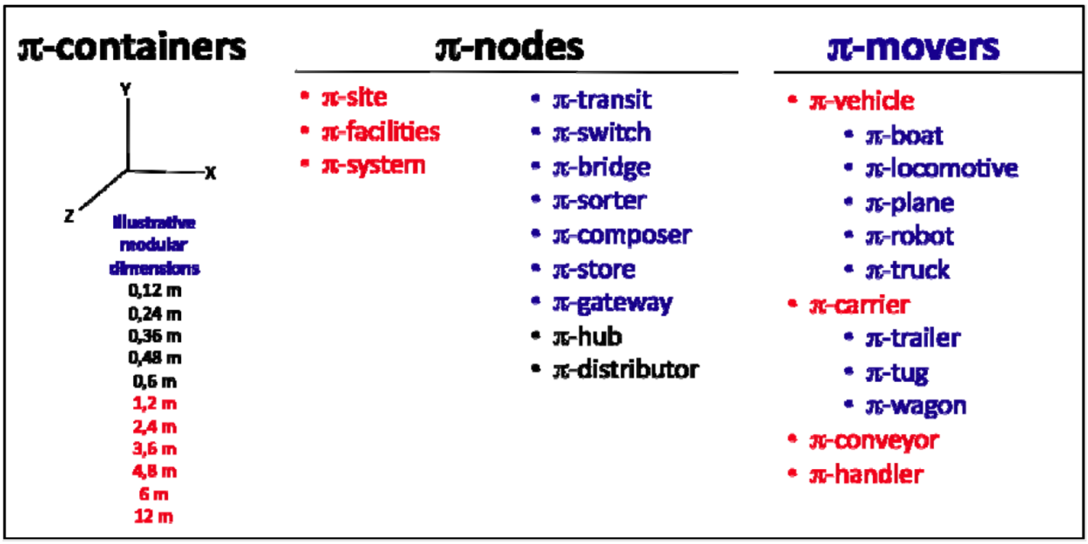

Figure 1. the components of PI (Montreuil et al. 2010)

With the components defined, Montreuil *et al.* (2012) devised a 7-layered Open Logistics Interconnection (OLI) model, imitating the standard Open System Interconnection (OSI) model and TCP/IP model in the DI. Given the theoretical designs, PI is defined as “an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols” (Pan *et al.*, 2017).

In a review paper by Ambra *et al.* (2019), a line graph is drawn (see Figure), showing that PI has become a popular research topic since 2015. This could be affected by the annual International Physical Internet Conference (IPIC) since 2014. This trend is verified and further sorted out by Treiblmaier *et al.* (2020), who conduct the most recent comprehensive literature review on PI and analyse the evolutionary stage of PI literature.

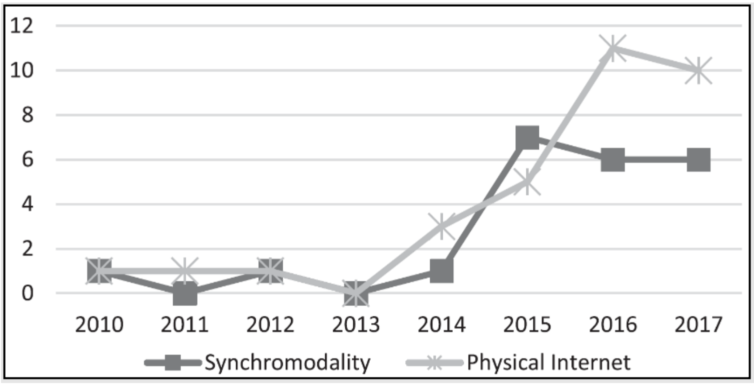

Figure 2. research trends of PI and synchromodality (Ambra *et al.*, 2019b)

They conclude that there are three stages: the *incubation stage* (2008-2011), the *exploration stage* (2012-2014) and the *expansion stage* (2015-the article publication). In the *incubation stage*, research almost completely focuses on the initial concept design of PI. Then, in the *exploration stage*, researchers mainly focus on the validation of the PI concepts and assessment of proofs-of-concept. Lin *et al.* (2014) study the effects on the fill rate of utilising different-sized containers for a 2-stage load, i.e., a container filled with items and a unit load (standard container/pallet) composed of containers. Sarraj *et al.* (2014) look at the similarities and differences between PI and DI, justifying the theoretical foundation of PI. They also carried out a computational model with simplified assumptions, indicating that PI has the potential to reduce flow travel (amount of cargo multiplied by travel distance) and transport distance. Other possible benefits that could be brought by PI include CO2 emission, travel time and overall transportation cost (Sarraj *et al.*, 2014b). In the *expansion stage*, researchers mainly begin to design and assess the solutions of a certain aspect of logistics, which uniquely exists in PI rather than conventional logistics. Earlier in this stage, PI containers are studied more deeply, for example, regarding their usefulness and physical design (Landschützer *et al.*, 2015) and the intelligent features of PI containers (Zhang *et al.*, 2016; Sallez *et al.*, 2016; Tran-Dang *et al.*, 2017; Gumzej *et al.*, 2020). Some researchers also study the operational management within a PI entity in terms of, for example, road-rail PI hub scheduling (Walha *et al.*, 2016; Vo *et al.*, 2018; Chargui *et al.*, 2020), inventory management (Pan *et al.*, 2015; Yang *et al.*, 2017b, 2017c), pricing model (Qiao *et al.*, 2019, 2020) etc.

PI also becomes more popular and studied together with other concepts at this stage. Ambra *et al.* (2019) compare PI with synchromodality, which is a developed form of dynamic multimodal transport that makes sure all the best possible modes are chosen for each leg of a shipment (Mes and Iacob, 2016), standing for the research direction derived from conventional multimodal logistic studies. Pujo and Ounnar (2018) connect cyber-physical system (CPS) with PI. CPS interconnects physical objects and virtual elements and enables in-between interaction like the remote control. In that sense, PI is regarded as an economic model of the cyber-physical logistical system (CPLS) in the supply chain domain due to their common digitisation and communication nature.

In short, the research on PI stresses the following characteristics compared with conventional research on logistics and supply chain management:

- Usage of ICT and smart devices (RFID, IoT devices)
- Container bundling and composing
- Flexible treatment against disruptions (order cancellation, weather changes, traffic congestions, etc.)
- Modelling over a PI entity
- Applying interconnective technologies to business as usual
- Improving the container fill rate and utilisation of spare resources (idle transport modes)

2.2 How will PI change logistics?

2.2.1 The PI to increase the resilience of logistics flows

This paragraph is based on the paper by Ambra T, Caris A, Macharis C. Should I Stay or Should I Go? Assessing Intermodal and Synchromodal Resilience from a Decentralized Perspective. Sustainability. 2019; 11(6):1765.

The focus of this paper is on synchromodality, but the concepts described are also valid for the disruption mitigation aspect of Physical Internet as both concepts are closely related.

The growing cargo demand, increasing road congestion, as well as an increased focus on reliability, safety and environmental concerns have heightened the relevance of more efficient and sustainable freight transport. Intermodal transport is suggested as a possible way of achieving this goal. However, the development of intermodal decision support models, where more actors and modes are incorporated (compared to unimodal), is hampered by limited data availability and its static nature (Caris *et al.*, 2013). Furthermore, shippers perceive intermodal transport as a slow and inflexible solution with a limited service offer, expressing a preference for unimodal road solutions (Meers *et al.*, 2017).

Synchromodal transport/synchromodality *[and Physical Internet]* presents an extension of intermodal transport by including real-time re-routing of loading units over the network to cope with disturbances and/or customer requirements (Riessen *et al.*, 2015; Verweij K., 2011). The main difference between intermodal and synchromodal transport is that the former is based on services which are predefined long in advance, posing a rather static and inflexible service level. As a matter of fact, realistic problems and dynamics such as disturbances, breakdowns and other delays lead to time/money losses. Let alone, newly incoming orders cannot be accounted for in time as the intermodal setting is rigid. In the synchromodal setting, decisions related to modal choice and route are not predefined long in advance, but are taken as late as possible based on real-time infrastructural and operational developments (Verweij, 2011). Thus, the synchromodal concept has the potential to offer better performance than intermodal transport on flexibility, reliability and other modal choice criteria.

We define supply chain resilience as the ability of a supply chain to return to normal operating performance within an acceptable period of time (Brandon-Jones *et al.*, 2014). To measure the resilience, the status quo (non-disrupted system) will be compared to reconfigured solutions which will emerge when imposing various disruption profiles that may occur in reality. Such profiles will include disruption length, severity and probability of occurrence. By doing so, various mitigation strategies will be tested while taking into account how the devised mitigation strategies (re-routing, bundling, mode switching) perform in terms of key performance indicators (KPIs) (costs, emissions, lead time).

Only a limited number of studies consider the operational level, such as (Huang *et al.*, 2011), who provide a disruption management method while considering road disruptions and their estimated duration. However, the work does not account for rail disruptions, and the analytical-numerical example does not include any time and distance elements. Burgholzer *et al.* (2013), on the other hand, account for the time component but exclude transport costs and focus only on a single corridor. More recently, Yang *et al.* (2017a) study disruptions in the physical internet context. The case study does not include terminals, terminal transshipments, pre- and post-haulage and IWW alternatives. Current synchromodal analytical models optimise corridor flows which increase efficiency in terms of cost and time for a given corridor of already existing rail and IWW services (Ambra *et al.*, 2019b).

To achieve the modal shift objectives mentioned in the introduction, models should also be designed for convincing shippers who have not yet tapped into the rail and IWW solutions. Therefore, decision support models should account for supplier origins (O) and delivery destinations (D) that are dispersed in geographical space.

Hence, each order, OD, pair has different spatial attributes which yield different distance and lead-time values. The main novel aspects of the model developed by (Ambra *et al.*, 2019a) are the following:

- decentralised agent process (bottom-up) simulations of each order/container and the modes it undergoes, as well as order performance in terms of distance, time, cost and CO2.
- more realistic routing strategies through geographically referenced space for trucks, trains and barges in a single model.
- disruption and system resilience assessment by decentralised reconfiguration of solutions induced by messages and spatial awareness.

The simulation experiments provide a range of alternatives and assessments which may also be of interest to other retailers who rely on truck-only transport. The modal shift potential in a static multimodal setting is 26.5% and may increase to 39.5% and 58.4% when allowing for synchromodal solutions. These solutions, however, rely on network openness and the benevolence of other carriers to change modes flexibly at any time. Our work presents the benefits of having such an open network where orders may be transported by a different mode, depending on their availability in geographic space. When allowing for a five-day time window, a 26.5% modal shift is possible, incurring savings of 5% in costs and 16% in CO_2 emissions per year. These estimates change if a stricter time window of 2 days is imposed. In that case, only a 14,5% modal shift is possible, but still relevant savings of 0,5% in costs and 10% in CO_2 emissions per year are possible

Next, 3 disruption profiles were tested and compared between the static and synchromodal setting. Deliveries under disruption profile 1[1] (frequent and short disruptions) are robust enough for small deviations. With regard to disruption profile 2[2] (less frequent and slightly longer disruptions), shifting modes dynamically is not always required because of the extra deviations and unnecessary pro-activeness decrease the potential emission and time savings. Therefore the disruption severity needs to be considered when thinking about proactive solutions and whether these proactive solutions are worth the deviations and switching in terms of KPIs. Synchromodality does present a significant improvement when dealing with longer and more severe disruptions under disruption profile 3[3]. In this regard, more advanced algorithms would be needed to answer each agent’s question: should I stay or should I go?

Knowing the state of the transport system and its evolution allows for **more accurate and efficient policy rules to mitigate the undesired effects** of the system and its sub-parts. Synchromodality does offer more alternatives, but these alternatives should be assessed carefully as the performance may not always be more beneficial than the more static intermodal solutions.

2.2.2 Changes to the Way of Working (compared to BAU)

This paragraph is based on the paper by Cassan C.; Duran Micco J. (oktober 2021) [paper presentation] Can governance principles and business models of digital internet be translated to Physical Internet? Vervoerslogistieke Werkdagen, Mechelen, Belgium.

Early research mainly focussed on the standardisation of containers and equipment as a way to make PI possible. Consequently, ‘real world’ steps taken towards the Physical Internet at this point look to either standardisation of containers or the digitalizing of different documents exchanged between logistic partners. Although this facilitates cooperation and decreases the cost of interoperability, this doesn’t fundamentally change the way the logistic chain functions. Although some authors have referred to the potential of the Physical Internet to change

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[1] Probability of occurance per year = 30-40%, duration = 1-3 hours

[2] Probability of occurance per year = 6-9%, duration = 3-6 hours

[3] Probability of occurance per year = 6-9%, duration = 1-3 days

the business models in logistics, an exploration into new forms of organisation in logistics is still limited (Montreuil *et al.*, 2012b; Sternberg and Norrman, 2017; Zijm and Klumpp, 2017, among others).

As we are looking towards the Digital Internet for inspiration on how to organize our logistic flows, it seems logical to look in the same direction to identify possible novel business and organisation models for the Physical Internet.

One of the first business models that comes to mind when thinking of the Digital Internet, is the selling of ad-space on websites, called ‘programmatic advertising’. In this concept, a content creator offers space on a website for adds through a Supply-Side Platform (SSP), which auctions this ad spaces off to interested parties through an ad exchange using a specific bidding strategy (which may differ from SSP to SSP). Interest (and as a consequence price) may vary depending on how much is known about the user currently looking at the website and whether or not this user fits the target audience of the ad. A similar pricing model based on smart auctions has already been described in the context of the Physical Internet. For now, this work is focussing on perishable goods auctioning linked to smart logistics (Kong *et al.*, 2016) and less-than-truckload (LTL) request pricing (Qiao et al. 2020 and earlier work). Qiao et al. (2020) show that dynamic pricing in freight transport has not been applied (or even studied) widely. On the contrary, price decisions are mostly statical and do not include the forecasted opportunities at the next hub. To fill this gap, a dynamic pricing system for LTL is proposed, where the hubs are the active players, issuing the request to the transporters. This organisation stays very close to the concept of the Digital Internet, where routers decide independently on the next link a package of data needs to take.

Alternatively, one could look at the subscription model existing between Internet Service Providers (ISP’s) and their clients. These subscriptions work at different levels: an end-customer subscribes to an Internet Access Provider (IAP), who subscribes to a higher-level (backbone)ISP and so on. ISP’s of the same level generally work together based on ‘peering agreements’, where they agree to route all traffic from each other’s customers. Mostly this is done free of charge (bill-and-keep), assuming the net payment would be zero. Instead, they charge their customers (who again charge their customers and so on) for their subscriptions. The prices can either be fixed or depend on the number of access points or the amount of traffic. ASP’s typically offer different levels of access to their customers, with different access speeds, where higher access equals a higher subscription fee. A similar system is conceivable for logistics: a customer can subscribe to the services of a LAP (Logistics Access Provider), who is responsible for the last mile and the general service a customer receives. The customer can choose the level of access they want (1-day delivery, fixed-day delivery,…) and the location to which the delivery should be made (home, work, dropbox, flexible,…). This system has the benefit of allowing customers (both private and business) to choose their LAP freely and, as a result, allow LAP’s to compete to offer the best service to the clients. It also puts part of the delivery cost with the end customer, which makes them conscious of the cost of transport. Allowing clients to consciously choose a slower but cheaper delivery might also allow LAP’s to optimise their last-mile deliveries.

2.3 Possible applications of data sharing in PI

2.3.1 Route planning in the PI

This paragraph is based on the paper by Sun S., Cassan C., Macharis C. A Privacy-protecting Routing Algorithm in Physical Internet. To be published.

Currently, there is only a little research on route planning in PI due to the novelty of PI and its combinatorial optimising nature. It has not been long since the PI was justified as efficient, and various consequent research was conducted. A PI network is usually decentralised and involves multiple stakeholders playing different roles. And a fundamental focus of PI is to maximise the utilisation of the transportation resources on the network in such a decentralised and flexible way, which could involve not only routing but also container packing, truck scheduling, inventory planning problems, etc.

Sarraj *et al.* (2014) conduct comprehensive research on the multimodal PI network considering cargo consolidation, routing, and container bundling algorithms using agent-based modelling (ABM). They define every node on the network as a hub, which contains the agents to perform the cargo consolidation, routing and bundling functions in an organised way. The optimality is justified by an empirical study in France in terms of costs, time and environmental effects. Fazili *et al.* (2017) compare the PI with the conventional logistic system regarding container packing, truck routing and truck scheduling problems on a unimodal corridor network with 5 PI hubs. Both Sarraj *et al.* (2014) and Fazili *et al.* (2017) identify the trade-off brought by PI between time needed for container transfer and conventional objectives like distance and CO2 emissions. However, the routing algorithm implemented in both articles is the A* algorithm, with the unimodal network in Fazili *et al.* (2017) and Sarraj *et al.* (2014) not specifying whether the optimisation of the usage of trains is considered.

In essence, the problems in the PI logistic network to be solved have been well-researched, including the vehicle routing problem (VRP), shortest path problem (SPP), facility location problem (FLP), etc., which are quite similar to those in, for example, synchromodal transport.

VRP aims at assigning optimal routes for a fleet of vehicles which have to visit one or several nodes on the network, while not violating a set of constraints,. The ‘vehicle’ therein can refer not only to trucks but also trains or vessels. Depending on the set of constraints, VRP has a wide range of variants, such as fleet size limitation (FSVRP), capacity limitation (CVRP), heterogeneous vehicle (HVRP, various capacity for vehicles), time window (VRPTW), backhaul planning (VRPB), dynamic order (DVRP), open vehicle route (OVRP, the vehicle does not have to return to the depot) etc. Caceres-Cruz *et al.* (2015) classify the VRP variants and define the categorisations of rich VRP as it combines multiple constraints for a more complicated problem.

While VRP looks at the problem in a holistic view, SSP focuses more on the individual level. More specifically, SSP seeks the optimal route for each individual transport call. In a survey conducted by Madkour *et al.* (2017), the categorisation of SSP is well-defined. Both VRP and SSP have been researched for decades, and a clear stream of the solution indicates the transfer from exact methods to approximate methods for problems on a larger scale, which are basically heuristics, and meta-heuristics that are tailored to the problem to be solved.

There is a recent concept of synchromodality that uses all the available resources on the network in an integrated way so that the transport process is optimised and flexible (Pfoser *et al.*, 2022). Synchromodality is generally regarded as a further step to multimodal and intermodal transportation with heavier stress on horizontal collaboration and information interconnectivity. Its problem setting is more realistic and complicated compared with VRP variants. Although it is not formally defined as such, it is generally considered as a centralised approach in which data collection and optimisation is done by a neutral orchestrator.

Going beyond the concept of syncrhomodal, PI adds a standardised design on the size and smartness of the transport units, decentralised management of the information system, different types of ‘nodes’ unified as ‘routers’ on DI, etc. Therefore, the design of the routing scheme of PI can learn from the synchromodal transport while being decentralised. Without the neutral orchestrator proposed in synchromodality considerate has the potential to increase the acceptance of the stakeholders due to the decentralised data-sharing protocol and **higher commercial privacy**. Without the neutral orchestrator, who is by definition local and linked to a specific area or corridor, PI also offers the ability to expand to a **true world wide web**, offering a direct service to global supply chains.

2.3.2 Agent-based modelling to investigate PI

This paragraph is based on the following paper: Ambra T, Caris A, Macharis C. Should I Stay or Should I Go? Assessing Intermodal and Synchromodal Resilience from a Decentralized Perspective. Sustainability. *2019; 11(6):1765.*

Agent-based modelling presents a solution to capture the behaviour of assets and their performance in recovery situations under disruptions. Agent-based models (ABM) have a very high potential as a result of the advancements in object-oriented programming languages in computer science that have the ability to represent heterogeneity in physical and human systems (Batty *et al.*, 2012). ABM include heterogeneous agents with different knowledge of their environment and layouts (Crooks and Castle, 2012). Agents may represent trucks, trains, barges, orders, terminals and various other entities. These entities have the ability to self-organise locally, which may lead to a significant reconfiguration of relationships and processes based on internal perturbations or external shocks (Raup, 1997).

Agents can process and **exchange information** with other agents as well as perceive other entities, and obstacles or sense their surroundings (Heppenstall *et al.*, 2012). Such agent characteristics allow for simulating the behaviour of assets from a decentralised perspective, mimicking the real-world behaviour of individual companies. In terms of freight transport and ABM applications, Baindur and Viegas (2011) focus on agent interaction by simulated contracts while considering road and short-sea shipping. A participatory simulation gaming approach in an urban freight transport context is studied by Anand *et al.* (2016). The agent entities are depicted as decision-makers who do not fully exploit the possibilities of autonomous and decentralised agent routing strategies and consequent distance collection in case of deviations induced by disturbances. Lastly, the work of Fikar *et al.* (2016) assesses the impact of the transalpine rail network disruption by using ABM. The work of Ambra et al. is continued within the PILL project, making use of all the above-listed research progress and combining synchromodal and disruption advances as well as advances in agent-based modelling.

Since agents are local, they **monitor** the value of system variables locally as well, without averaging and thus without losing the local idiosyncrasies or individual specificities that can determine overall system behaviour (Berinde *et al.*, 1975). In this regard, there is only a limited number of quantitative studies (Zhang and Pel, 2016; van Riessen *et al.*, 2017; among others). Earlier, more analytical approaches assessed freight systems from a central perspective, considering how the solution can work in the most efficient way for the given centralised system or corridor. Yet little has been done from a decentralised perspective where the needs and objectives of cargo owners can be considered.

In PILL, we use an Agent-Based Model to simulate the PI’s peer-to-peer network where information is shared, like node capabilities and transport information, as well as the physical movement of containers between the different locations. This is explained in more detail in chapter 6 of this document.

2.4 Research gap addressed in PILL

The Physical Internet holds the promise of realising a more efficient, fair and sustainable logistic system. Standardisation of both physical assets and related data can increase the access to and use of alternative modes significantly, also for smaller shipments and/or players. Through ABM modelling, where individual 'agents' can mimic the decisions of individual companies and drivers, the opportunities for increased modal shift, lower costs, lower emissions and potential higher resilience have been proven. However, a strong gap between this academic research and real-life applications remains, as the high level of data sharing necessary to achieve these benefits conflicts with the commercial interests and the current way of doing business of the individual companies involved.

Within PILL, the goal is to investigate how a real-life application of this concept could function within the context of the Port of Antwerp-Bruges, and its hinterland connections. Initially, five research questions were formulated in the proposal:

1. What type of data infrastructure is needed for maritime ports to act as PI nodes?
2. What should a Digital Twin of a PI node look like?
3. How can PI containers be equipped to support maritime ports in their role as PI nodes?
4. How can complex Agent-based modelling contribute to the PI node interface for maritime ports?
5. What business value can the PI create when utilising ABM and Digital Twin components in PI nodes?

During the exploratory phase, we regrouped and rephrased these questions to better suit the main issues brought forward by reviewing the literature and discussing them with the advisory board members.

1. The Physical Internet is founded on extensive data-sharing between (competing) logistic companies: **How can the necessary data be shared without infringing commercial privacy?** This question starts from RQ1 and RQ 3 but takes a slightly broader view:
    - The specificity of a maritime port is abstracted away from the data infrastructure: any node within a PI would be similar in structure, and a maritime port is only a larger and more complex manifestation of a node.
    - On the Flemish scale, it makes more sense to look at the maritime ports as a cluster of individual nodes (terminals, hubs,…) rather than one big node. We found that in practice, logistic companies responsible for the hinterland connections plan transports based on these individual nodes rather than on "the port" as such (see chapter 3.2).
    - Data shared by individual containers is only one possible source of data to be shared and is not necessarily the most appropriate source of this data. We found that most movers are already tracked by their respective owners (or operators), who also have an overview of which container is linked to which mover. The main focus then becomes how to consolidate and share this data with the appropriate parties.
    - For specific containers (reefers, dangerous or valuable goods), additional monitoring might be appropriate (temperature, shocks and vibrations, door opening and closing) might be relevant. Some of the advisory board members already offer solutions to track this kind of data. We, therefore, decided to focus on the aspect of integrating this data into the larger data infrastructure rather than focusing on the infrastructure needed for the collection of this data as such.

2. Logistic planning is often still done by humans. When the amount of available data increases due to the PI, keeping track of these large amounts of data will go beyond the capabilities of the human brain. It therefore becomes relevant to develop modelling tools to support human decision-makers: **How can ABM contribute to evaluate the impact of implementation details and management and policy decisions?** This question starts from RQ 2 and RQ 4 but turns the focus towards the practical uses of these models and their data requirements.
    - The first iteration of the ABM model developed in PILL is mainly aimed at creating a risk-free environment to test potential PI configurations within the PILL project. As such, it serves as a tool to test implementation details (such as routing algorithm parameters, reservation time limit, inclusion and possible types of reliability measures, disruption handling rules,…).
    - This type of model could be adapted to be used as a tool for individual logistic companies to run their own tests and simulate the effect of service, infrastructure or policy adaptions or for governments to test the effects of new policies or infrastructures. This type of application requires aggregated historical data on the entire network. It is therefore relevant to investigate which are the minimal data requirements to run this type of model and if this is data other parties would be willing to share.
    - The current model is based on historical data of the advisory board members. The same components could be used for handling real-time data, again providing a risk-free environment to test, for instance, possible reactions to disruptions. This type of application requires detailed real-time data to make accurate predictions and enable fast decision-making. As this data is sensitive, access will probably be more limited. It is therefore relevant to investigate if this type of application is accessible for private players or if this is an application that would be more oriented towards infrastructure managers (port authorities, railway, waterway or road network managers,…)
    - Apart from (more complex) modelling tools, decision-makers would also need appropriate routing algorithms to help them devise routes through the complex network at an operational level. Therefore we added the question of how a PI-based route-finding algorithm could look and what the advantages are compared to more classic approaches.
3. For any new system to be accepted in the real world, it needs to make sense from a business perspective. We found that, although ABM and Digital Twins are relevant tools individual companies or governments might use, the main issue is the business logic behind sharing the relevant data. We therefore rephrased RQ 5 to: **What business value can the PI create while respecting the commercial privacy and individual interests of each actor?**
    - We aim to assess the (perceived) risks of data-sharing among logistic companies and propose alternative ways to share the data needed while avoiding those risks.
    - We aim to map the attitude of the different players towards what is (perceived as) a fair way of sharing the benefits (and risks) of a PI network.

3 The current logistics ecosystem connected to the Port of Antwerp-Bruges

3.1 General port operations

The PILL project focuses on providing alternative routes for the existing container import and export flows adapted to the concept of PI. To get a good idea of what would need to change to make this happen, we must first look at the current flows.

Port functions as the interface connecting the waterway and road transportation, handling the import and export of cargo with different types of terminals. Many companies and organisations, such as forwarders, shipping agents, customs, and factories, are based in the port area to provide swift logistic services like container maintenance, clearance, etc. The container terminal has a frontier, yards, freight station, control tower, gatehouse and supportive facilities. Containers are loaded/unloaded through the frontier, which can also shortly store containers. Containers for longer storage or re-stuffing goes to yards or freight station. These containers enter and exit the terminal through the gatehouse, while the control tower manages the plans for stowage, yard and shipping. Supportive facilities maintain and wash containers for future use.

A short description is given below. For a more extensive overview of general port operations and container flows, we refer to D1.3: Maritime port and container logistics infrastructure and procedure mappings.

3.1.1 Container export process

The process described below gives an indication of a simple container export process, which involves a shipper (owner of cargo), forwarder, carrier (or its shipping agent), trucking company, a port operator and customs. It is assumed that the container is stuffed and unstuffed at the shipper's site, and the cargo is not required to be inspected by a permit-issuing authority (PIA).

Pricing

When a shipper receives an order from a buyer, he will have the need for shipment. However, maritime shipment has complicated processes and lots of documents to prepare, for which the shipper does not always know well about the maritime transport process. A freight forwarder can be an intermediate agency to provide service for shippers, carriers, and customs. Sometimes, a forwarder can have its agencies at ports all over the world to ensure the full coverage of shipments. To respond to the enquiry, the forwarder should calculate the price according to the goods to be shipped. The pricing could be different for a full container load (FCL) and less-than-container load (LCL).

The total maritime freight charges include inland transport costs, port charges, ocean freight, and document and handling charges, in which ocean freight (O/F) is the sum of basic ocean freight (BO/F) and surcharges. Inland transport costs and port charges can be calculated according to the incoterms agreed between the shipper and buyer. The calculation of BO/F varies in the charging policies, mainly by the number of containers to be shipped, either dependent (freight for class, FCS) or independent (freight of all kinds, FAK) on the class of the cargo.

The pricing is generally the same with FCL. However, if the cargo to be shipped cannot fill a container, the shipper can either request a pick-up service at his factory or warehouse or deliver the cargo to CFS so that the forwarder can consolidate it according to the destination of the cargo. Sometimes, if the destinations are not the same, the container could be further unstuffed and re-consolidated. This will vary the total freight charges.

Booking

According to the information on the cargo to be shipped, the shipper and the forwarder sign the Shipper's Letter of Instruction (SLI), in which the following information is confirmed and included: port of loading (POL), port of destination (POD), shipper, consignee, goods description, weight, measure, and price. Special instructions are also to be specified here, for example, loading terms (door-to-door, CFS, CY), cargo prepared time, clearance party, fumigation, bill of lading (B/L) instructions (original B/L, Telex release (TLX) or seaway bill), etc. Then the forwarder makes the booking request by sending a booking note (B/N) to the carrier. If the carrier accepts, booking confirmation is sent back with specifications on the time and location to pick up empty containers and return full containers.

Stuff cargo and declaration

The declaration can happen either after, during or before stuffing cargo to save time for transporting and exchanging nonconforming products. The basic process is preparing documents, audits, tax payments, random inspections, and releases, but we do not elaborate on it here as it is less relevant to physical logistics.

For FCL, usually, trailers are arranged to pick up empty containers from an Empty Depot (where empty containers are stored) and transport the full containers to the terminal, during which the containers are loaded and sealed at the factory or warehouse of the shipper. The operations should be done before a few deadlines, or some costs can be incurred. For example, a late fee should be paid for the late return of containers; if containers need to change vessels, the movement and storage during the waiting period will be charged. While for LCL, the cargo should normally be sent to CFS for consolidation.

Bill of lading

After containers are loaded to the vessel, the master bill of lading (MBL) will be issued by the carrier to the forwarder or the shipper (according to the party in the 'consignee' field in the MBL). MBL is the proof of the ownership of cargo, by which the corresponding containers can be picked up at POD by the 'consignee' written on the MBL. However, for LCL, the usual case is that both shipper and the consignee specified in the MBL are the same forwarder because carriers are not going to handle the consolidation of containers and are not well aware of the contents in the containers. If MBL is issued to the forwarder, a house bill of lading (HBL) is then to be issued to the shipper by the forwarder, which, however, cannot be the real proof of ownership. Instead, the forwarder owns the actual control of the containers and the goods, and the consignee can pick up the cargo with the HBL from the forwarder.

The previously mentioned B/L with the consignee specified is called straight B/L, and the container can only be picked up by the specified party. But as B/L is issued when containers are loaded onto the vessel, at the time point when the name is specified on the B/L., the ownership of cargo is transferred. Therefore, sometimes, the order B/L is issued for the shipper rather than the consignee to remain the owner of the cargo before the payment arrives. The' consignee' field is 'To order' instead of a specified name. Order B/L can be transferred by endorsement (and thus the ownership of goods). Very occasionally, a blank B/L (also called bearer or open B/L) is issued, with the 'consignee' field left blank, indicating that anyone who holds the blank B/L can pick up the containers from the carrier.

3.1.2 Container import process

The import process is much simpler than the export. When the ship arrives at the POD, the port operator will request the manifest (M/F) and bay plan of the ship. A terminal operation plan will be made accordingly, and the containers will be stored in the CY. For FCL, in which the consignee holds the MBL, he may contact the agency of the shipping company and obtain an EIR and Delivery Order (D/O). MBL and D/O are on the list of needed documents for clearance in the next step. After the cargo is released, the consignee may contact the transport company to pick up, unstuff and return the container.

If the consignee is not located in the customs territory of the POD, customs transit can happen to get clearance at the customs other than the customs of the POD. The broker can apply for customs transit. Then the imported containers will be sent to the local customs, and the logistic parties will go through the rest of the procedures similarly. Customs transit can also be applied for export containers in a similar way.

In the case of LCL, when the forwarder is the actual consignee, the forwarder presents the MBL to customs to get multiple D/O’s. Then the cargo owners can exchange their D/O’s with their HBLs with the forwarder and pick up their cargo at the port warehouse.

3.1.3 The process at the Port of Antwerp-Bruges

In Port of Antwerp-Bruges, many applications provided by the NxtPort platform already aim at digitalizing the different cargo flows moving through the port. The main focus of these applications is to alleviate the administrative burden of import and export goods and to increase the throughput of the port by better planning possibilities. The NxtPort platform and the applications offered by it could be considered as a ‘pre-PI’ system, offering better datasharing and planning to its users. Although connections to other port-platforms worldwide have been made, the NxtPort platform still has a more centralising tendency. We therefore cannot consider it to be a full PI system yet.

An application specifically relevant to mention is the Certified Pick-up (CPu). CPu is a neutral and centralised data platform by NxtPort. It provides the service of real-time notification of Pickup Right to the authorised entities securely and timely. Within the platform, Pickup Right functions like the B/L, representing the right to pick up the cargo from the terminals. The Pickup Right can be transferred among the parties in the system depending on the operations process, while once a party transfers a Pickup Right, it can no longer use it.

CPu mainly affects the container import process. Under the framework of CPu, a Ship Agent must notify the manifest to the platform about the import data. After containers are unloaded from a vessel and permitted to leave the terminal, the Terminal Operators will have to send the respective notice to the platform. A ship agent sends notice of Commercial Release to the corresponding Release Right owner and identifies the owner in the collection process (e.g. truck and train operators). The customs also must give a green light before the containers are ready for pick up. Finally, the Pickup Right will be validated when collecting the containers from the terminal.

Using CPu, the container import process has been following the diagram below:

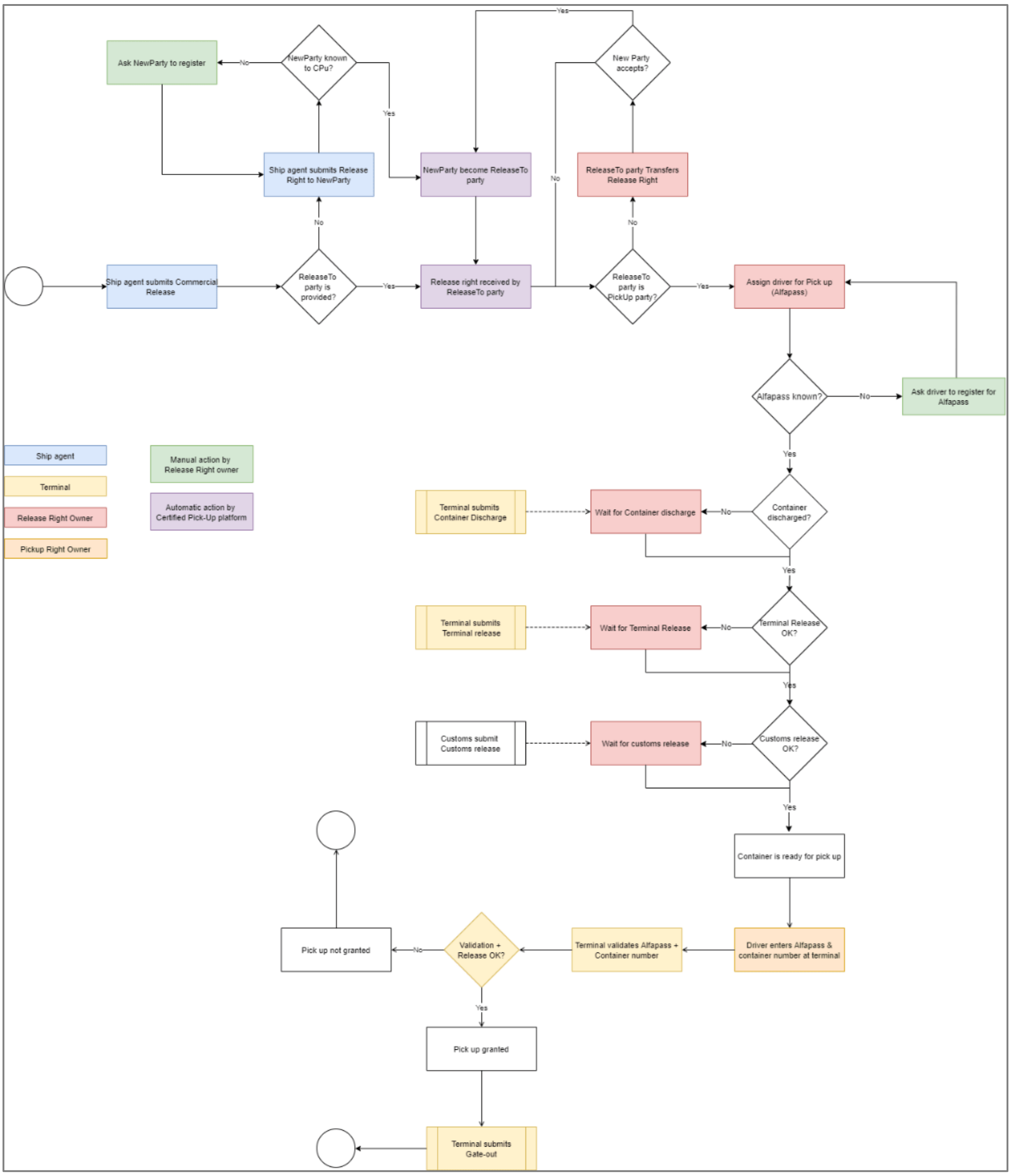


Figure 3. demonstration of CPu import process

The digitisation in the port by CPu involves external parties, and the process is thus automated. This is different to the conventional intra-port information management system. Therefore, although being a centralised system, we also consider it as a step towards PI.

Apart from NxtPort, there are a multitude of existing platforms and projects that are relevant to mention as they provide services that represent elements of PI. We refer to D1.1 Business case review - PI-related platforms and PI-related projects for a more detailed overview.

3.2 Zoom on our stakeholders

This paragraph summarises the results described in deliverable D1.2: Stakeholder map. A more in-depth sketch of the PILL stakeholders and their interactions can be found there.

3.2.1 Stakeholder overview

The stakeholders of PILL represent three distinct groups involved in the logistic process. A more in-depth explanation of the different roles is given in chapter 4.5 Business Layer and D1.2 Stakeholdermapping.

- Logistic roles: these are the roles directly involved in the moving of cargo
    - Delcatrans: Delca Transport is a family-owned company that was founded in 1980 in Dadizele. In 2000 they moved to industrial zone LAR in Rekkem, where they now own their own rail terminals. In Wielsbeke they partake in an inland water terminal. From these terminals they organise both national and international shipments of containers to and from the port of Antwerp and Bruges.
    - ECS: ECS is a leading provider of integrated supply chain logistics and intermodal transport solutions. Founded in 1995, our family-owned company with headquarters in Zeebrugge, spreads its activities over more than 35 European countries, specialising in transport and logistics between the UK and Ireland, and the European mainland. ECS doesn't own any movers but organises transports with other companies, with a focus on (long distance) train and short-sea travel.
    - Lineas: Lineas is a European rail freight & logistics company which is the successor of the freight division of the former Belgian national railway company NMBS/SNCB. They operate a rail-road hub node within the Port of Antwerp. As a major stakeholder provider of rail freight services in Belgium, it is a crucial actor to facilitate PILL's PI-oriented Living Lab interventions.
    - DPWorld: DP World is a leading stevedore in the Port of Antwerp. DP World Antwerp operates the Antwerp Gateway terminal at the Deurganckdock. Complementing the container terminal is Empty Dpot Services, a 100% dedicated container maintenance service primarily for DP World Antwerp Gateway customers. On the right bank, DP World Antwerp is operator of the HUPAC rail terminal.
    - PSA: PSA Antwerp is a leading container terminal operator in the Port of Antwerp and belongs to PSA international. PSA operates 3 container terminals and 1 breakbulk terminal in the Port of Antwerp. All our terminals have tri-modal access and are equipped with state-of-the-art infrastructure, facilities and equipment. Additionally, containers can be stuffed and stripped by specialised personnel at all our terminals.
    - P&G: Procter & Gamble is a multinational corporation developing, manufacturing & marketing consumer packaged goods in numerous sectors. P&G has a production site in Mechelen where containers come in from and go out to the port of Antwerp. In 2010, P&G declared a set of goals and commitments to reduce our environmental footprint across climate, water and waste. P&G's ambitions for 2030 include reducing carbon emissions. To realise this goal, the plan to advance at least 10 significant supply chain partnerships to drive circularity.
    - TRI-VIZOR: TRI-VIZOR nv is a spin-off company of the UA founded in 2008. The mission of TRI-VIZOR is to support logistic companies in their evolution to the highest maturity level in supply chain management today. During the last years, TRI-VIZOR has acquired a unique and strong reputation in cross company horizontal collaboration and consolidation. TRI-VIZOR acts as 'neutral trustee' and 'orchestrator' for logistics horizontal collaboration.

    - ETP Alice: ALICE is the European Technology Platform for Logistics, recognised as such by the European Commission. ALICE is setting up a research and innovation strategy for logistics in Europe. We believe future logistics will be based on an open global system of systems connecting logistic networks seamlessly and founded on physical, digital and operational interconnectivity enabling substantial increase in efficiency and sustainability. This vision is called the Physical Internet (PI). We expect first industry use cases to be fully functioning by 2030. In the long run, by 2050, we envision a world in which freight transport and logistics is close to zero emissions.

- Policy roles: these are the roles responsible for setting the framework. They can be part of a government but not necessarily
    - Port of Antwerp & Bruges: The port of Antwerp is the second largest European port, 237 mio tons of cargo flow through the port each year and generates 20 billion € added value on an annual basis. Port of Antwerp of Antwerp handles about 10 mio TEU of containers each year and is a gateway to the European industrial hinterland. Zeebrugge, the seaport of Bruges, is one of the world’s foremost roll-on/roll-off ports. Here, 47 million tons of goods were transhipped in 2020, of which 38% were containers (1,8 mio TEU). As a non-industrial or “clean” port, Zeebrugge is the ideal location for combining perishable food cargoes.
    - Air cargo Belgium: Air Cargo Belgium (ACB) is an innovative cluster of air cargo companies. ACB’s main objective is to achieve a competitive advantage for ‘our’ air cargo community in Europe. Therefore, on behalf of forwarders, handlers, airlines, the airport authority, and other stakeholders, ACB contacts all stakeholders and governmental agencies to discuss topics of common interest and we take the lead in different (innovative) improvement projects. At all times, our goals and objectives are in the interest of the air cargo community as a group and to the overall benefit of our industry.
    - POM West Vlaanderen: The West Flanders Development Agency (POM West-Vlaanderen) implements the social-economic policy of the Province of West Flanders by means of initiating and coordinating activities and projects focusing on sustainable entrepreneurship, business infrastructure, innovation, and international business support. The aim is to reinforce West Flanders as an internationally oriented, dynamic, competitive, and innovative region with a positive working climate and attractive business environment.
    - Flemish Waterways: The Flemish Waterways (Vlaamse Waterweg nv) manages and operates the Flemisch waterways as a powerful network that contributes to the economy, prosperity, and liveability of Flanders. Vlaamse Waterweg nv strengthens transport via inland shipping, ensures water management and increases the attractiveness of the waterways for recreation, tourism and nature.
    - MOW: The Flemisch Department of Mobility and Public Works (MOW) supports the policy of the Flemisch minister responsible for mobility and public works and supports management and operation of the Flemish transport and port infrastructure.
    - Belgian Customs: The customs authorities oversee protecting the European Community’s and its Member States’ financial interests, with the collection and the checking of the import duties, the excise duties and the VAT at importation. The excise authorities oversee the collection and the control of products with excise duty in Belgium or the European Community.

- Governance roles: these are roles responsible for handling the digital requirements of the PI. They provide IoT devices, software or algorithms.
    - Dockflow: Dockflow is a company that enables forwarders, shippers and importers to transition from an old-school paper-based way of doing business to digital operations. To achieve this Dockflow has developed various software products that offer visibility of the internal and

external processes. As a result, enormous amounts of time and effort can be saved and costs can be cut, which allows these parties to focus on their core business.

- Ubidata: Dockflow is a company that enables forwarders, shippers and importers to transition from an old-school paper-based way of doing business to digital operations. To achieve this Dockflow has developed various software products that offer visibility of the internal and external processes. As a result, enormous amounts of time and effort can be saved and costs can be cut, which allows these parties to focus on their core business.
- GS1: GS1 is a global standardisation organisation with local presence in over 15o countries including Belgium. We empower organisations to develop efficiently, sustainably and safely — helping transform the way we work and live. Our standards enable organisations to identify, capture and share information smoothly, creating a common language that underpins systems and processes all over the world.
- Lanark: Lanark is an Antwerp-based startup active in Digital Supply Chain Engineering. We see supply chains as value drivers opposed to cost drivers. This is driven by better visibility, data sharing and new ways of collaboration between supply chain partners. Our team of Digital Supply Chain Engineers helps our customers with design, selection or development, implementation and operational use of digital solutions.
- Rombit: Rombit helps industrial organisations to excel in efficiency, safety and security through innovative technologies. Supported by a specific know-how of the port industry and the technological capacity to develop integrated hardware and software solutions, Rombit enables its customers to become and stay resilient in a changing world.
- Sensolus: Sensolus is an Industrial Internet-of-Things company, based in Ghent, Belgium. Sensolus brings value to the supply chain & asset monitoring processes of their clients by offering end-to-end IoT solutions. By combining smart sensors, low power communication networks (LPWAN) and cloud analytics. Sensolus reduces operational costs and increases asset up- and usage time.
- Microsoft: Microsoft Corporation is a multinational technology company. It develops, manufactures, licenses, supports, and sells computer software, consumer electronics, personal computers, and related services. For the PILL project Azure IoT Edge, a fully managed service built on Azure IoT Hub33 is relevant. This system allows the deployment of cloud workloads—artificial intelligence, Azure and third-party services, or business logic—to run on Internet of Things (IoT) edge devices via standard containers.
- T-Mining: Based in Antwerp, T-Mining makes maritime logistics processes like Secure Container Release more secure and efficient. Every day, more than 1.000 companies in over 20 different countries use our solution and infrastructure. By using decentralised technologies such as blockchain and implementing concepts like Self Sovereign Identity (SSI) and Commercial Privacy, we provide the industry with easy-to-use instruments to remain in control of their data. T-Mining has a radical new vision on how to design and develop applications, using decentralised technologies like blockchain, allowing businesses to take back control over their identity, privacy, and data.
- The Beacon: The Beacon is an innovation community, bringing together tech companies, research, skills, innovation actors and citizens to collaborate on smart solutions for keeping this world livable and sustainable. It focuses on Smart Cities, Smart Mobility, Smart Port & Logistics, Smart Industry and Smart Buildings. The Beacon is an AI and IoT community and the launchpad for your products and solutions, through interaction with a larger ecosystem which is expanding every day.

3.2.2 Geographical links

Many of these stakeholders are active in or have a connection to the Port of Antwerp-Bruges. This makes the Port of Antwerp-Bruges the main node in our π-model. Besides the port authorities, several PILL stakeholders operate a node within the port. These are:

- MPET terminal (PSA)
- DP World terminal (DPWorld)
- PSA Europe & North sea terminal (PSA)
- Lineas Main Hub (Lineas)

Within the port of Zeebrugge, ECS operates a warehouse from which transhipments of local truck movements to European rail and shortsea destinations are organised.

Other stakeholders operate nodes outside of the ports, creating the connection between the maritime port and the Flemish hinterland. These are:

- Wielsbeke river terminal (Delcatrans)
- Rekkem train terminal (Delcatrans)

The P&G warehouse at Willebroek is connected through the port via the Trimodal Container Terminal (TCT) operated by Hutchinson Ports at Willebroek.

These nodes connect to form an extensive network for the transport of maritime and continental containers through the Flemish hinterland. As all nodes are connected by road, these are not stated explicitly in the figure below. In addition, all nodes within the Port of Antwerp-Bruges have a connection by waterway (dedicated to shuttling or by inland barges that visit multiple terminals). As these are highly irregular, they are not mentioned in the figure below either.

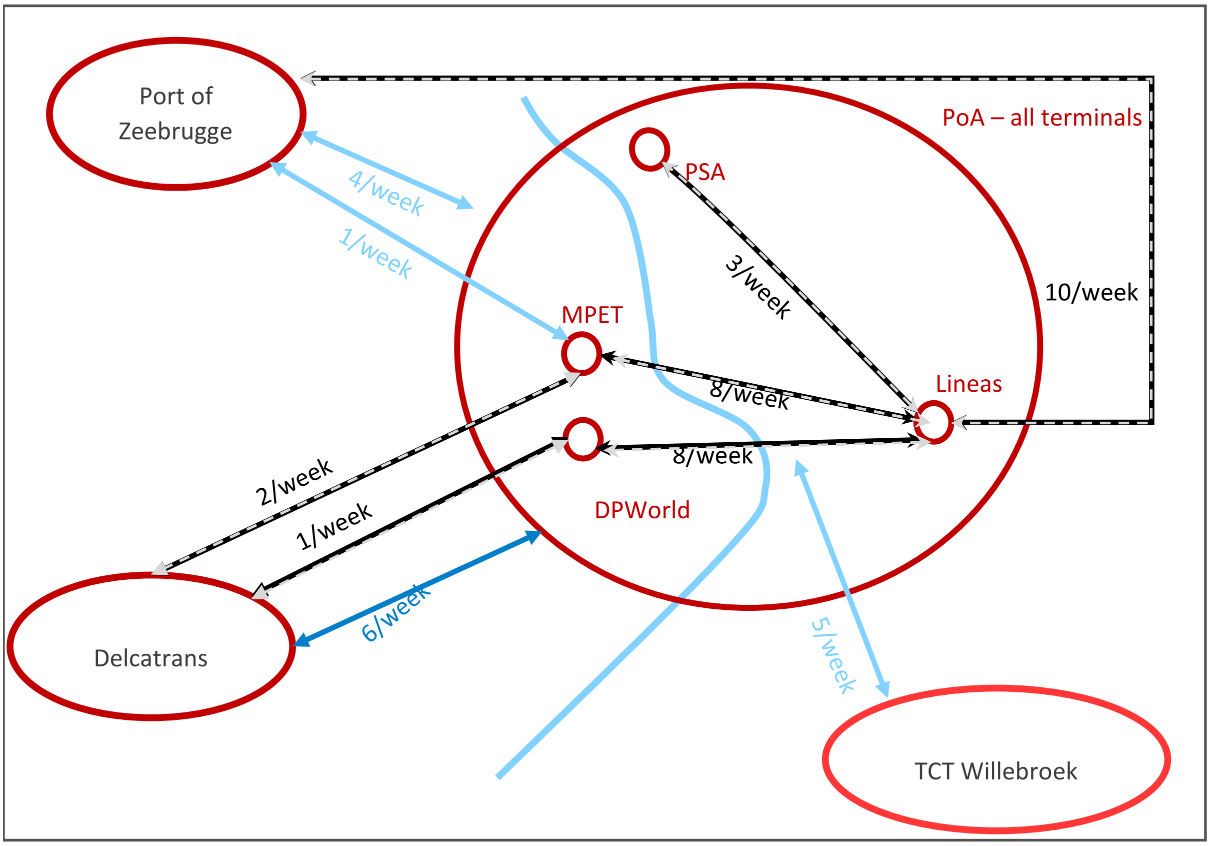


Figure 4. connections within the Port of Antwerp-Bruges (lighter colours: not operated by PILL stakeholder)

3.2.3 Functional links

All partners in this project are today, directly or indirectly, linked to each other in their day to day business. This means they already exchange information, goods, services and/or money with each other. As described above, a main desired outcome of the project is improved data sharing. This in turn is expected to result in other outcomes, such as better utilisation of assets and positive impact on sustainability and business results.

A first conclusion that could be drawn from the interviews with the board members and the board meetings is that connections between all actors are very intertwined and have a web-like structure. There is no one central player, connecting everybody, nor are there distinct groups to be determined. The board members with the highest number of connections to the others are Delcatrans, Lineas, PSA and both ports (now Port of Antwerp-Bruges).

The PILL board members form a good representation for the Flemish logistic ecosystem. Representatives of the tree main business roles involved (logistic, governance and technological) are present.

We also found that the PILL board members have a lot of connections to other logistic players within Flanders and further. Although only 24 stakeholders are directly involved in PILL, changes made by the project to the logistics sector could possibly impact a much larger number of actors.

3.2.4 Conclusion

As shown in this chapter, the board members of PILL are stakeholders with an active interest in PI, already exploring the possibilities for future developments within their own company. They expect PI to provide important benefits to their current day to day business, and are eager to incorporate key learnings of this project. This will ensure the incorporation of the PILL findings in the Flemish logistic ecosystem.

We have also shown that the PILL board members are key players within the logistic ecosystem in Flanders and even the world. This makes them influential partners who’s choice to adopt a certain technology or way of working may affect the choices of many other players within the ecosystem. If the test proves successful, the solution is therefore not only likely to be adopted by these partners, as they are already open to the concept of PI and were active participants in the project, but is also likely to be adopted by the larger ecosystem.

We also found that connections between all actors are very intertwined and have a web-like structure. There is no one central player, connecting everybody, nor are there distinct groups to be determined. This supports our approach of a decentralised network, as this aligns with the current organisation of the network.

3.3 User story and assumption maps

After the first step of familiarising ourselves with the stakeholders, their main interests and motives and their relationships, we continued to identify the main challenges, requirements, and solutions for the PILL information system to address during this process. We also defined specific business roles PILL stakeholders can fulfil, grouped into three main roles: logistic, policy and governance. These business roles were then used to construct the specific user stories in the current document (see D1.2 Stakeholder mapping for a detailed overview).

We then focussed on the development of the use cases and assumptions. In the following paragraphs, the main challenges and high-level use cases will be laid out. Next, we give an overview of the main assumptions that exist towards the use cases and were identified during the process of creating the use cases. For a more detailed overview of the use cases and assumptions, we refer to document D1.4 User story and assumptions map.

3.3.1 Key Wicked Problems

As explained before, freight transport today is under pressure to revise its way of working between increasing demand on the one hand and high ambitions for sustainability on the other hand. At the same time, logistic companies are not yet using the full capacity of the network. Many companies focus on road transport with known partners and have little knowledge of optimisation opportunities. They are unable to evade known bottlenecks in the network as they have only limited insights into workarounds and optimisations. The basis of this is a digital disconnect between the different stakeholders. Because of this, companies focus on internal optimisations. Digital transformations are done through non-scalable point-to-point solutions, making a more interconnected network hard to achieve. This specifically hinders smaller players, as they are forced to either commit to work with one higher-level LSP only or to combine the use of several non-matching standards (adding to the administrative workload and the risk of errors).

Through discussions with our Advisory Board members, we identified three key (Wicked) problems arising from this state of affairs, which are to be addressed in PILL:

(1) Due to the steady increase in maritime vessel size (leading to a decrease in costs) and the importance of global supply chains, container transport has risen all over the world. The current logistics system has not been built for these (peak)volumes of containers and is becoming more and more incapable of keeping up with this increasing (peak)demand. This leads to congestion on specific nodes or links in the chain while other nodes and links still have capacity available. Due to the digital disconnect between parties, expeditors lack visibility on the overall capabilities and are not able to even consider alternative solutions.

(2) Due to the nature of the logistics process, it is vulnerable to small ad-hoc disruptions. Not everything in the real world can be predicted long in advance, like traffic jams due to accidents, technical malfunctions of infrastructure or equipment, flooding,… These disruptions are often out of the control of the individual stakeholders and often only appear late in the transport process. This necessitates the system to respond in real-time, while only limited real-time information is available. Solutions are therefore often suboptimal, adding to delays and costs.

(3) The asymmetric nature of most logistic flows often leads to equipment imbalances, which makes it necessary to reposition empty assets. This is mainly an issue for maritime containers and trucks, as they need to return to their home location. Although this imbalance is inevitable to some extent, it can be limited by taking the flows of other companies, moving in the reverse direction, into account. Filling up this empty capacity will reduce both costs and external impacts, as an additional trip is avoided. Additionally, being able to predict where and when an imbalance will occur will allow for a more efficient repositioning.

These three factors lead to a cascading effect of delays and changes in routes, making it hard to plan ahead and anticipate changes along the way. From this, three key wicked problems were identified: Improving interoperability between stakeholders, increasing resilience against disruptions and optimisation of the use of assets. Consequently, the PILL use cases were determined to provide (part of) a solution for each of the three problems.

The Wicked Problems, use cases and user stories in this chapter have been derived from in-depth interviews with stakeholders (following the stakeholder map Task 1.2) and refined through workshops and validation meetings with the PILL consortium partners.

Table 2. overview of wicked problems and related use cases

Wicked Problems:	**Focus of Use case:**
Improve planning reliability How might we increase the transparency of the activities of different stakeholders, so we can create more reliable planning?	**Optimisation of intra-port logistics processes** ***As a*** *logistics company active in the Port of Antwerp-Bruges,* ***I want to*** *better align with the planning of other stakeholders in the port* ***So I can*** *work more efficient and reliable.*
Increase resilience against disruptions How might we increase communication (data) about real-time availability across and the status of the network, so transporters and forwarders can make more validated decisions during disruptions?	**Aligning import and export in the hinterland** ***As a*** *logistics-related stakeholder in Flanders,* ***I want to*** *increase the real-time visibility of the hinterland network* ***So I can*** *better anticipate my route*
Optimise future (planning) processes How might we increase overall collaboration between stakeholders, so we can improve the overall efficiency of the logistics process	**Empty container flow optimisation** ***As a*** *container user,* ***I want to*** *better coordinate the flow and balance of my empty containers across the network* ***so I can*** *increase the efficiency of my transport flow*

3.3.2 Overview Use cases & User stories

In the previous chapter, we discussed how use cases were created based on the three key Wicked Problems that will be the focus of the π-blueprint. For each of the use cases, we defined 3-5 user stories together with logistics stakeholders that represented specific key challenges that logistics companies are struggling with today. These user stories were determined based on the 80/20 principle, which states that 80% of the problems derive from 20% of the activities. By solving these key user stories, we can thus assume we solve the majority of the challenges for each use case.

The three use cases were as follows:

1. **Planning of intra-port logistics processes**
   As a *logistics company active in the Port of Antwerp*-Bruges*,*
   I want to *better align with the planning of other stakeholders in the port*
   So I can *work more efficient and reliable.*

2. **Respond to disruptions**
   As a *logistics-related stakeholder in Flanders,*
   I want to *increase the real-time visibility of the hinterland network*
   So I can *better anticipate my route*

3. **Empty container flow optimisation**
   As a container user,
   I want to better coordinate the flow and balance of my empty containers across the network
   so I can increase the efficiency of my transport flow

Table 3. overview of the Use Cases and User Stories

Title	Description
Use case 1: planning of intra-port logistics processes	
Intra-port alternatives	**As a** (road)transport provider **I want to** have a better view of cross-bank transport possibilities (barge, train) **so I can** avoid congestion delays during truck transport
Next mode of transport	**As a** terminal operator **I want to** know the next transport modes **So I can** gain time to optimise my operations and reduce waiting times4nm1ew
Increase reliability of import moves	**As an** expeditor, **I want to** increase the reliability of my import moves, **So I can** optimise work schedules at the unloading location.

Title	Description
Optimisation of flows	**As a** policymaker **I want to** optimise logistic flows **So I can** reduce external costs.
Use case 2: Responding to disruptions	
Adapt to changing ETA	**As a** cargo owner **I want to** get an updated ETA **So I can** optimise my flow of goods
Make free capacity findable	**As a** transport provider **I want to** make my free capacity findable **So I can** reduce my empty kilometres.
Adapt route selection	**As an** expeditor, **I want to** be able to keep track of changing conditions in the logistic network **So I can** be able to optimise my transport flows as much as possible.
Optimise infrastructure use	**As an** infrastructure manager, **I want to** be able to guide traffic flows **So I can** make maximal use of capacity and reduce congestion to a minimum.
Use case 3: Empty container flow optimisation	
Container reuse	**As a** cargo owner **I want to** check if the reuse of an empty container is possible/profitable **So I can** avoid unnecessary trips with empty containers
Container repositioning	**As a** hinterland terminal operator **I want to** check if empty containers will be available/needed **So I can** balance my equipment

3.3.3 *The focus of the π-solution*

At the beginning of this chapter, we explained three key Wicked Problems (WP's) in the logistics sector that will be addressed in the π-blueprint solution through the use cases. These 3 Wicked Problems can be considered to appear in chronological order: first, the challenge of improving planning reliability before a transport, next, increasing resilience against disruptions during the transport. And lastly, optimising future logistics processes.

When scoring our solution assumptions, we notice this chronological order recurring as well in the importance of assumptions. Assumptions that relate to planning overall have higher perceived importance (by stakeholders) than assumptions to resilience or future optimisations (the latter which has the lowest). This is not only true for the perceived need or business perception but also from a technical standpoint. Being able to align planning (WP

1) is needed to reroute a shipment in real-time during or right before a disruption (WP2), as well as to optimise future planning processes (WP 3)

We can conclude that improving planning reliability (WP 1) is the most critical aspect of our solution, and with it, the capability to generate and compare route options based on information shared by the network. Consequently, this problem and its related use case and stories will be the main focus of the development and testing of the π-blueprint.

Considering the importance score for the 3 Wicked Problems, the first version of the π-blueprint will focus on Wicked Problems 1 and 2 (planning optimisation + resilience against disruption), with WP 1 being the priority. WP 3 (future planning) will be disregarded in the first version of the π-blueprint, with the assumption that this problem will rely heavily on the outcome of the first two challenges. This problem will be developed in a later phase of the project or in follow-up projects.

Table 4. summary of key assumptions (importance score = 5)

Parameter	**Assumption**	**Wicked Problem**
Desirability	All logistics roles want to improve their planning	1
Desirability	All logistics roles want to decrease the (unpredictable) delays in logistics	2
Desirability	Barge & train operators want to become more competitive by using their economies of scale	1
Desirability	All logistics roles want to optimise their free capacity	1
Desirability	Policymakers want to reduce the overall external costs of logistics	1
Feasibility	Routes can be generated between nodes	1
Feasibility	The π-solution is technology agnostic, meaning all logistics companies can integrate with it	1,2,3
Feasibility	Relevant alternative routes can be found already with a limited # of parties that join the system	1
Feasibility	Routing software can create optimised, multimodal route options with the available data	1
Feasibility	All stakeholders in the network have access to an updated list of each other’s business information and capabilities in order to calculate routes	1,2,3
Feasibility	Stakeholders in the network can interact with each other to plan or alter routes	1,2,3
Feasibility	Interaction between stakeholders can be automated	1,2,3

Parameter	Assumption	Wicked Problem
Viability	Logistics companies will accept integration costs to integrate with the π-system	1,2,3
Viability	The solution will result in more reliable transport that reduces the cost of delays or disruptions	2
Viability	All players are willing to share the relevant data with the network	1,2,3
Viability	The solution can work without compromising commercially sensitive data	1,2,3
Viability	The solution is capable of increasing the number of potential routes to choose from	1
Viability	The solution will reduce the cost of the overall logistics process by optimising the planning process	1
Viability	The solution will follow a set of rules that leads to a better flow compared to the BAU	1,2,3
Viability	The solution will result in a reduced CO2 logistics process	1,2,3

3.3.4 *Key challenges*

Reviewing the most important assumptions that determine the success of our solution (see Table 4), we can determine our key challenges in creating the solution, which is focused on solving Wicked Problem 1. These challenges will be the basis of the future stages of this project and the development and testing of the π-blueprint.

The key challenges can be defined and categorised as follows:

Table 5. research questions and key challenges

Category	**Data Sharing**	**Perceived Business Value**	**Decision-making (ABM)**
Research question	How can the necessary data be shared without infringing commercial privacy?	What business value can the PI create while respecting the commercial privacy and individual interests of each actor?	How can ABM contribute to supporting decision-makers in logistics, and can this evolve into a Digital Twin?
Key challenges: How might we...	Connect stakeholders with each other Share stakeholder data across the network? Share data without infringing stakeholders' commercial privacy Minimise data-sharing requirements to generate sufficient route options?	Create interoperability between stakeholders to plan routes? Automate the planning, booking and payment processes? Offer commercial value for all stakeholder groups?	Determine the unique roles in the transport chain that need to be planned? Use the ABM to determine the PI internal rules that lead to improved logistics planning and flow? Use the ABM to determine the PI internal rules that lead to optimally handling disruption? Compare route options based on price, cost, ETA and reliability

These research questions align with the research questions defined in chapter 2.4.

3.4 Conclusion

The container import and export process involve a large range of stakeholders having to interact with each other but is largely handled manually, which makes it a complex system prone to error. The improvement of data exchange for this flow would greatly improve administrative efficiency. On the other hand, the ISO-containers, with their fixed size, can be considered as a standardised PI container, in scope with the aim of PILL and PI. This makes the implementation of PI, where different actors are handling the same container, more easily achievable. Additionally, all ISO-containers are already identified by a standardized container-number, simplifying implementation of automated data exchange.

The Port of Antwerp is a central logistics node, not only within Flanders and Belgium, but within Europe and even worldwide. As a logistic centre, it has connections to a large number of transport service providers in multiple transportation modes, providing the possibilities to improve the container flow. The PILL board members from a network within Flanders strongly connected to the port, both physically (by providing logistic services from, to and within the port) and organisational (by joining in port related projects and communities). The Port of Antwerp is therefore also a central node withing the PILL network.

On the other hand, the high concentration of transport flows created by the ports key position creates congestion and decreases reliability of the hinterland flows. Additionally, the high number of concerned stakeholders, each with their own focus and interests, means there is only limited information available to each of them. As the visibility stakeholders have on the state of the network and the occurring disruptions remains limited, their ability to find alternative routes and react to disruptions remains limited as well. The goal of PILL is therefore to tackle these issues by improving data sharing between the relevant parties and, in doing so, create a better visibility and easier cooperation between the stakeholders.

The Port of Antwerp therefore is a logical choice as the focus of the PILL project:

- the high concentration of container flows and transport alternatives needed for testing the PILL solution;
- the port forms important connection between the PILL board members (and other relevant stakeholders), offering a collection of nodes where we can concentrate all interactions;
- the wicked problems identified are significant enough for the stakeholders to want to change their way of working.

4 Definition of the Physical Internet

This chapter provides (together with chapter 4) the content foreseen in deliverable D1.5: Technical Backlog and Architecture design

The Physical Internet (PI) is a concept that proposes to optimise logistics by applying principles of computer networks and the Internet to supply chain planning and operation. As such, it tries to perceive the network of logistics hubs and their connecting roads, railroads, waterways and air connections as a physical variant of the Internet. It then attempts to optimise logistics operations in the same way it is done on the actual Internet.

PI abstracts from the kind of logistics and the size of the network and can be applied to any kind of logistics network ranging from urban parcel delivery to global container transport.

PI tries to address problems resulting from the way supply chains are typically organised today. Some examples are:

- congestion points in logistics networks resulting from a focus on road transport
- capacity problems by limited knowledge of transport alternatives
- sustainability issues related to emissions, safety, livability and cost
- missed opportunities for optimisations in the network and planning

For a more detailed description of the concept of PI in literature, we refer to chapter 2. In this chapter, we introduce the concepts of PI as they are applied in the PILL project. As such, we are focusing primarily on container logistics.

4.1 The 5-layer model

The Physical Internet uses many concepts and abstractions for modelling logistics networks. In order to maintain oversight, we present a layer model for PI that groups concepts according to their concerns. We discuss each layer and its concepts in the following sections.

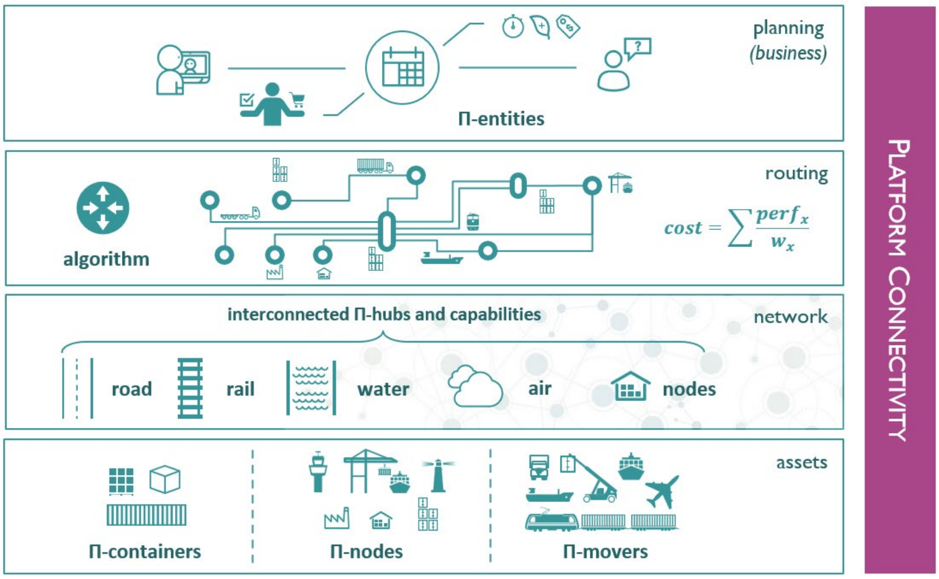


Figure 5. the 5-layer model

4.2 Asset layer

The assets are the basic building blocks of the Physical Internet. We divide them into three categories:

4.2.1 π-Containers

The Physical Internet does not manipulate physical goods directly, whether they be materials, parts, merchandise or yet products. It manipulates exclusively containers that are explicitly designed for the Physical Internet and that encapsulate physical goods within them. These containers designed for the Physical Internet are called π-containers.

The π-containers are the unit loads that are manipulated, stored and routed through the systems and infrastructures of the Physical Internet. They must be logistics modules standardised worldwide and defined according to open norms. They must be designed to facilitate their handling and storage in the physical nodes of the Physical Internet, as well as their transport between these nodes and, of course, to protect goods.

π-containers act as a counterpart of packets in the digital Internet. They have an information part analogous to the header in the digital Internet. Yet contrary to the digital Internet packets, the π-containers have a physical content and structure rather than being purely informational.

4.2.2 π-Nodes

The π-nodes are locations expressly designed to perform operations on π-containers (concept), such as receiving, routing, sorting, handling, placing, storing, picking, monitoring, labelling, (dis)assembling, (de)composing, and so forth.

There exist a variety of π-nodes delivering services of distinct natures, from the simple transfer of π-carriers between π-vehicles (see π-movers (concept)) to complex multimodal multiplexing of π-containers (concept): terminals, warehouses, container hubs, rail yards.

4.2.3 π-Movers

In the Physical Internet, π-containers (concept) are generically moved around by π-movers. Moving is used here as a generic equivalent to verbs such as transporting, conveying, handling, lifting and manipulating.

The main types of π-movers include π-transporters, π-conveyors, and π-handlers (humans that are qualified for moving π-containers).

These are respectively vehicles and carriers specifically designed to enable easy, secure and efficient moving of π-containers. They are differentiated by the fact that π-vehicles are self-propelled while π-carriers have to be pushed or pulled by π-vehicles or by π-handlers.

4.2.4 A note on asset IoT

In PILL we are not focusing on IoT devices and the possibilities they bring to track assets such as well as detecting potential disruptions. However relevant in the context of the Physical Internet, we believe it is too early to include them in the equation at this stage.

From a conceptual point of view, the IoT data streams can be used in several ways, for example:

- Track & trace: in this case the data is used to keep the stakeholders informed on the status of the container and the cargo. For this, the π-client (see chapter 5) needs to be able to receive push notifications coming from the decentralized network. Also, a security architecture is needed to ensure these notifications are only sent to the correct stakeholders.

- Detection of congestion and disruptions: in this case the π-client network can be used to detect congested roads by notifying third parties of unforeseen slowdowns.

Despite the clear added value of IoT data in the Physical Internet, the design aspects of making it flow across the π-client network are currently left out of scope for mree feasibility of the project.

4.3 Network layer

The network layer models the different networks (road, open water, inland water, rail, air, …) and their connections (typically terminals). It also defines the possible connections between the different nodes based on their π-node capabilities. The capabilities express what actions are possible within each node. We consider the following capabilities:

Table 6. the capabilities in PILL

π-transfer	Transfer of π-carriers from their inbound π-vehicles to their outbound π-vehicles.
π-hub	The intermodal transshipment of π-containers from an incoming π-mover to a departing π-mover.
π-store	Storage of π-containers during mutually agreed upon target time window.
π-gateway	Transfer of π-containers between (sub)networks of the physical Internet.
π-depot	π-depots are nodes where empty π-containers can be retrieved from or returned to their owner.
π-composer	Constructing or deconstructing composite π-containers from specified sets of π-containers. E.g., stuffing or unloading a container.
π-service provider	Nodes where services around π-containers are provided, such as customs clearance, weighing, and fumigation.

The capabilities of the node determine what can happen where. As such, the capabilities determine what valid connections can be made by the π-route planner, and so the network layer is instrumental for the π-route planner (see routing layer) for finding valid routes across the network of π-nodes.

4.4 Routing layer

The routing layer captures the algorithms and the information required to route π-containers across the network. It keeps track of known nodes, routes between nodes, their performance and their reliability. The routing layer is also aware of the business constraints that apply to the routing for individual containers (see 4.5 Business layer).

4.4.1 Network state

In order to plan container transport across the PI, there is a need to have an understanding or snapshot of the current state of the network and asset layer. This is important to enable the routing engine to explore different routes and effectively plan a π-container transport. Thus, the network state is the collection of information that represents the available π-nodes and their capabilities, π-movers and their schedules, as well as the physical networks that allow the movement of these π-movers.

4.4.2 Booking details

We consider a booking to be a set of constraints and requirements that dictate the π-container transport plan. It includes information such as:

- Booking type – import/export
- Container type and weight
- Pick-up location
- Cargo owner location
- Drop-off location
- Earliest pick-up time
- Cargo owner unloading/stuffing time-window
- Latest drop-off time

This information is treated as a set of hard and soft constraints for the routing algorithms when searching for route options.

4.4.3 Order state

When planning and executing a π-container transport, we define the state of the order by the following information:

- The **π-container state**, which can be full or empty
- The **π-container location**
- The **π-mover identification**, this defines which mover is currently assigned to this order
- The **π-mover state**, that determines if the π-mover is carrying, or not, the π-container
- And **π-mover location**, which is important because there might be a situation where the π-mover and the π-container are at different locations.

4.4.4 Route

A route consists of two phases, a pick-up phase and a drop-off phase. The former is comprised of all actions which take the π-container from the defined pick-up location to the node where composing/decomposing is performed. The latter defines the steps to return the π-container to the drop-off location. A π-container might be transported and stored on multiple π-nodes for each phase of a route.

The following table describes the possible actions or transitions that form a transport plan and that are executed on a π-container route:

Table 7. actions and state transitions

Move	Transporting or moving a π-container by a π-mover between two π-nodes.
(De)compose	In the case of an import order, the π-container is unloaded. For export, it represents the stuffing of the π-container. This requires the π-node to have the π-composer capability.
Pick-up	When π-container is placed on a π-mover.
Drop-off	When a π-container is removed from a π-mover.
Store	The temporary storage of a π-container at a π-node that offers the π-store capability.
Find mover	The act of finding an actual π-mover asset available to carry out the next legs of the route.

Given the concept of order state and actions, a route can be represented as a state-transition diagram, where each state is followed by an action until the pick-up phase and drop-off phase are complete. The diagram bellows shows the initial, middle and end state of a complete route, and all states and actions in between.

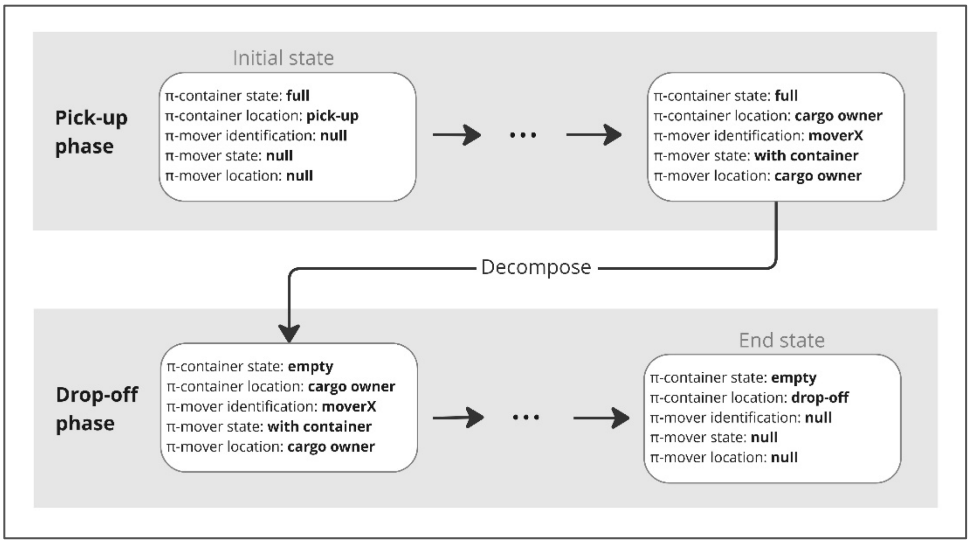


Figure 6. state transition diagram for an import order

In between the initial and end state of both phases, there are several transport legs between different π-nodes. A leg is then defined as a set of states that detail the movement of a π-container between π-nodes. The possible actions of a transport leg and their order is strictly defined as:

1. Find mover – assign a new π-mover to the order
2. Move – move from the π-mover's current location to the π-container's current location. If both the π-mover and π-container are in the same location, we ignore this transition.

3. Pick-up - π-container is placed on the π-mover
4. Move – move with the π-container to the next location
5. Drop-off – remove the π-container from the π-mover
6. Store – temporarily store the π-container at the new location
7. Move – if applicable, π-mover returns to base

For more information on the proposed routing algorithm, please see chapter 5.

4.5 Business layer

More details about the aspects discussed below can be found in the separate document D1.2 Stakeholdermapping.

The business defines the constraints for logistics flows. The focus can be on (a combination of) Origin-Destination, time, cost, speed, legal constraints, emission, … The routing layer needs to take these into account. This is done by providing a cost function to the routing algorithm that allows for an objective comparison of viable routes in order to select the most appropriate one.

The business layer includes several key concepts:

Entities

Within the PILL project, the term ‘entities’ is used for the legal entities responsible for different parts of the logistic chain. These are the overarching decision-makers who set the main goals of the companies and negotiate the general business agreements in relation with other entities. Any one entity is considered to have multiple possible business roles within the π-ecosystem. The definition of each entity as a combination of different business roles allows for a clear definition of each role, while still allowing for the multiple combinations of roles each real-life entity may incorporate. We consider the following roles to be relevant within the π-ecosystem:

Logistic roles

The business layer defines **logistics business roles** involved in the moving of cargo.

- The **Transporter** role is responsible for the actual movements of goods. They organise the actual transport and are in charge of the schedules and routes of individual movers
- The **Node operator** role is responsible for the operations within a π-node. They have one or more fixed locations and decide which capabilities they offer and at which capacity.
- The **Expeditor** role is responsible for the planning of the route cargo takes. They select a series of transporters and nodes to fulfil this move and handle all administration involved.
- The **Container (asset) owner**: is the entity that owns the specific assets. For simplicity reasons, we do not consider asset owners for movers within PILL. Assets which are leased or chartered are considered to be owned by the transporter. Only container owners are considered as separate entities, as they define the return location of empty containers, which is relevant for the routing.
- The **Cargo owner** (**shipper** or **consignee)** is the party currently responsible for the cargo (either sending or receiving, depending on the Incoterm). As such, they control most aspects such as itinerary, modalities, incoterms and so on. In PILL, they will be the business parties that determine the KPIs driving the choices for the best possible routing.

The **Policy** roles are responsible for setting the framework. They can be part of a government, but not necessarily are.

- The **Infrastructure Manager** role is responsible for a certain network in a certain area. They can decide on passage rights, set costs for the usage of (part of) the infrastructure. They can take an active role in managing capacity and sending out alerts in case of accidents or other disruptions.
- The **Landlord** is the owner of the land on which a node is operated and is responsible for the basic layout and infrastructure present. They can set a number of rules to be followed. Within PILL, only the Port of Antwerp-Bruges is considered. For other nodes, the node operator is assumed to be the owner.
- The **Customs & Taxation** role is responsible for controlling the legitimacy of cargo flows and collecting excise duties and taxations.
- The **Policy maker** sets the ground rules for all aspects related to national and international trade within a certain area, including traffic safety rules, employment rules, ...

The **Governance roles** are responsible for handling the digital requirements of the PI in terms of identity management, certification, standards and transaction management. As they are yet to be defined, we will not discuss them in detail here.

4.5.1 Connecting

For more details on how different parties connect technically, we refer to section 4.6. From the business perspective, it is important that the network π-network is decentralised: there is no single party that controls the infrastructure, connectivity or data. However, decentralised does not necessarily mean ungoverned. In order to properly function, a physical internet requires:

- **Trust**: trust is offered in the form of verifiable identities issued by an authority and equally verifiable claims (such as the capabilities offered). Trust is also needed for payments and can be filled in by an independent authority.
- **Interoperability**: interoperability is needed for the decentralised components (the clients) to be able to exchange data. This is achieved by agreeing on standards for the exchange of data (protocols) and the formats, structure and meaning of data (refined schemas).
- **Liability**: a legal grounding is required to assure all partakers in the physical Internet where their responsibilities and liabilities begin and where they end.

This highlights the need for and importance of some of the aforementioned roles.

4.5.2 Data Sharing

In PI, the sharing of data to find optimal routes is essential, as was explained in the paragraph on the Network/Routing Layer. However, entities don’t want to share more sensitive data, such as available capacity and prices openly with their competitors. Therefore, we make the baseline assumption that entities are only required to share their capabilities and that sharing capacity is optional. This enables other entities to find routes in the network, but requires them to still check (automatically) with each actor along the route to confirm availability.

In the future PI system, entities might decide to share more data in the network or with specific parties. If so, specific agreements and/or contracts would be set up through the business layer.

Specific data can also be shared with governmental organisations. This concerns things like customs data, turnover data, entry into cities, etc. Specific alerts could be sent automatically when a shipment requires entry into a specific city with access restrictions.

4.5.3 Payments

Within the PILL POC, entities will handle payments as they do today. As the current systems are used to make the actual booking, the current way of invoicing can also be applied.

Looking further into the future of PI, a new, more automatic organisation of negotiating prices and organising payments should be developed. Currently, only limited research is done in this field, focusing mainly on systems for automated bidding in perishable goods (Kong *et al.*, 2016) and less-than-truckload (LTL) (Qiao et al. 2020 and earlier work). This organisation could be compared to the ad bidding market on the Digital Internet, where companies automatically bid for ad space on a website based on the profile of the viewer. Cooperations in this kind of model are on an ad hoc basis, with high flexibility and limited to unsteady relationships. This type of organisation is therefore most suited for smaller cargo flows (LTL) or flows with high variability.

Cassan, Duran Micco en Macharis. (2021) showed that another type of structure, common in Digital Internet could also be considered: the subscription model. In this model, a client pays for a certain amount of cargo (data) at a certain quality level (up- and download speed). In this model, one logistic service provider makes a commitment to handle all cargo (of a certain type or flow) for a company. This type of organisation is well suited for steady flows.

In Digital Internet, this model is complimented by individual agreements between the Internet Service Providers, who operate under a peering or transit relationship (Crémer *et al.*, 2000).

4.6 Communication layer (vertical layer)

The final layer embodies the underpinning infrastructure that allows all components and entities to be interconnected into the Physical Internet. This comprises the collection of technical components, protocols, standards and agreements that are part of it:

4.6.1 π-Client

The π-agent is a software component that connects π-entities to the network. It has the following responsibilities:

- Register the node’s capabilities for each node operated by the business entity (if any) in the network and make it discoverable for other entities in the network;
- Responding to routing requests from the home entity by searching the network for optimal routes, taking into account the KPIs as configured by the entity;
- Maintaining a cache of viable routes that are needed for efficiently finding routes upon request;
- Responding to reservation requests from other entity’s agents;
- Subscribing to the π-disruptions feed, so that any disruptions impacting planned logistics flows can be responded to by re-routing the cargo.

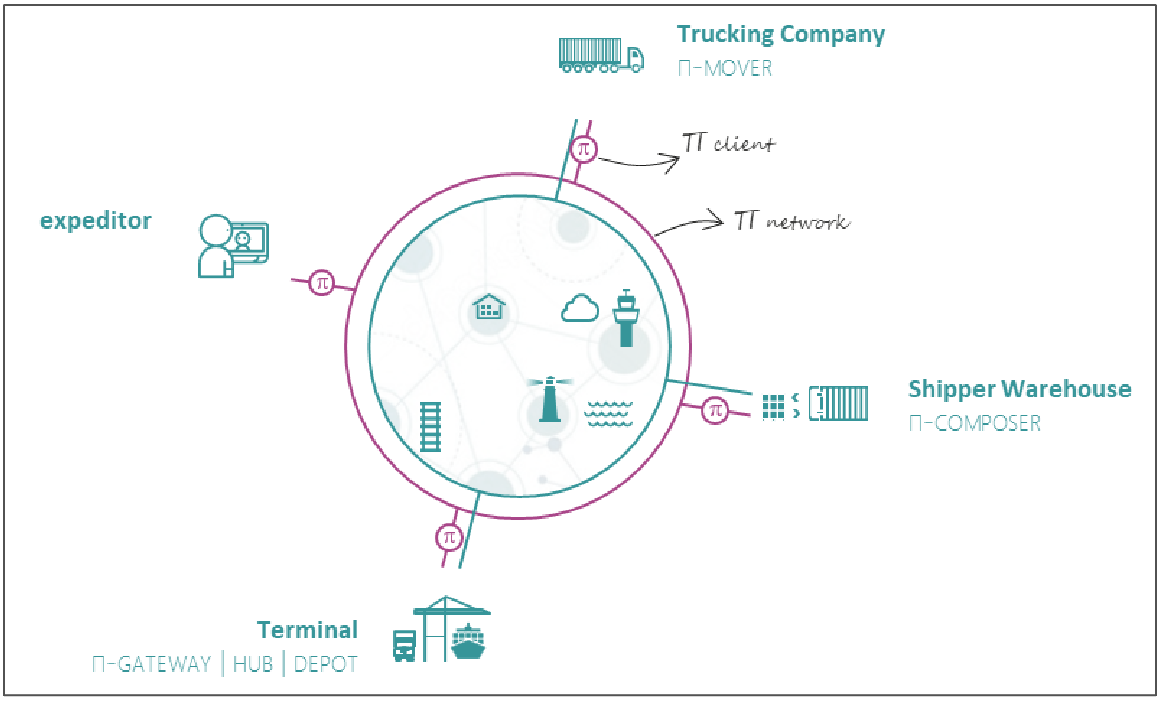


Figure 7. the π-client connects the different nodes and operators of the physical Internet, forming a decentralised network of peers

4.6.2 π-Authority

In order to ensure a trustworthy environment, there will be a need for a certification authority. Depending on how the network is organised, this authority could be entitled to

- Issue verifiable identities,
- Issue verifiable claims to partakers of the network, for instance, in the form of the capacity and/or authorisation to deliver certain services,
- validate claims regarding cost/emissions/punctuality made by network participants,
- act as a trusted third party for charging partakers in the network for services delivered.

This authority will need central infrastructure in the form of identity management, digital signature technology and digital certification systems. For the independence, transparency and openness of the network, it should be possible to have multiple certification authorities.

4.6.3 π-Protocols and Standards

A Physical Internet can only be successful if it remains open. This entails, among other things, that there can be different π-agents offered by different digital service providers. In order to ensure interoperability, this requires open standards for data exchange formats and (API) protocols for the Physical Internet.

Physical Internet standards should build upon existing standards for logistics, such as EDIFACT, DCMA eB/L, GS1 GLN, … as much as possible. The protocols should rely on commonly available open transport and communication protocols such as HTTPS.

In the PILL project, we will propose information models that cover the minimal scope of the Living Labs context. It is loosely based on elements of the information model of the DCSA Bill of Lading standard. Further convergence with other existing standards may be needed, as well as an open vocabulary definition for logistics to accompany it.

4.6.4 π-Transaction Broker

The Physical Internet will allow making reservations for transport and logistics services across the network of connected π-agent. The reservation and execution of these services will have to be paid for by whoever is placing the booking. The certification authority will ensure that the booking party is known and can be trusted. But in order to reliably and trustfully register transactions, broker infrastructure is required.

Such broker infrastructure needs to be open and independent. It can be controlled centrally by an authority, but it can be distributed as well in the form of a blockchain infrastructure that is part of the distributed software components. This will allow reliable tracking of transactions and can be used as a basis for invoicing and payment of services.

4.7 Conclusion/key takeaways

The Physical Internet, as introduced for the organisation of logistics (see chapter 2), is the foundation of our approach to creating a decentralised network with the purpose of digitally transforming, automating and optimising different aspects of logistics and supply chains within the scope of hinterland container transportation.

In this chapter, we have identified (i) the conceptual building blocks of the physical Internet in a layered design as well as (ii) the required business roles to operate the physical Internet. In the following chapter, we look at matching technical blueprints to bring these concepts into practice.

5 Blueprint of the Physical Internet (PI)

This chapter provides (together with chapter 4) the content foreseen in deliverable D1.5: Technical Backlog and Architecture design

In this chapter, we will describe the envisioned software architecture, the main components and the decisions behind the selection of certain types of technologies.

5.1 State of the art

More detailed information can be found in D1.1. PILL Literature Review.

As a result of the significant importance of information exchange in PI, the design of a proper information system or exchange protocol has been stressed since PI was first promoted (Montreuil *et al.*, 2012a). However, the actual research on this aspect was not started until the *expansion stage*.

Qiu *et al.* (2015) devise a physical asset service system (PASS) and its information structure and decision support system for a supply hub industrial park. Wang *et al.* (2016) proposed a PI-based manufacturing system in which a concept of “initiative scheduling” is mentioned, suggesting that entities should be smart and take over some jobs in a decentralised way, so as to make the system more adaptive by the interactions. For a logistic network, Zhang *et al.* (2016) test the efficiency of the smart box as a form of PI container, and design the 3-layered information system while mainly focusing on the accommodation of container operation functions rather than the data exchanging structure. In line with the idea of initiative scheduling, Sallez *et al.* (2016) design a local-scale communication framework based on the activeness of smart containers. Additionally, at this stage, PI systems are more often proposed and validated in the case studies for manufacturers with complex operation needs, who have high error cost out of production management, such as solar cell manufacturer (Lin and Cheng, 2018), mass-customised production (Zhong *et al.*, 2016), and prefabricated construction (Chen *et al.*, 2018). This is because they have higher improvement needs, and the small scale of a manufacturer makes it easier to come true.

From then on, researchers have been focusing on designing more universal architectures for problems of a larger scale. Tran-Dang and Kim (2018) review the PI elements that had been designed and come up with a service-oriented architecture using IoT, which is composed of 4 layers – physical, network, service and interface layer. The same architecture is further developed into a PI management system (PIMS) by Tran-Dang *et al.* (2020), in which the authors also define the typical information system structures for smart IoT devices, PIMS, PI hub, etc.

Different from this conventional evolution of information system design, the blockchain has become a popular topic very recently. Meyer *et al.* (2019) point out the decentralised essence of PI and blockchain and justify the feasibility and cost-effectiveness of this new blockchain idea using the Ethereum virtual machine, as the blockchain is going to make a radically different architecture compared with the conventional information system. Due to the computational power required by blockchain, they also design a conceptual framework for different levels of PI entities to accommodate the varying computational power limitation of different types of objects. Using Ethereum, Betti *et al.* (2019) estimate the blockchain size for a transportation network, in which each entity is regarded as an agent. Their study supports that blockchain is a ready technology for PI with some minor problems (like malicious agents) to overcome. Hasan *et al.* (2021) discuss how blockchain can fit in with the requirements of PI and suggest Hyperledger Fabric and Besu as the most appropriate architectures, while they acknowledge that integration of PI and blockchain still entails much effort.

5.2 PILL blueprint – the π-agent/client

In order to enable the PI, we propose a decentralised software system, composed of π-Clients, which relies on a peer-to-peer (P2P) network setup for exposing and publishing capabilities, planning container transports and exchanging transport related data.

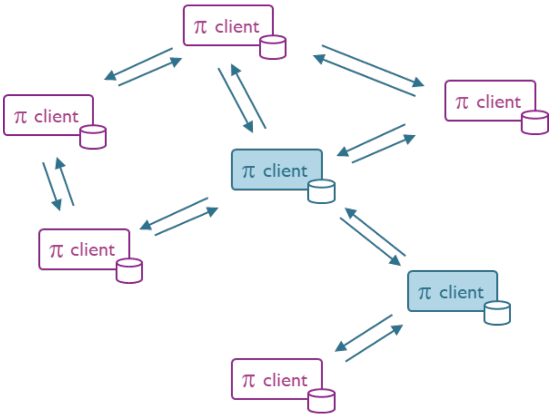


Figure 8. π-Clients together form a peer-to-peer network in which every client keeps an up-to-date view of the network so that an algorithm can use that to plan routes for container transports.

The π-Client software design includes the following modules:

- The user interface allows configuring the π-client, for instance, by:
    - Authenticating with the network using a verifiable identity
    - Configuring preferences for π-route finding
    - Selecting/configuring the capabilities of π-nodes (if any)
- The API is the main communication gateway towards the other π-clients. It is specified in terms of technical and semantic standards. It is also the interface for the UI component and allows to integrate with back-end systems.
- The network manager manages the connections to the other π-clients (or peers) in the network and allows to keep track of the network state using distributed database technology.
- The reservation manager manages the reservations for local capacity made by remote π-clients. If applicable, the reservations are also relayed to back-end systems. In case the reservation is accepted, this module also sends back a confirmation to the requesting π-client. Otherwise, a rejection message is passed back.
- The booking orchestrator takes care of finding applicable routes for a shipment, and when a route is chosen, it will send reservation requests to the remote π-clients that represent the π-nodes on the route.
- The route planner is an interchangeable module that is tasked with finding routes for shipments using the locally synced network state. It is interchangeable with other route planners with different characteristics. It is also able to take into account parameters coming from a back-end planning system.
- The configuration manager is the module that manages and stores the π-client preferences and settings.

Some of the modules are explained in more detail below.

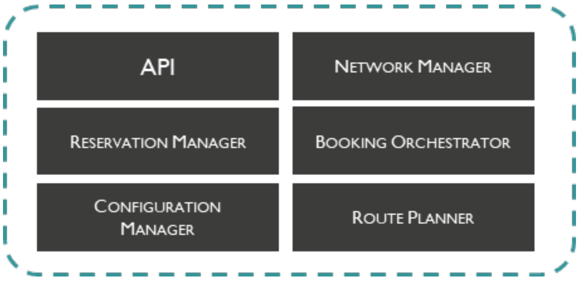


Figure 9. the different modules of the π-client

5.3 Routing Algorithm

In chapter 4, we introduced several concepts related to routing, namely the booking details, network state, order state and the different actions that form a route. The goal of this section is to describe how we translate the concepts beforementioned into a routing algorithm capable of searching transport plans for π-containers in the proposed PI implementation. This routing algorithm is not the final routing engine implementation, but is a module of our proposed architecture, which can be replaced by other routing engines that satisfies a particular objective. Herein, we propose a route-searching algorithm with embedded heuristics to reduce the search space, by pruning weaker solutions based on a set of user-defined parameters. These parameters take the form of weights used to score a complete or incomplete route and cover aspects such as emissions, costs, distance and duration.

5.3.1 Network State

The network state is defined as the collective set of π-nodes and their π-capabilities as advertised by all the connected π-clients. Every π-client maintains a synchronised copy of that state locally so that it can be used by the route planner. For this, distributed ledger technology can be used.

The distributed ledger is a database that is spread across several nodes in a peer-to-peer network, where each node replicates and saves an identical copy of the ledger and updates itself independently. Ledger updates are synchronised using a deterministic conflict resolution strategy. Security can be accomplished through cryptographic signatures.

5.3.2 How the routes are found

When the network receives order information (origin, destination, number of containers, closing time, etc.), the user also inputs the preferences over the importance of variables (e.g., time, emission, cost, etc.). The algorithm first seeks a node to take the first step from the origin node. All the other nodes on the network provide their availability information to form a route starting from the origin node.

There are a few “hard constraints” that cannot be violated during routing:

- Containers must be picked-up before the earliest pick-up time
- Containers must be dropped off before the latest drop-off time
- Containers should be stuffed or unloaded within the proposed time window at the cargo owner’s location

During the process above, the destination node is also among the nodes asked and could also reply with multiple plans from the origin node to the destination node (because there might be more than one means to transport). Such routes are tagged as “complete”, while the other routes whose last stop is not the destination are “incomplete”. But as long as there is not enough route found, the following processes are to be taken in loops to find a list of routes for the user to choose.

The last node on each of the existing “incomplete” routes is the temporary end of the “incomplete” routes, from where the route is also possible to grow to “complete”. For each last node, ask all the other nodes on the network to reply with their availability to compute a route in between. If hard constraints are not violated, a new route can be formed in this way.

Finally, when enough routes are found, their time, emission, cost, distance and duration are calculated, respectively. Thus, the routes can be ranked and presented according to the customer’s preference.

5.3.3 *Routing scheme in PILL*

There are three major components that allow this routing algorithm to generate π-container transport plans: the networks state, booking details and a set or parameters that govern the search process. Given this information, the search will start on from the cargo owner’s π-node, respecting the proposed time window, and will first identify feasible pick-up plans (see chapter 3 on the different components of a route). From these it will search compatible and feasible drop-off plans, the combinations any of these two plans for a complete route.

The basic routing scheme is presented above, while in PILL, a route for an order is composed of two phases, pick-up and drop-off phase. The routing starts after acquiring the network state to have the information on the network infrastructure, connections, node capabilities, etc. The routing module then finds routes between the origin node to the composer’s node while assuming the container arrives at the earliest slot in the composer’s time window. This step is also called ‘back-tracking’ as the compose time is fixed in a future slot first, and the previous actions are found step by step until the initial state. If these steps do not return enough candidate routes, the compose slot is delayed within the time window, and the above steps are repeated until enough routes are found, or the slot cannot be deferred anymore. Thus, a set of candidate routes are found from the origin to the composer’s node.

Then the ‘forward-tracking’ search is conducted to find routes from the composer’s node to the destination. The tracking starts from the compose slot(s) in the set of candidate routes found by back-tracking, aiming to deliver the container before the closing time. By the end of this step, a group of complete routes are finally concluded from the origin to the destination, with the composer’s node visited in between.

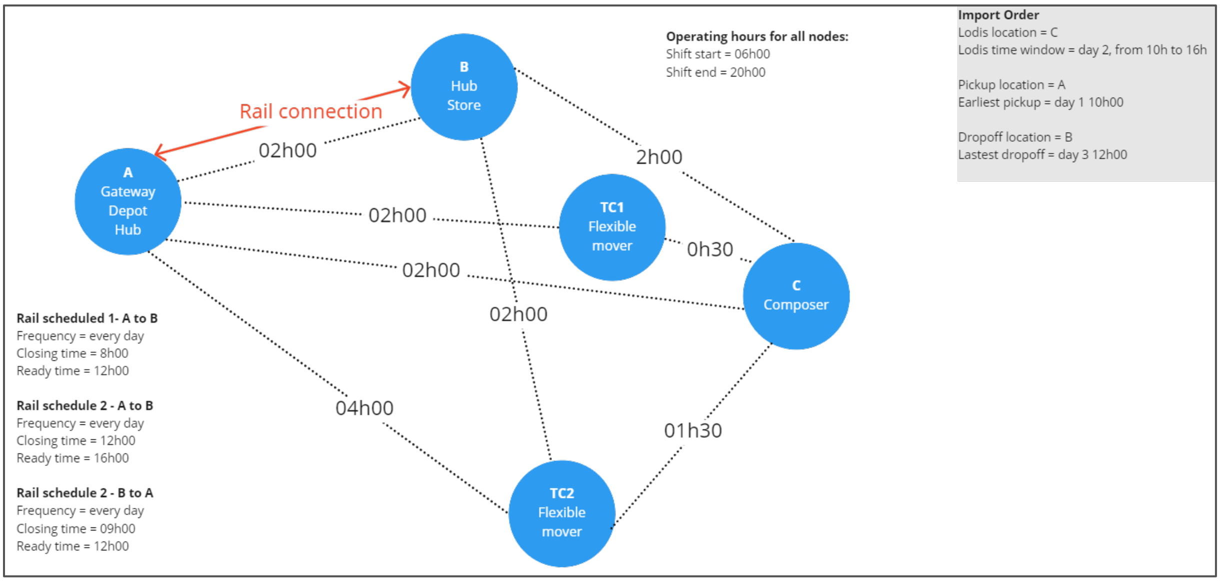
5.3.4 What is different in PILL

Unlike the existing shortest path algorithms that simply calculate a route for cargo, this routing process also considers the round trips of the trucks and the transport of empty containers. Thus, this algorithm can also take the composers’ information as input. For example, in a container import task, the routing starts by finding a means to take the full containers from the pick-up location to the composer’s site, where the containers are unloaded and become empty containers. Then the algorithm also finds the route to send back the containers to specified locations. The empty run of trucks and run with empty containers also account for parts of the routing.

5.3.5 An example

Given a transportation network of 5 π-nodes below in Figure 10, in which their respective roles are specified. There are two truck companies with different connections to the π-nodes. The reachability and travel time of the truck companies are also shown. This example demonstrates a full container imported from node A (a seaport) to be decomposed at node C, and the empty container is then sent back to node A. Every node has opening hours, which are shaded in red and assumed to be the same for all the nodes.

In this demonstration, we name the plans as P.XX.X.X…. The XX is composed of a letter and a number. The letter stands for the position of the compose slot, and the number specifies how many store states are in the plan. The following X stands for the numbering of the branches of plans. For example, P.A0.1 is likely to be the first plan to be found because the compose/decompose time is not moved (A), this is a direct plan from the origin to destination (0), and there is no store state for one-step plans.



Operating hours for all nodes:
Shift start = 06h00
Shift end = 20h00

Import Order
Lodis location = C
Lodis time window = day 2, from 10h to 16h

Pickup location = A
Earliest pickup = day 1 10h00

Dropoff location = B
Lastest dropoff = day 3 12h00

Rail scheduled 1- A to B
Frequency = every day
Closing time = 8h00
Ready time = 12h00

Rail schedule 2 - A to B
Frequency = every day
Closing time = 12h00
Ready time = 16h00

Rail schedule 2 - B to A
Frequency = every day
Closing time = 09h00
Ready time = 12h00

Figure 10. demonstration of the network

The routing starts with fixing a decomposing time slot as early as possible, based on which it back-tracks routes from all the other nodes (A and B) on the network. Note that the same route fulfilled by different truck companies is considered different. If any operation happens during off-hours, the plan is considered “infeasible” and excluded from the candidate list for further search. For all the incomplete plans (P.A0.3), node B finds the way to all the unchecked nodes (A), resulting in P.A0.3.1. Since not enough feasible plans are found, the incomplete plans are seeking routes with storage. The length of storage time depends on the arrival time of the previous train. After the plan P.A1.3.1 to P.A1.3.6 are found, the feasible plans are still not enough, so the decomposing time slot is moved, and the above steps are repeated to generate the family of P.BX plans.

When enough candidate plans are finally found, the forward-tracking phase begins, as shown in Figure 12. According to the existing decomposing time, the routing is done similar to the back-tracking, until enough plans are found between A and C. These forward- and back-tracking routes will be combined in a permutation way to finalise the route plans that bring the container from A to C and then back to A. Their optimality is calculated respectively according to user-set preference on time, distance, emissions, etc. A specified number of plans ranked highest will be returned by the routing layer to the user.

0

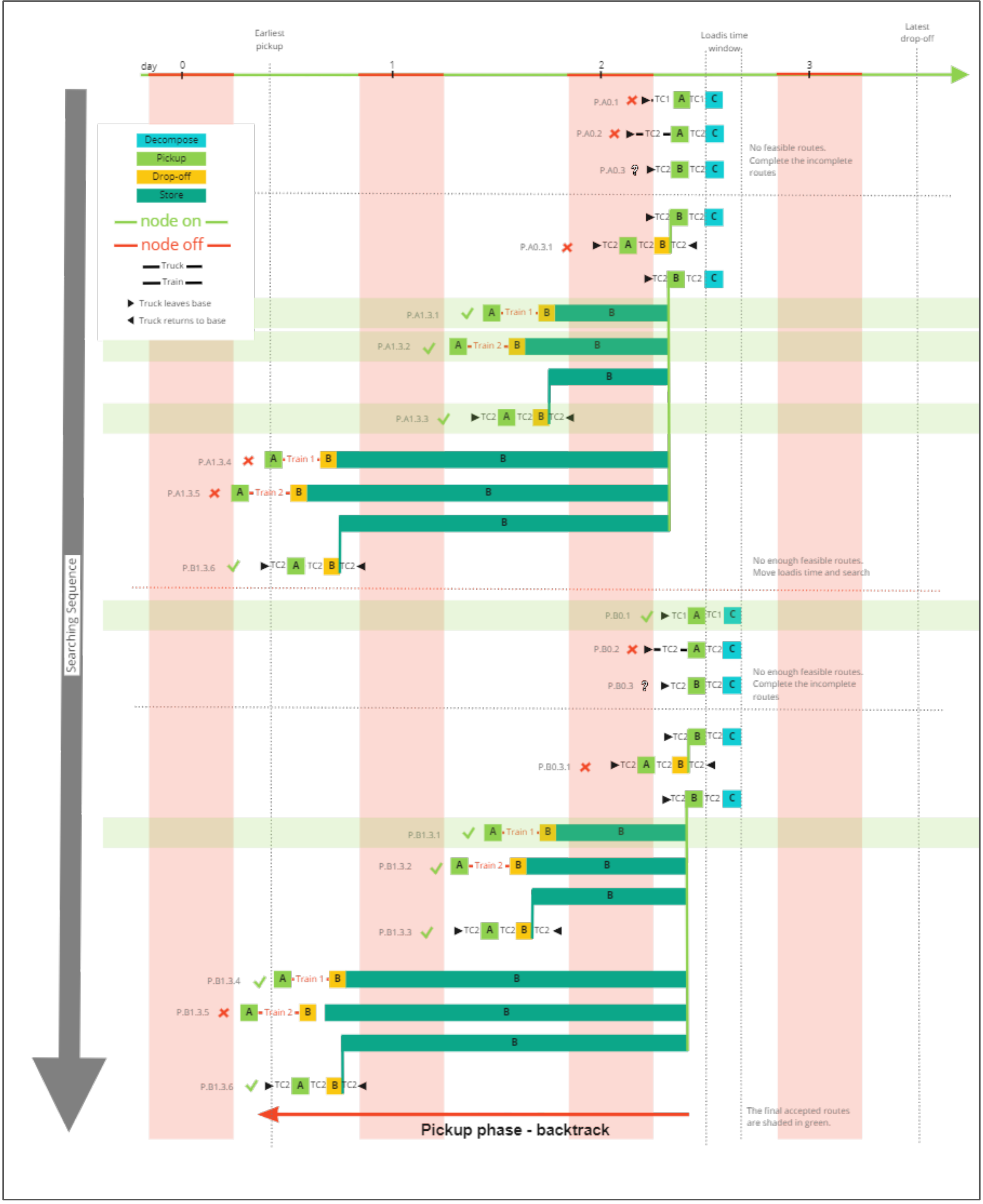


Figure 11. back-tracking of route finding

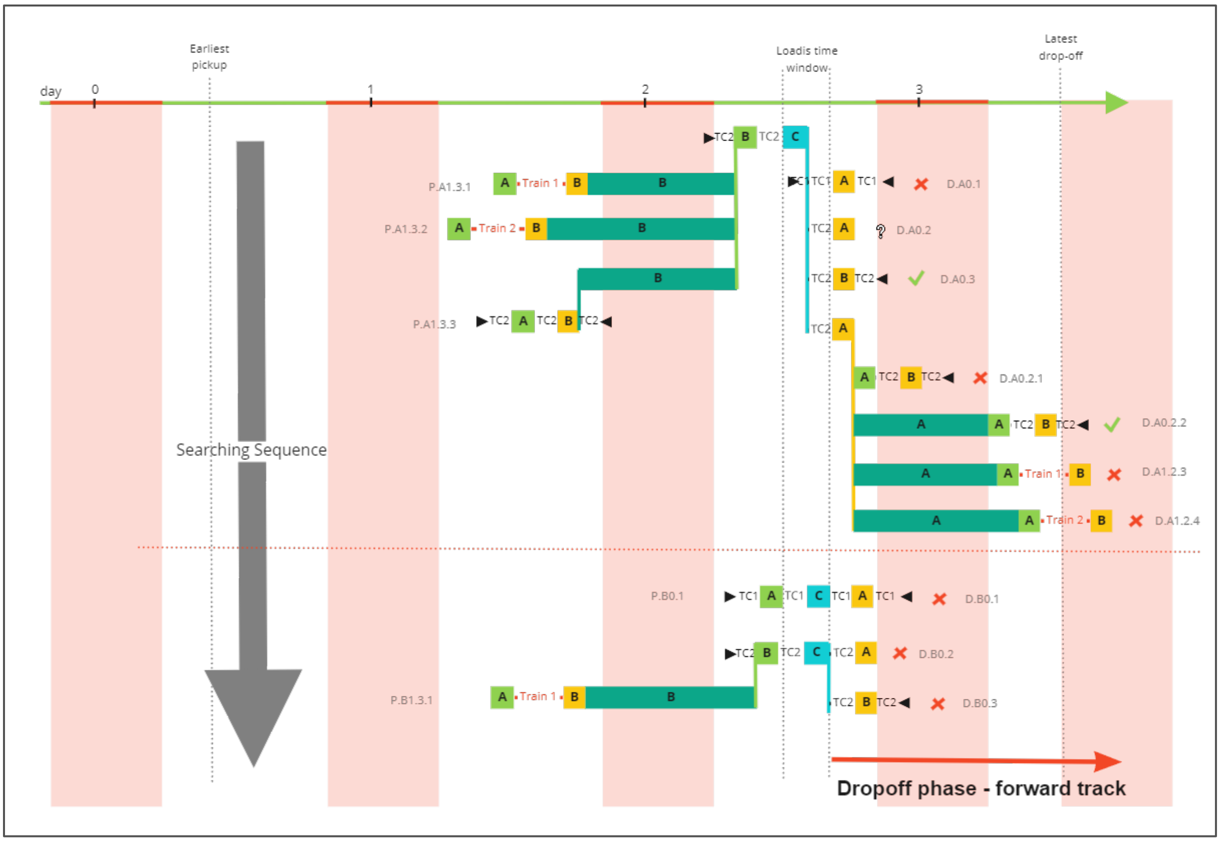


Figure 12. forward-tracking of route finding

5.3.6 *Search pruning*

The search mechanism mentioned above relies on a brute force search of all the possible routes, back-tracking from the cargo owner's location to the pick-up location, and tracking from the cargo owner's location to the drop-off location. For smaller network states, this approach is quite effective and makes sure we haven't missed any solution, but in larger network states, this is not efficient. To tackle this problem, we suggest a pruning technique where we exclude certain routes as soon as their score is below a certain threshold. The route score, or cost, is composed of a weighted cost function:

$$c_i = w_1 \frac{c_i}{c_{max}} + w_2 \frac{e_i}{e_{max}} + w_3 \frac{d_i}{d_{max}} + w_4 \frac{t_i}{t_{max}}$$

Where w_1 to w_4 respectively denote the weights given to cost, emissions, distance and route duration. Hence, we can score a route and compare it to any set of other routes. During the search, we will abort the route search if the incumbent's score is lower than the top percentile of the previously found routes. For extra flexibility, this percentile is user-defined, resulting in different levels of computation performance.

5.4 Bookings & Reservations

Bookings are shipment requests that can be given to the π-client in order to determine viable routes for the shipment in the known π-network. They include the basic details of the shipment along with the constraints that the route planner must take into account. Examples of such constraints are:

- Departure point (container pick-up)
- Earliest time of pick-up
- Destination point (container drop-off)
- Cargo closing
- Latest arrival times
- Loading locations and time slots

A booking management system manages these bookings in the following way:

- Upon receipt, request the routing algorithm to find viable routes in the network
- Arrange the routes by desirability, which is determined by a configurable cost function for the routes
- Upon selection of a route (a manual process), the booking management module makes reservation requests to the involved nodes.
- When a route cannot be reserved in full, the user is requested to select another route or start over.
- Otherwise, the route is booked and saved with the shipment data awaiting execution.

5.5 API and standards

The current data model is inspired by the DCSA standards for electronic Bill of Ladings and Track & Trace for maritime container shipments. It is a minimalistic approach and includes only what is needed at this stage of the development of our Physical Internet client.

It is clear that in order to be interoperable with potential other π-client implementations, a transparent and open specification for the client interface will need to be specified. Ideally, any data exchanged with the client is also covered by a semantic specification that allows bridging to other standards and interface specifications.

The π-client can also act as a gateway for exchanging all sorts of logistics information. We are thinking of verifiable electronic CMRs, customs declarations, Bill of Lading data, VGM weight registrations, ADR documents and more.

The potential value of the π-client as a standards-driven gateway to the logistics network will be a huge vector for the adoption of the Physical Internet concept and should be given proper attention.

Further development of interface and data specifications for the π-client is part of the ongoing development effort.

5.6 User Interface

The PILL project will provide a user interface for the management of the π-client and for planning routes and managing reservations. Although ideally, some of these tasks are handled by back-end systems that integrate with the π-client, this will allow us to conduct our real-life experiments with the very early version of the Physical Internet.

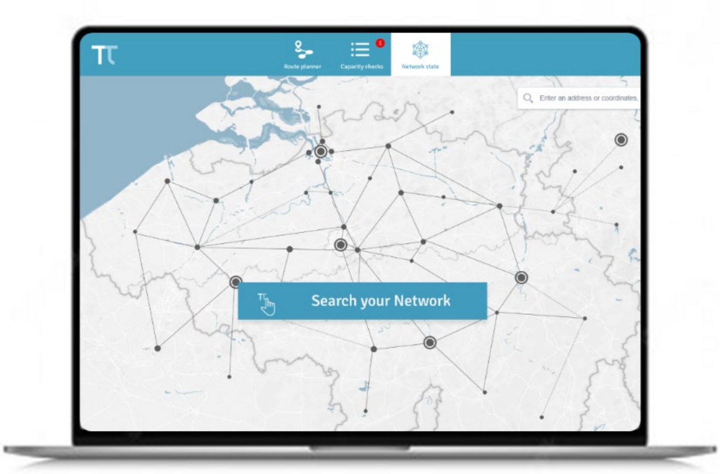


Figure 13. a mock-up of the user interface to be built

5.7 Positioning PI in dataspaces

The Physical Internet requires many of the concepts that can be found in dataspaces as architecturally defined by IDSA. Many of the Gaia-X federation services are equally relevant for PI. We discuss a few of these below.

In this context, π-clients can be seen as both data providers and data consumers, relying on the many building blocks of dataspaces to give shape to the physical internet together.

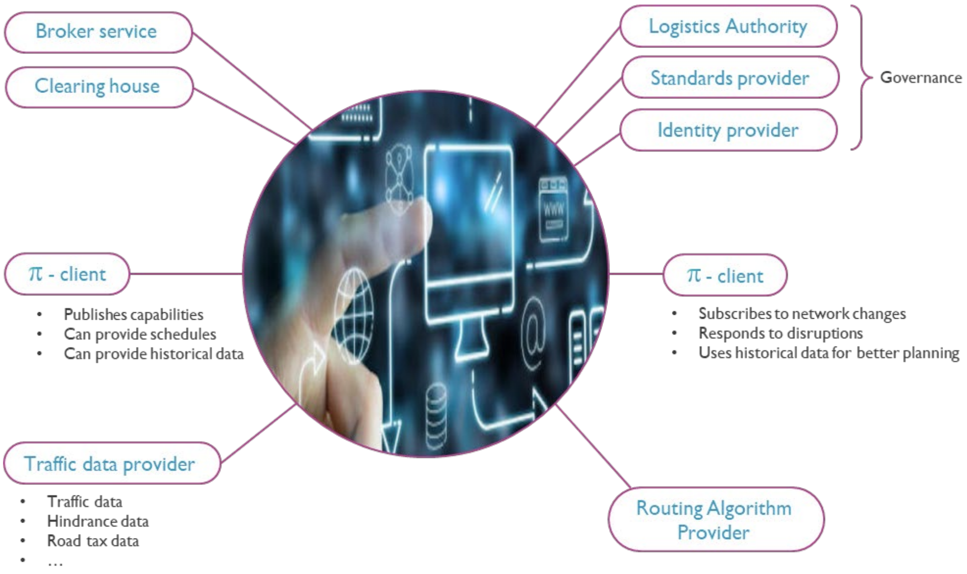


Figure 14. a view on the dataspace components and roles that are relevant in the context of the physical internet

Meta-data brokers & data providers

The many clients in the network are all data providers in a way. Either by contributing to the network with their published capabilities, schedules and, optionally, their remaining free capacity. But aside from the clients themselves, there are other data providers that can add value to the Physical Internet dataspace:

- Traffic data (actual and historical) may help to decide which route is better by assessing or predicting the traffic circumstances
- Weather data (actual and historical) may help assess and predict traffic circumstances and/or the likelihood of disruptions
- Economic data may provide inside into cycles of business and predict the possibility of demand for transportation means rising or chances of disruptions increasing

Discovering this data and figuring out how to use it is facilitated by dataspace concepts such as meta-data brokers. This is one of the main reasons to position the physical internet into the dataspace concept.

Standards and standards providers

The importance of standards to the physical internet is explained in section 5.5. We point out that dataspaces are mainly driven by standards. These standards also need governance so that they can evolve along with the ever-changing business needs. This implies that any π-specific standards will also require a governance body that can act as standards providers in a dataspace context.

Identity providers

To ensure trust in the physical internet, there is a need to verify identities. Although the network and the surrounding data space are decentralist by design, identities will need to be managed by some entity. In a dataspace this is done by (independent) identity providers that are trusted by the community. They issue identities and allow the participants in the data space to verify the identity of anyone they interact with, preferably independently of the services of the identity provider (see self-sovereign identities).

Authorities

Authorities are trusted third parties, usually independent in nature, that can either manage and verify claims or that can broker and verify transactional information.

- Claims can be used for controlling access to resources in the data space. E.g., the claim that a certain identity belongs to a specific security access group or the claim that a certain logistics service provider is certified to perform certain activities.
- Transaction verification is needed in order to log reservation requests and trace service delivery so that invoicing and payments can be properly coordinated based on the records of a trusted third party.

5.8 Concluding overall view

The Physical Internet and our approach towards it in the form of a decentralised network of independent π-clients offer much more than advanced route planning for logistics. It has the potential to achieve far-reaching digital transformation of many logistics-related processes, especially labour-intensive administrative tasks.

Another important part of the added value is the use of the PILL components in a simulation environment that can be used for various purposes. Two examples are:

- Policymakers can simulate the effect of changing the status quo by adding infrastructure and changing processes in the virtual world and assessing their desirability in terms of the outcome of the simulation
- Logistics operators can study the effects of disruptions in order to organise their operations in more resilient ways

Finally, the possibility of interconnecting a large part of the logistics community will create new possibilities for reporting statuses, disruptions, exceptions, … in a more real-time manner which will allow a more efficient and resilient organisation of logistics operations.

6 Simulating the PI

In chapter 5, we introduced the π-client, a software system that is central to the success of PI. In order to understand, measure and test this software operating at a greater scale, we need a simulated environment free from real-life constraints. Hence, in this chapter, we introduce the π agent-based model (ABM). We start by providing an overview of the model, and what and why we are trying to represent in this simulated environment. It is followed by a description of the agents involved, the simulated world and what processes determine the agent's behaviour with respect to other agents and their surroundings. It finishes with a description of the data inputs needed to run a simulation.

6.1 Overview

This model represents a set of logistics players operating within the proposed physical internet (PI) framework and captures behaviour and emerging phenomena by simulating the PI's peer-to-peer network of π-clients. There are two main aspects represented, (1) the different logistics networks where π-nodes represent physical locations and π-movers represent assets that can move π-containers, (2) the set of entities that operate these logistics networks, in this case, a set of π-clients. Containers will then flow through the different logistics networks according to routes determined by the π-clients. Thus, the routes taken depend on the π-clients configuration, implementation rules and data received from other π-clients.

In order to assess a variety of scenarios, we designed this model to be data-driven. The initial conditions and configurations of the different agents are determined by pre-defined input data. This allows us to experiment with different sets of logistics networks managed by different flavours of π-clients, see section 6.2.1 of this chapter for more details. Hence, the main goal is to understand how to organise the PI on a larger scale and how to operate the different software modules to improve the overall logistics performance. These goals are linked to the research questions posed in chapter 1, section 2.4.

Since this model is highly configurable, we can simulate a version that closely resembles the business-as-usual (BAU). This is achieved by limiting the flow of information between clients, mimicking the siloed information structures in the real world. We will use this as a baseline to measure any improvements achieved by our π-setup, where, contrary to the BAU, the information network state information is shared with all other π-clients.

6.2 Agents

In this type of simulation modelling, agents might represent a physical object, a business entity, or some other form of abstraction. Their behaviour is, to a certain extent, independent and decentralised, trying to maximise an objective by acting upon changes in the environment and surrounding agents. Once combined and operating in the same environment, complex patterns might emerge. These patterns can be quantified, and their impact measured. For this model, we expect to measure the overall performance of multiple logistics networks like overall greenhouse gas emissions, cost, delays, robustness and resilience to disruption events.

6.2.1 Client

The **Client** agent will simulate an active π-client in our logistics scope. As explained in chapter 5, the π-client is responsible for connecting to other π-clients. It is linked to one or many nodes and is responsible for publishing the node's capabilities, planning transport routes, answering capacity checks and reserving and booking capacity.

For now, the different types of nodes the client controls and their cost function parameters (see chapter 5 for further details) will be the differentiation point between clients. For instance, a transporter's client might be active in publishing its π-movers information and answering capacity checks, whilst an expeditor's client will be responsible for planning and sending booking requests to other clients. In the future, we might include more characteristics, such as parameters that define disruption handling policy or other real-world implications that might have a significant impact on PI performance.

This agent will be responsible for planning and choosing a transport plan for a π-container, in which both import and export orders will be handled. Once the planned event takes place, the client will use the received node capabilities and capacity data to generate and choose a transport route. The route search and selection are determined by the cost function parameters. Once the selection is made, it will split the route into different legs and initiate a booking process with the different clients that operate the given logistics networks. The preference for certain routes might result in different transport patterns, for instance, an over-utilisation of a particular type of transport or facility.

Besides planning, clients will receive capacity check requests as well as capacity booking confirmation. For now, the decision upon these requests is as simple as: if there is capacity at nodes or movers, it will be accepted. In the future, this type of decision-making might be modelled in a more complex way to assess different strategies.

6.2.2 Node

The Node agent represents a physical location and closely matches the PI's π-Node definition. It is composed of a set of π-capabilities, which define the possible operations at its location, e.g., container storage or the ability to service a truck. Each node agent is linked to its parent client, suggesting that a client can manage multiple nodes. The different physical operations at nodes are constrained by their capacities and operating processes. Even though this is an agent-based model, to better represent the proposed system, we will use concepts of Discrete Event Simulation (DES), namely queues and delays, that will simulate physical operations at the node.

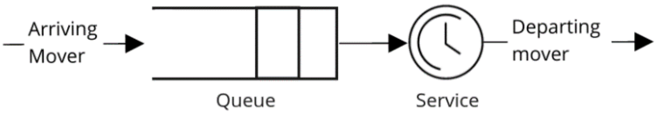


Figure 15. node servicing

The following capabilities will be modelled according to the diagram above, where the service is capacitated, meaning only a certain number of movers can be served at the same time, and the duration it takes to service a mover is sampled from a probability density function, which was constructed using historical data:

- π-Composer represents the operation of stuffing or unloading containers at the cargo owner's node.
- π-Hub defines the ability to put or remove a container from a mover.

This type of modelling will allow us to explore the over-utilisation of an asset and how those result in delays and reduce the reliability of the entire system.

The remaining capabilities, i.e., π-Depot π-Store and π-Gateway, will be mainly used for route planning. For further information about the definition of capabilities in the PI, please refer to chapter 4.

Hence, the different kinds of capabilities will characterise the nodes. This allows us to model diverse types of logistics facilities, for instance, to model a container terminal, or a hub.

6.2.3 Mover

The **Mover** agent, represents an asset that can pick up, move and drop off containers at specified nodes. As mentioned in chapter 4, the π-mover concept might represent any type of equipment or asset, but since we are focussing on freight container logistics, for this model, we limit it to trains, trucks, and barges. This agent movement is defined by schedules, or on-demand requests in the case of a transport plan that needs a flexible mover.

The **Node** and **Mover** agent receive instructions, or tasks, from the clients. When a client has successfully determined which transport route a container will take, it will distribute these instructions to the participating nodes and movers, such as pick-up, drop-off, move, and store.

This agent type will be split into two main categories:

- Scheduled mover. Its moving instructions follow a pre-determined schedule, where the origin and destination are pre-defined, as well as the expected departure and arrival time. This is typically a train or barge.
- Flexible mover. On-demand assets that can be requested to move a container within its time/distance range. In this context, these are typically trucks.

The ability to connect two nodes with a scheduled or flexible mover, effectively defines the logistics network available for planning and execution. Please read section 6.3.1 for further information on this topic.

Both types of movers, scheduled and flexible, have a concept of the base node. It defines where the owner of the mover is in the GIS environment. In the case of a flexible mover, when it is requested for a task, we assume that the mover always departs from its base. Hence, if a flexible mover is tasked with moving a container from one location to another, it will depart and return to its base.

6.3 Environment

6.3.1 Space

Agents that have a physical dimension, **Node** and **Mover**, will be part of the GIS environment, namely the Flanders region. Nodes will be located given the inputted geographical coordinates. Regarding movers, depending on the modality (road, rail, or water) they will follow a representation of the real infrastructure in the region, I.e., barges will follow a representation of the available water network (blue polylines in the figure below), and trains will follow the rail network (red polylines below).

Figure 16. the GIS map representing the rail and water network considered in PILL

Regarding network topology, scheduled movers will define the edges that connect different nodes. The nodes and inputted schedules will form a network in which containers can travel. A special case is the use of flexible movers. These movers, like trucks, have a limited driving range or duration. Hence within their driving range, we consider that all nodes are connected to each other, i.e. as a complete graph.

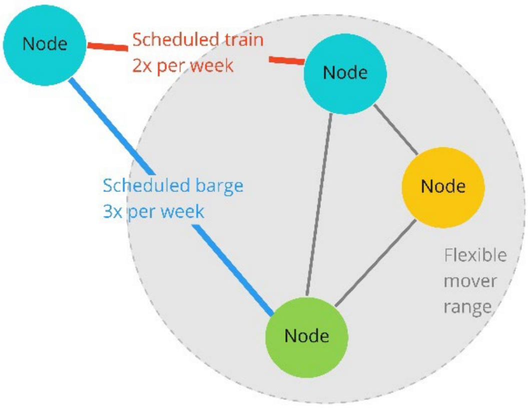


Figure 17. connection of the nodes on the network

Since clients do not have a physical component, their environment is purely functional in the sense that they share and receive information from other clients and distribute bookings to nodes and movers in the GIS environment. As presented in the picture below, the clients serve as an information-sharing network, where the logistics network state is shared using the communication network:

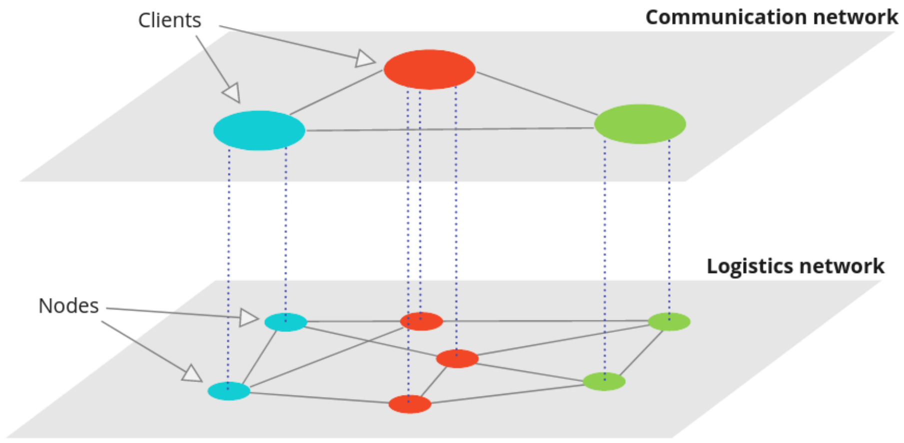


Figure 18. relationship between the communication network and logistics network

Both networks, logistics and communications, are configurable via the input data.

6.3.2 Communication network

In this context, the network state is the collection of node capabilities and mover schedules. One can represent this as a connected graph, where capabilities are attributes of the node, and the mover schedules define the edges between nodes.

One of the goals of the PI is to reduce the imperfect information about the logistics network. A company is usually limited to its business partners to plan container transports. Hence, to simulate the business operations and the benefits of information sharing via the PI, we have two ways of running the simulation. First, using a pre-defined communication network, where the information that a client receives comes only from directly connected clients. Thus, depending on the setup, clients will not have the full information about the totality of the local area network (LAN) in which they operate, but will only receive the capabilities and schedules of directly connected clients.

The second communication structure is by using the decentralised PI. Where the different clients pass the information along to the next client. This results in every client holding an up-to-date version of the state of the network.

Therefore, when a client uses the routing algorithm to plan a container transport, the known information about the transport network and node capabilities will depend on the connected clients' received information. This allows us to define different scenarios and measure the benefit of sharing information, as well as observe emergent phenomena.

6.3.3 Time

Since we are interested in simulating an actual logistics network, facility working hours and movers travelling in GIS space, the simulation time granularity is in minutes. This enables us to accurately simulate the planned routes coming from the routing engine described in chapter 5.

6.4 Process overview and scheduling

This ABM aims to understand how container flows might be optimised if horizontal collaboration is enabled by participating in the PI. To do that, as the simulation progresses in time, expeditors are responsible for generating and planning transport orders. This process will trigger the spawning and subsequent movement of containers by utilising movers' and nodes' capabilities.

6.4.1 Demand

For each booking data entry, which includes data such as pick-up and drop-off location, and time constraints, it will also specify when the container enters the simulated environment. This data is then transformed into an event that will trigger the planning and booking process. Once that process is complete, the different movers should take the container from its pick-up location to its cargo owner's location and drop-off location, according to the planned route.

6.4.2 Disruption events

NB: This aspect of the simulation is not yet fully defined. The following information serves as an introduction of what kind of disruption mechanisms will be studied in the later stages of the project.

Another aspect that needs to be measured is the robustness and resilience aspect of this type of logistics network. How do the containers get re-routed in the case of:

1. Delayed container release, where a vessel arrives at a port is delayed. This results in a delay in the release date of the container, and previous plans might be rendered obsolete.
2. Delayed transport, happens when a mover arrives late to its destination, disrupting the initial planning.

This type of simulation modelling allows us to run experiments where we vary the parameters that trigger the delays above, increasing or decreasing their severity and duration. Hence, we can measure and compare the robustness of our proposed system with varying degrees of disruption.

6.4.3 Randomness

Inputs to experiments made with this model are based on historical data. Because there is uncertainty, we can more closely simulate these systems if we translate the historical data into probability density functions. The following processes will be considered stochastic and modelled using a probabilistic approach:

- The mover handling time at a hub. When a mover is being serviced at a node, the duration of this service will be sampled from a probability density function derived from historical data of this exact same process.
- Scheduled mover-free capacity. Because the focus of this simulation is to optimise container flows, I.e., allow for modality shift, we will be interested in the free capacity on scheduled movers. Hence, the inefficient routes can be re-routed to other modalities. The free capacity for each scheduled trip is then sampled from a probability density function built from historical data.

This results in a non-deterministic model, where every simulation is different since we are sampling from distributions. By using Monte Carlo experiments, we can statistically process the results of multiple simulations to assess the different outcomes.

6.5 Inputs and setup

This model is data-driven, where its inputs determine all aspects to be simulated. Hence it can be initialised from many different scenarios. To define a scenario, the following data must be provided:

- Client information and communication network, i.e., which clients communicate with which, as well as the parameters that configure its cost function for route selection.
- Node geographic information, capabilities (hub, depot, gateway, store and/or composer) and operating hours.
- Transport orders data for each client, which includes:
    - Pick-up and drop-off node
    - Loading/discharging node
    - Time constraints (earliest pick-up, loading/discharging time window, latest drop-off)
    - Container information (weight, size, and type).
- Scheduled mover information, where it is defined when and with what frequency these movers depart. It also provides information about the expected free capacity, which is a distribution to be sampled during the simulation.
- Flexible mover information, where the bases are located and what capacity is available. The driving range is defined by the base’s operating hours.

6.6 Outputs

Given the fact that ABM is a bottom-up approach to modelling, the different components are modelled as individual agents, and this allows us to measure many different aspects at an individual level and later aggregate these metrics to understand the overall picture. For instance, because we model a mover as an agent moving through the representation of its physical infrastructure, we can, at any point in time, pinpoint its current location. Hence, as each simulation evolves in time, different metrics are going to be collected. For each task that makes up a route, we will collect:

- Expected and actual start time
- Duration
- Start location and end location
- Type of activity
- Activity cost
- Distance and emissions
- Mover information
- Node information

Aggregating the outputs above, we can determine the overall network performance regarding throughput, emissions, cost, or any other relevant metric.

Regarding asset utilisation, we will also collect information on the utilisation of the free capacity for all different scheduled movers as well as the utilisation of the flexible mover pools.

6.7 Conclusion

This simulation model becomes a tool to test the proposed information system implementation that underpins PI. We can see this model as a sandbox to test different implementations, routing preferences and different strategies to handle disruptions. We will run a certain number of experiments, where for each scenario, we will test different π-client configurations and determine which set of parameters and rules outperform the business-as-usual situation. Because this is a non-determinist model, we will run Monte Carlo experiments in order to statistically treat the outputs and compare results. In the following chapter, it can be found further detail on how this model will be used to validate the proposed solution.

7 Validation of PILL

This chapter provides the content foreseen in deliverable D2.1: Verified, calibrated and validated PI operations

In chapter 3, we highlighted the key Wicked Problems in the Logistics sector and the challenges and assumptions our solution had to overcome in order to respond to these Wicked Problems. Next (chapter 4 and 5), we explained the concept and technical blueprint of our solution, the π-client, and the way it was created through the ABM (chapter 6). In this chapter, we will evaluate our π-client and see how well it answers our initial challenges and assumptions. This chapter conveys a 3-staged validation framework to evaluate the desirability, viability and feasibility of the solution. The approach suggested in this chapter will unveil the success and shortcomings of our solution.

7.1 Goal & scope

7.1.1 The validation framework

In business innovation modelling, a new solution should be validated on three criteria: Desirability, viability and feasibility. If a solution is validated on these three criteria, we can assume there is a good product-market fit.

- Desirability:	Does the solution solve a need for users who are willing to use the product
- Viability:	Does the solution provide ample added value that users want to pay for it?
- Feasibility:	Do the capabilities that contribute to the added value work accordingly?

Desirability

The desirability of the use cases will be validated during validation interviews with critical stakeholders of the logistics network that will be the first users of the Pi-client, as well as through the entire advisory board stakeholders. The final result of this validation will be a desirability score in the form of a Net Promotor Score (NPS).

Viability

Validating the viability of the Pi-client consists of two aspects: (1) Proving the π-client results in a theoretical improvement of the current logistics processes and (2) proving there is sufficient business value for stakeholders to invest in integrating with the π-client

(1) To validate that the Pi-client achieves a theoretical improvement of the current logistics processes, the Agent-Based Model (ABM, ref. chapter 6) will be used to simulate a set of scenarios that represent the key assumptions identified in D1.4 User Stories & Assumptions map. The outcome will be theoretical proof that the Pi-client offers business value and an improvement compared to the BAU.

(2) To validate the actual viability of the π-client, we have to prove that logistics stakeholders see enough value in the solution in order to invest in it. This investment can occur in many ways: from an initial integration cost, to the actual payment for access to or 3rd party services on the π-platform (Access to the Physical Internet itself is not meant to be monetised but meant as a validation tool). The actual validation method will still be defined in a later stage of the process.

The viability validation of the π-client is still in progress and will not be further expanded in this version of the report (October 2022). By the final deliverable, a detailed description of the viability validation and its results will be shared in the final version of this report.

Feasibility

The feasibility of the π-client will be validated through a series of Proof-of-Concept (POC), focussing on the user stories from chapter 2.3 Use Cases and by integrating with actual logistics players and aimed at validating the key technical components of the π-client. The outcome of these pilots will be to prove that the π-client can successfully (and automatically) generate a shared data network and interoperability between the stakeholders in its network in a real-life environment.

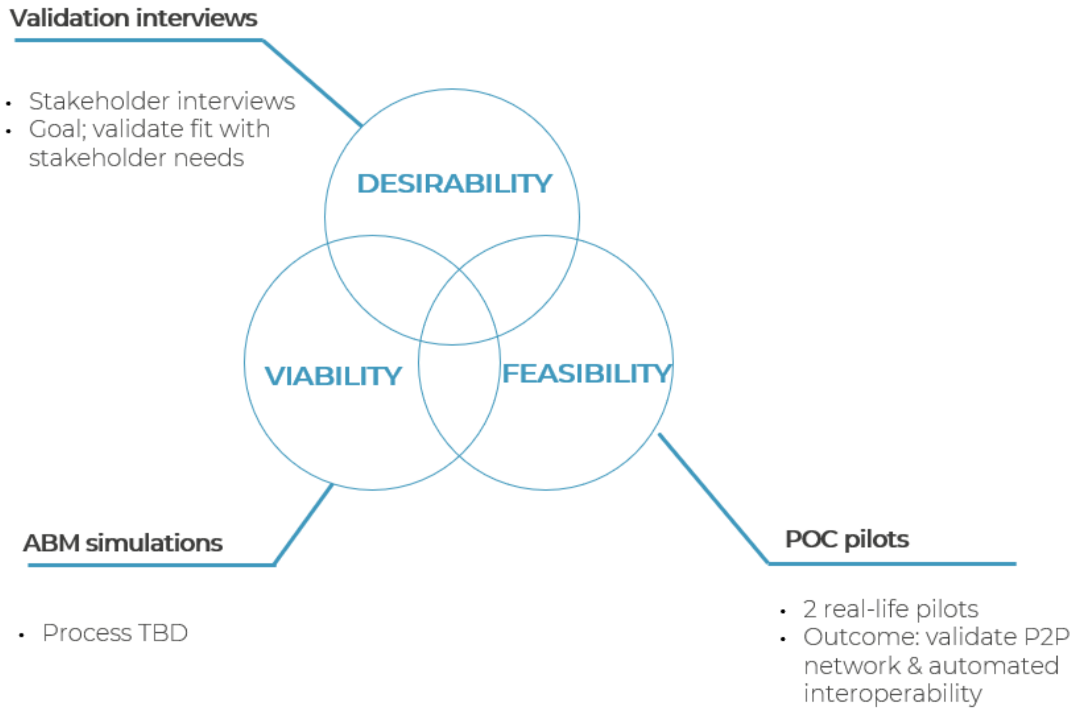


Figure 19. validation framework

7.1.2 Validation scope

In the document D1.4 User story and assumptions map, we mapped out all the assumptions on desirability, viability and feasibility, and rated them on the importance for the stakeholders or development of the solution. We also described the three key Wicked Problems in the logistics industry and concluded that Wicked Problem 1: improve planning reliability was the most critical problem that impacted the other 2. Thus, to prove the success of our solution, we will focus on validating the assumptions that

- Relate to Wicked Problem 1: improve planning reliability
- Score a 4 or 5 in importance

Table 8. assumptions that are in scope of validation (importance score = 4,5; Related to Wicked Problem 1)

Parameter	Assumption	Score
Desirability	All logistics roles want to improve their planning	5
Desirability	All logistics roles want to decrease the (unpredictable) delays in logistics	5
Desirability	Cargo Owners want to increase their view of possible transporters to find solutions that better fit their priorities	4
Desirability	Expeditors want to increase the reliability of their transports	4
Desirability	Transporters want to improve the fill rate of their movers	4
Desirability	Transporters want to reduce the buffer time needed when planning their transports and/or want to reduce the amount of overtime caused by unexpected delays during transport	4
Desirability	Barge & train operators want to become more competitive by using their economies of scale	5
Desirability	Transporters want to make reservations (given all of them can be done through one platform) rather than wait for an available slot on site	4
Desirability	Transporters want to optimise their free capacity	5
Desirability	Policymakers want to reduce the overall external costs of logistics	5
Feasibility	Routes can be generated between nodes	5
Feasibility	The π-solution is technology agnostic, meaning all logistics companies can integrate with it	5
Feasibility	Data collection needed to predict the future network state can be done without installing (much) extra sensors	4
Feasibility	Relevant alternative routes can be found already with a limited # of parties that join the system	5
Feasibility	Transport providers need to digitalise (part of) their planning process to be able to interact with the PI	4
Feasibility	Routing software can create optimised, multimodal route options with the available data	5
Feasibility	Routes can be compared on parameters such as time, emissions and reliability (optional cost)	4
Feasibility	Interaction between stakeholders can be automated	4

Parameter	Assumption	Score
Feasibility	All stakeholders in the network have access to an updated list of each other's business information and capabilities in order to calculate routes	5
Feasibility	Stakeholders in the network can interact with each other to plan or alter routes	5
Feasibility	Interaction between stakeholders can be automated	5
Viability	Logistics companies will accept integration costs to integrate with the π-system	5
Viability	The solution will result in more reliable transport that reduces the cost of delays or disruptions	5
Viability	All players are willing to share the relevant data with the network	5
Viability	The solution will make it easier for expeditors to select the more optimum route for their preferences (time, reliability, cost, emissions)	4
Viability	The solution can work without compromising commercially sensitive data	5
Viability	The solution is capable of increasing the number of potential routes to choose from	5
Viability	The solution will reduce the cost of the overall logistics process by optimising the planning process	5
Viability	The solution will follow a set of rules that leads to a better flow compared to the BAU	5
Viability	The solution will increase the fill rate of movers	4
Viability	The solution will result in a reduced CO2 logistics process	5

7.2 Desirability – Validation interviews

The desirability KPIs are based on interviews with Advisory Board members, and a list of motives and success factors from the Advisory Board stakeholders to determine what their needs and hopes are for the Physical Internet. The desirability KPIs will be validated through user interviews and surveys with the stakeholders to see whether they experience our solution as answering their needs.

Table 9. desirability assumptions that score a 4 or 5 on importance

Desirability Assumptions (importance 4 and 5; WP1)	**Desirability KPIs: the solution should be..**
All logistics roles want to improve their planning (predictability)	...an improvement to planning predictability
All logistics roles want to decrease the (unpredictable) delays in logistics	...reducing delays in logistics
Barge & train operators want to become more competitive by using their economies of scale	...increasing visibility in the market
All logistics roles want to optimise their free capacity	...optimising free capacity
Policymakers want to reduce the overall external costs of logistics	...reducing external cost of logistics
Shippers want to increase their view of possible transporters to find solutions that better fit their priorities	...increasing better overview of and access to alternative route options
Transporters want to improve the fill rate of their movers	... emphasising routes with low fill rate
Transporters want to reduce the buffer time needed when planning their transports, and/or want to reduce the amount of overtime caused by unexpected delays during transport	...increasing the speed of the logistics process

Three to five bilateral interviews with each of the key stakeholder groups will be planned. During these interviews, the stakeholders will receive a demo of the key functionalities that the π-Client will be able to offer. Mock-ups of the solution will be used to show how the solution would work and how users would interact with it. Next they will have to answer a series of questions based on their desirability needs (eg. “Would this improve your planning?”).

PI-CLIENT VALIDATION

WOULD THIS SOLUTION IMPROVE YOUR PLANNING ?
PLEAS EXPLAIN

NO – PARTIALLY - YES

Figure 20. example of an interview slide

We will conclude with an overall rating of the solution, which can be translated into a Net Promotor Score (NPS), a well-established marketing tool to validate the desirability of a new product. The NPS will give you a score on how happy a customer is or might be with the product you offer. Eventually, we will be able to confirm or refute each of our desirability requirements and provide an overall NPS for the solution.

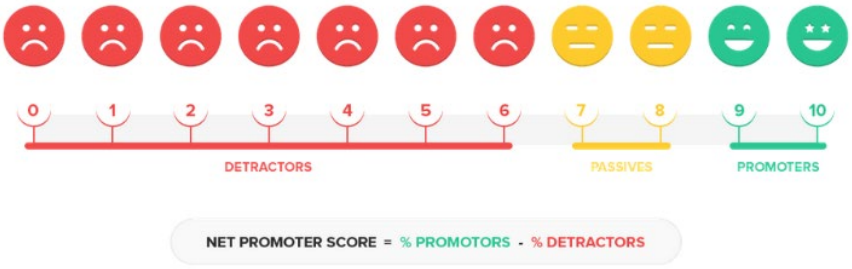


Figure 21. example of a Net Promotor Score (source Zonka Feedback www.zonkafeedback.com/blog/net-promoter-score-definition-and-examples)

Due to the cultural difference between Europeans and Americans, the European version of the NP shifts the score for passives and promotors one to the left (passives = 6-7; promotors = 8-10.

7.3 Feasibility - Real-life POC

The feasibility assumptions are based on technical requirements that are needed to answer the desirability and viability needs of the users. The feasibility of the solution will be validated through a series of real-life tests, for which a first Proof-of-Concept (POC) from the π-blueprint will be developed. The POC capabilities will be based on the feasibility KPIs that answer the key assumptions.

Table 10. feasibility assumptions that score a 4 or 5 on importance

Feasibility assumptions (importance 4 and 5; WP1)	**Feasibility KPIs: the solution should be able to**
Routes can be generated between nodes	..share hub capabilities from all nodes
The π-solution is technology agnostic, meaning all logistics companies can integrate with it	...integratable in all logistics companies' software
Transport providers won't need to digitalise (part of) their planning process to be able to interact with the PI	...integratable in all logistics companies' software
Data collection needed to predict the future network state can be done without installing (much) extra sensors	...create a plan without installing additional sensors
Relevant alternative routes can be found already with a limited # of parties that join the system	... offer a minimum of [tbd] routes per transport request
Routing software can create optimised multimodal route options with the available data	... provide multimodal alternatives to a truck-only route that are faster, more reliable or more cost-effective
Routes can be compared on parameters such as time, emissions and reliability (optional cost)	...filter route options for time, emissions, reliability
All stakeholders in the network have access to an updated list of each other's business information and capabilities in order to calculate routes	share a single and updated state of the network across all actors in the network
Stakeholders in the network can interact with each other to plan or alter routes	facilitate capacity requests & bookings in the system
Interaction between stakeholders can be automated	automate capacity requests & bookings in the system

We define a POC as an experimental pilot where specific capabilities that demonstrate the feasibility of the concept are developed and launched in a test setup.
Unlike a Minimum Viable Product (MVP), which proves the business value of a product, a POC does not necessarily need to result in an improvement to the current situation yet. Hence the goal of the POC pilots is not to prove an improvement of the logistics processes, but rather to prove the interoperability of that system within a network, which can later be used to prove improvements.

7.3.1 POC goal & scope

The objective of the POC is to validate the key technical components of the π-client, related to Wicked Problem 1: improving planning reliability. For this, we will focus on setting up the first network of logistics players, where routes are generated using information from the network, and capacity is manual checked (YES/NO) by the transport operators involved in the routes, resulting in the selection of a suitable route with available capacity.

For this POC, we will not yet include an actual transport booking flow, since this requires a real-time view of capacity, which requires technical integrations of the participants with the π-solution.

Looking at the technical components discussed in *chapter 5: Blueprint*, we can consider the three key components to develop and validate in the POC to be the (1) network manager, (2) route planner and (3) booking orchestrator. For each of these, we determine the goal we want to achieve in the POC.

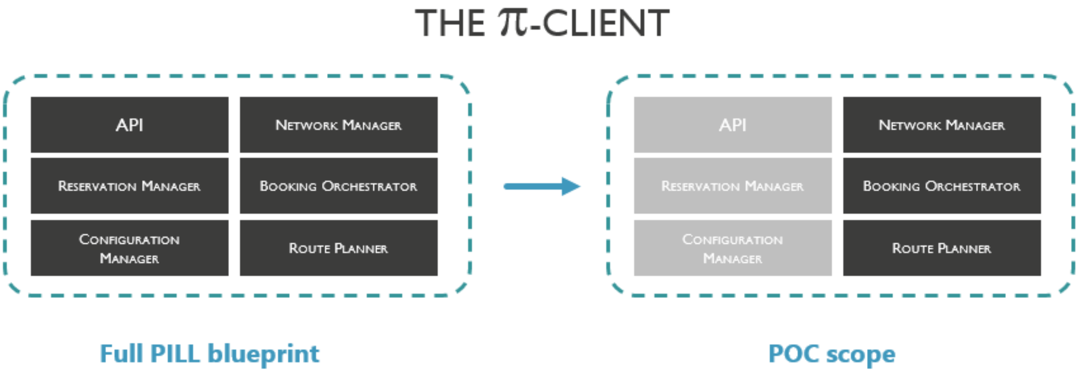


Figure 22. overview of π components and POC scope

POC goal - Network Manager
Establish a first decentralised P2P network log where data is shared across the network and stored locally

POC goal - Route Planner
Generate and compare a set of route options, using data shared across the network.

POC goal - Booking orchestrator
Enables the first case of (decentralised) interoperability in the form of manual capacity requests and confirmations between expeditors and transport providers.

7.3.2 POC project scope & setup

The first POC will tackle User Story 1.1: Intra-port Alternatives. In this use case, the π-client is used to offer transporters and forwarders (multimodal) alternative route options for Cross-Bank transport, avoiding delays due to congestion on the ring roads.

POC Challenge

Containers often arrive at a terminal on the left bank of the Port (of Antwerp), after which they need to be transported to the train terminal of Lineas at the right bank to continue their journey. Forwarders almost always use truck transport for this cross-bank journey, since there is little margin between left bank arrival and right bank departure. Trucks performing this cross-bank transport need to travel on the Antwerp Ringroad, often during working hours, leading to high congestion on the ring and unpredictable arrival times on the right bank.

How might we use our PILL blueprint to:

- Connect a network of stakeholders that can offer alternative routes
- Calculate different cross-bank and compare on time and reliability
- Request and confirm capacity for the generated routes directly with the stakeholders

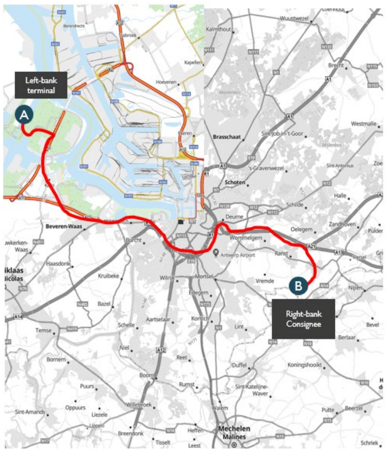
POC scenario

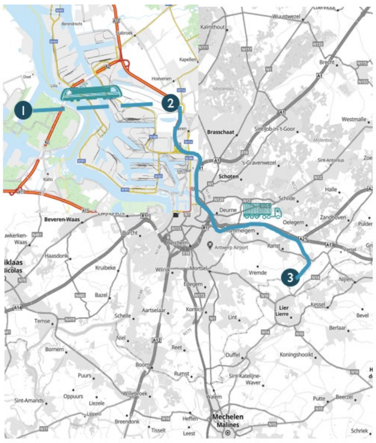
In the POC we will tackle this challenge by setting up an initial network of transporters, capable of comparing three route options to see which one offers the most reliable ETA.

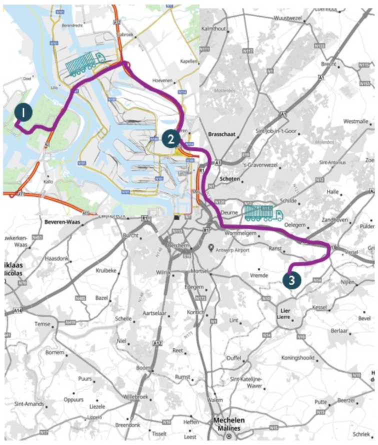
1. Cross the bank by truck during the day (BAU)
2. Cross the bank by train
3. Cross the bank by night truck

Through a dedicated platform, a participating Expeditor can generate the three options, based on information and capabilities from the other participants. Next, he or she can filter and rank the routes according to their preferences, and request capacity. The involved transport operators will receive a notification of this request through their platform and can then confirm or refuse, based on their real-time capacity. The first route in the list, which has confirmation from all transporters, will be selected and communicated as the chosen route.

The expeditor and transporters can now individually arrange bookings with each other (for the scope of the POC, this will still happen outside of the platform)







Option A: Business as usual
The truck crosses the bank by truck during rush hours

Option B: Train transport
The truck crosses the bank by train and continues by truck

Option C: Night transport
The truck crosses the bank at night and continues during the day

Figure 23. 3 routing options included in POC

7.3.3 POC user functionalities

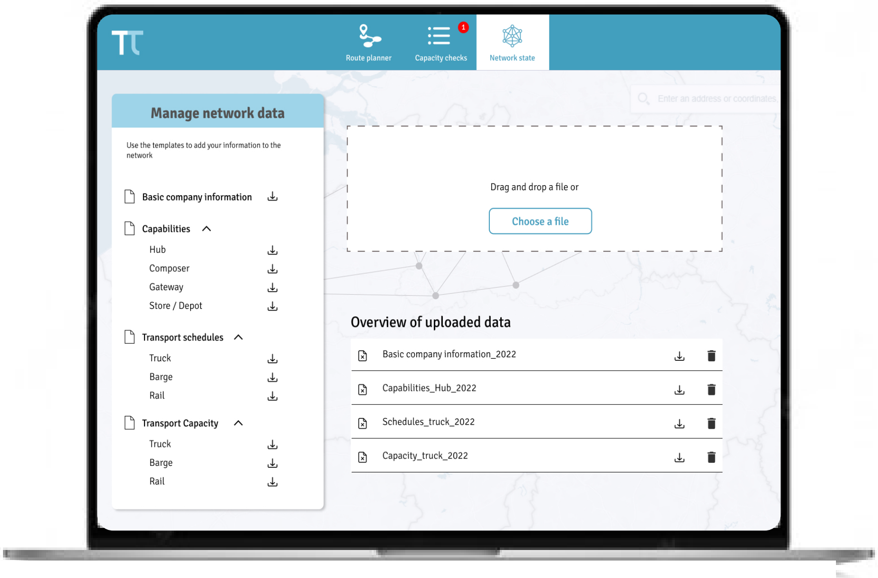
To achieve our before mentioned How-might-we challenges, the initial π-platform will provide three core user functionalities:

- Managing information on the network (for all stakeholders)
- Creating & requesting routes (for expeditors)
- Checking capacity (Y/N) for route requests (for transporters)

Managing information on the network

All stakeholders will be able to identify themselves as a certain actor on the PI, such as a transporter or expeditor. They will be able to add or update their business information and capabilities to the network, as well as have a full overview of all the available data on the network. The so-called 'network state'.

Once a stakeholder adds or changes any of their information on the network, the network manager will forward those changes to all other stakeholders' π-clients and ensure everyone has an updated version of the network state.



Use the templates to add your information to the network

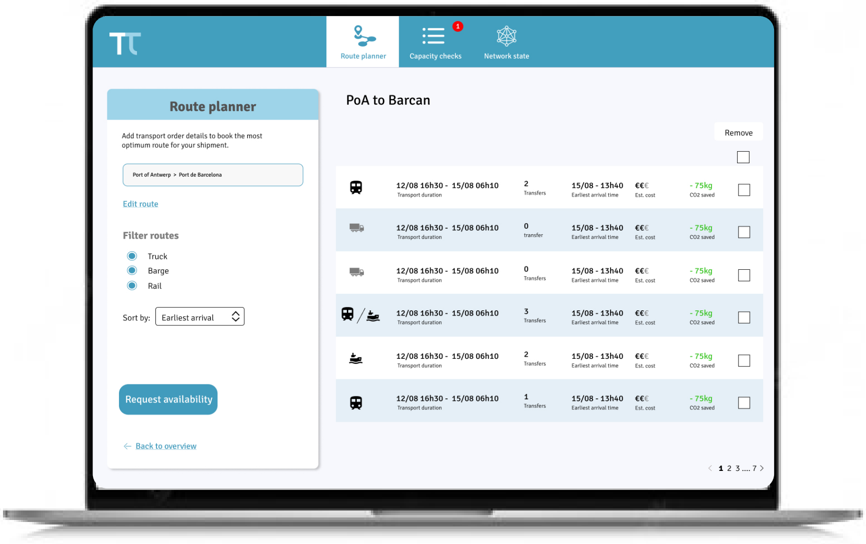
Figure 24. managing the network state - mockup

Creating & requesting routes

Expeditors will be able to input a transport order and receive a list of route options, generated by the route planner with the current network state.

The route overview will show comparative information for each route, such as ETA, emissions and reliability indication (in %). Expeditors can prioritise the route, based on these criteria and even delete route options that they don't like.

When an expeditor is happy with the prioritisation of their list of route options, they can simultaneously request capacity for these routes, starting at the top.



Add transport order details to book the most optimum route for your shipment.

Port of Antwerp > Port de Barcelona

● Truck
● Barge
● Rail

Sort by: Earliest arrival

PoA to Barcan

	12/08 16h30 - 15/08 06h10 Transport duration	2 Transfers	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐
	12/08 16h30 - 15/08 06h10 Transport duration	0 transfer	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐
	12/08 16h30 - 15/08 06h10 Transport duration	0 Transfers	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐
/	12/08 16h30 - 15/08 06h10 Transport duration	3 Transfers	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐
	12/08 16h30 - 15/08 06h10 Transport duration	2 Transfers	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐
	12/08 16h30 - 15/08 06h10 Transport duration	1 Transfers	15/08 - 13h40 Earliest arrival time	€€€ Est. cost	- 75kg CO2 saved	☐

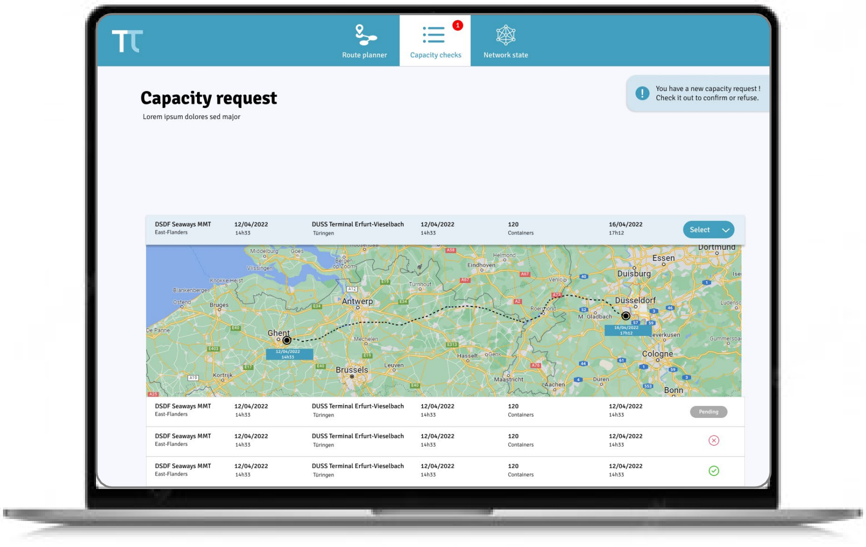
Figure 25. generating & comparing routes - mockups

From the expeditor's point of view, there is a simultaneous request for all routes. In reality, the Booking orchestrator reaches out to the transporters of the first route and only continues with the next route in case of a rejection.

Checking capacity (Y/N) for route request

Transporters will have an overview of all the capacity requests that they receive. They can accept or refuse a certain route request.

Once a route is confirmed by all transporters and selected, the expeditor will receive a confirmation that the route is available for booking with the specific transporters, and the transporter will receive a reminder to reserve this capacity for a certain period of time (or until the booking is confirmed by the expeditor)



Capacity request

Lorem ipsum dolores sed major

You have a new capacity request ! Check it out to confirm or refuse.

DSDF Seaways MMT East-Flanders	12/04/2022 14h33	DUSS Terminal Erfurt-Vieselbach Türingen	12/04/2022 14h33	120 Containers	16/04/2022 17h12	Select
DSDF Seaways MMT East-Flanders	12/04/2022 14h33	DUSS Terminal Erfurt-Vieselbach Türingen	12/04/2022 14h33	120 Containers	12/04/2022 14h33	Pending
DSDF Seaways MMT East-Flanders	12/04/2022 14h33	DUSS Terminal Erfurt-Vieselbach Türingen	12/04/2022 14h33	120 Containers	12/04/2022 14h33	⊗
DSDF Seaways MMT East-Flanders	12/04/2022 14h33	DUSS Terminal Erfurt-Vieselbach Türingen	12/04/2022 14h33	120 Containers	12/04/2022 14h33	✓

Figure 26. overview capacity request for Transporters

7.3.4 *POC participants*

Based on the three route options that the POC will aim to generate, a small group of participants will be recruited specifically to achieve these route options.

Transporters will be recruited from the Advisory Board, and expeditors will be recruited either through the network of the advisory board or through the personal network of the researchers.

Table 11. stakeholder recruitment list

Stakeholder	**Recruitment status**
Left-bank terminal	No recruitment needed
Train terminal	Lineas confirmed
Rail operator	Lineas confirmed
Truck transporter	*Recruitment in process*
Night truck transporter	*Recruitment in process – possible candidate Gommeren*
Right-bank holding place (parking)	*Recruitment in process – possible candidate Gommeren*
Shipper/expeditor	*Recruitment in process*

7.3.5 *POC roadmap*

In order to ensure an agile development process, the POC will be built up and tested in two phases:

- Phase 1: Generating interoperability between stakeholders in the network
- Phase 2: Automating the process of sharing information across the network

Phase 1: Set up interoperability

The first phase of the POC, will focus on setting up the network and integrating all the user functionalities. The participants will already be able to perform all the tasks as described in chapter 7.3.3*:* POC user functionalities. However, the back-end automation of these processes will be postponed until the second phase. In the first phase, manual intervention by a back-end operator is still needed to forward information across the stakeholders and to enable interoperability between stakeholders.

The goal of this phase is to validate the network manager and the capability of the route planner to generate route options from information from the network state.

Phase 2: Automate the network

In phase 2, the back-end processes will be automated. From this point on, we can consider the π-client to be a fully decentralised and automated system that enables communication and interoperability between stakeholders.

The goal of this phase is to validate that the booking orchestrator is capable of facilitating interoperability (i.e. capacity checks) between stakeholders, in an automated way without a centralised system.

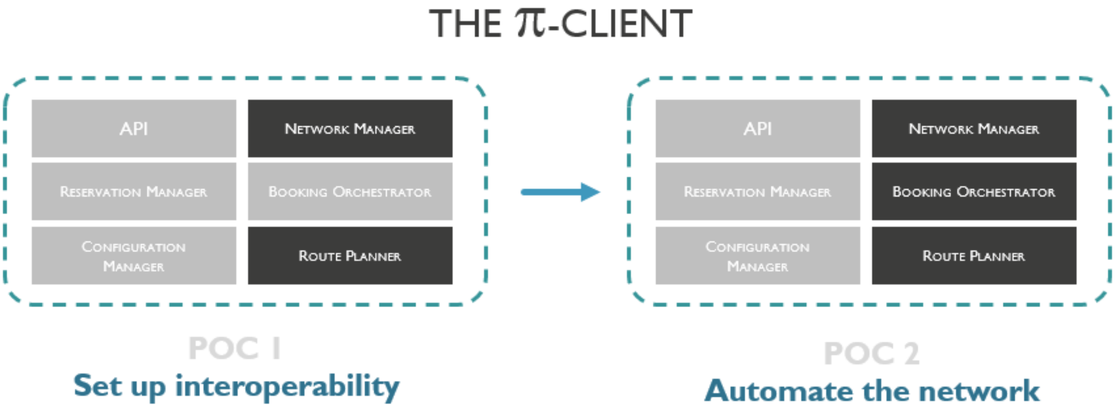


Figure 27: POC development roadmap

POC timeline

The POC recruitment will start in Q4 2022 together with the development of the first components. The POC launch is planned by the end of Q1 2023 and is expected to run until the end of 2023, when it will undergo the two above-mentioned phases.

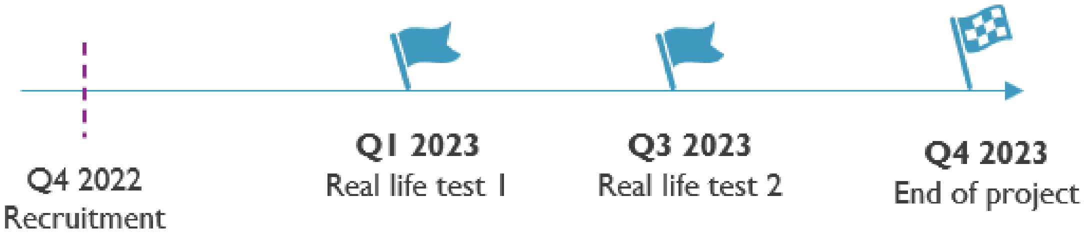


Figure 28: high-level POC timeline

7.4 Viability – ABM simulations

To be included in the final version of this report

7.5 Findings

To be included in the final version of this report

8 Follow up & Next steps

This chapter provides the content foreseen in deliverable D5.3: Follow-up and funding plan

In this chapter, we will look beyond the validation track of our current PILL project (as explained in chapter 7) towards potential future projects. The ideas behind these future projects derive from both open-ended questions in our current research track, as well as Advisory Board feedback given on our proposed π roadmap and current solution throughout the project.

The next steps discussed in this chapter are based on feedback & open questions in the current phase of the project at the moment of this writing (October 2022). These next steps may still alter by the final report, depending on new insights or questions that might arise during the upcoming validation process.

8.1 Feedback from Advisory Board (October 2022)

So far, this report has outlined the key challenges in the logistics sector and the requirements of our solution in order to answer these challenges. It then explained the concept and technical blueprint of the π-client, our answer to these challenges, and shared the first steps in validating the desirability and feasibility of this π-client through interviews and POC tests. This story – consisting of the details of our π-client together with the POC planning – has been presented to the PILL Advisory Board on a regular basis. The goal of these Advisory Board meetings was (1) to validate whether the π-blueprint and our POC were a good first step towards a Physical Internet, and (2) to discuss what the next crucial steps would be in bringing the π-blueprint closer to a real-life application.

(1) In general, the Advisory Board participants understood what the capabilities of the π-client were and how it would be used in a Physical Internet for logistics. The overall feedback of the Advisory Board participants was that the π-blueprint was a good first step towards a Physical Internet milestone for 2030. When looking further to 2040 or 2050, more automation and additional streamlining of the logistics flow were still expected. The goal of the POC – to validate the network capabilities and decentralised interoperability in the form of a capacity check on routes generated with data from the network – was perceived as being a first, major milestone in the Physical Internet implementation.

(2) When discussing the real-life implementation of this π-client, certain considerations emerged about the scalability of the solution. Once the π-client is implemented in a real-life application and economies of scale come into place, there will be a different dynamic between the stakeholders in the community. The most prominent considerations focus on the rules and trust around data sharing, and the proof of Utilisation as a business value and Buy-in towards stakeholders to join the network.

The key questions that emerged from the Advisory Board, related to this feedback were as follows:

- How might the π-client ensure trusted data sharing among stakeholders?
- How might the π-client ensure fair data sharing happens on the network?
- What are the rules around what data is seen and shared by each stakeholder?
- What data-sharing policies can benefit the adoption of the π-client?
- How will the π-client handle contractual relationships in larger and more dynamic systems (digital handshakes)?
- What buy-in can the π-client prove to the onboard stakeholders? (synchromodal, utilisation,...)
- How might implementing 3rd party value-added services contribute to a business model on the PI?

Pricing and payment integrations were also explored by the Advisory Board and will form a key aspect of the next steps. They are, however, not included in this chapter's summary to keep the focus on feedback on the proposed solution.

8.2 Proposed valorisation track

The next steps after the completion of this project will aim at preparing the π-blueprint for real-life implementation. *Chapter 2* outlines the 3 key research questions for the PILL project, that formed the basis for our π-solution.

- How can the necessary data be shared without infringing commercial privacy?
- How can ABM contribute to evaluating the impact of implementation details (regarding disruptions, routing algorithm rules, policies...)?
- What business value can the PI create while respecting the commercial privacy and individual interests of each actor?

The 3 components of these research questions (data sharing, ABM model and business value) remain the focus of the proposed validation track. Based on the feedback from the Advisory Board, we identify the following focus areas for each of the components

Table 12. focus on the next steps in order of importance

Data Sharing	Valorisation of data sharing regulations and standards in a decentralised community
Business value	Innovation research into the business model of the π-network
ABM Model	Reshaping the ABM model towards a first 3rd party commercial tool on the network

8.2.1 Valorisation of data sharing

Data sharing is a critical capability in the π-network, but also one of the major impeding factors for stakeholders to joining the network (together with technical integrations). Stakeholders today are very protective of their data and concerned about making data public to their competitors. To overcome this, regulations need to be agreed on concerning fair data sharing and data privacy. This track will focus on tackling these challenges.

In the valorisation track, a first beta π-community could be set up that would actively use the π-network. This community would be the testing ground for components and policies, as well as measuring the impact of data sharing on business processes. Ideally, the membership of this π-community would remain generally stable, allowing members to follow the progress as it happens, reducing their buy-in cost for every new project.

In the first phase of this track, the baseline rules and standards for data sharing will be investigated and set up in a data space-like environment. Components or policies developed in different projects could then be added and/or updated on a frequent basis, based on user feedback from the beta π-community. As the beta π-community would run for an extended period of time, measurements can be taken to prove the business value of sharing data (increased utilisation, reduced administrative costs...). This would provide buy-in for early adopters in a later stage.

Some steps to accelerate the wider data standardisation and data sharing have already been taken within the PILL project. Firstly, the standards used within the project are derived from the DCSA standard. In doing so, we connect to the existing standards for maritime traffic. Secondly, through the ETP Alice network, discussions are being organised to align the main PI architecture components and standards between the different projects on

PI and related topics (FENIX, FEDeRATED, SENSE, ICONET, DISPatCH, COREnect, TOKEN). The goal of these discussions is to bring research on these topics from a diverging into a more converging phase.

Another pathway to larger data standardisation might be found through an OSLO project in cooperation with the Flemish government (Digital Flanders). As the methodology used in this project is strongly community-based, this approach would also help in growing the beta π-community.

Goal:

- Set up a fixed beta π-community to decrease the implementation costs of testing
- Validate the governance principles for the decentralised π-community
- Valorise direct benefits of fair data sharing in a decentralised π-community
- Research the correlations between the π-network and a Data Space

Research topics:

- Physical Internet component requirements
- Data sharing standards
- Fair data sharing policies: receiving vs. sharing data
- Data sharing governance
- Direct benefits of data sharing (utilisation rate, administrative costs, reliability of planning,…)

8.2.2 Business model innovation research

A key accelerator of the adoption of the internet was the rise of commercial use cases during the so-called dot.com era. Similarly, the Physical Internet will most likely also grow significantly once commercial applications are implemented. This academic track might research and – to a certain extent – validate how logistics companies might do business on the π-network and how the Physical Internet could become the birthplace of various new business models.

The business model research track can be considered a follow-up research track for academic research that zooms in on the business dynamics of the Physical Internet. This track might refine and validate the business interactions between logistics stakeholders within the context of booking transport orders. Through several tests, this track could validate how stakeholders will handle business relations on the Physical Internet, and how pricing and payment can be handled. Additionally, it would explore and map the additional business dynamics on the Physical Internet, which in turn could be the inspiration for commercial tracks or new startups to emerge on the Physical Internet.

Goal:

- Define and evaluate potential business models for PI through business modelling
- Evaluate the impact on the current day logistic players and derive transition plans if necessary
- Detect possible unwanted side effects and propose policy measures to counteract them
- Define and evaluate policy measures to strengthen the sustainability impact of PI.

Research topics

- Potential new business models for PI
- Evolution of logistic business models within PI
- Policy guidelines to mitigate unwanted effects of PI
- Pricing strategies on the π-network
- Transaction policies & standards on the π-network
- Business dynamics (e.g. Digital handshakes) on the π-network
- The role of 3rd party commercial tools (e.g. microservices) on the π-network

8.2.3 ABM-Digital Twin and other plug-in PI microservices

As mentioned in chapter 5, the Physical Internet will provide a data space-like environment, offering a large body of data with the same standard. This will give the opportunity to develop a new series of commercial tools aimed at supporting and improving the logistics processes. Once the work described under 8.2.1 has progressed far enough, this development could be taken on by independent IT companies or startups (with or without funding).

Within the PILL project, we already developed two demonstrators for these potential plug-ins, an ABM simulation model and a routing algorithm, as they were needed to initiate the project. For now, these solutions are far from market ready and are only designed to function in an exploratory research setting, but they could be imagined to be further developed into independent PI plug-ins.

The Agent-Based simulation model (ABM) was created as a tool to test the scalability of the π-client and compare network behaviour to the BAU. In the future, this model might be developed into a Digital Twin, used to optimise future logistics processes through What-If scenario simulations. The Routing Algorithm was created to calculate feasible and valid routes for containers and will be used both in the ABM and in the POC. In the future, it could be further developed and implemented by (at first) companies already working together. These commercialisation tracks could be considered a co-creation track where the proposed applications would be further refined and adapted to a real-life setting. Through co-creation with policy-making and/or commercial parties a first commercial use case and demonstration could be achieved.

Goal:

- Demonstrate the commercial potential of PI plugins
- Demonstrate how these plug-ins can increase the value of PI
- Develop commercially viable PI-tools

Research topics

- Can our current modules be further developed into commercially viable solutions?
- What-additional plug-ins could be developed?

8.3 Dissemination and publications

For this information, we refer to the updated version of D5.1 Dissemination Plan.

8.4 Valorisation potential

The potential impact of the PI concept on both business and sustainability in the logistic sector could be significant. However, we found that it is yet too early in the research process to define the validation potential in a detailed manner. As described above, we expect that quite some additional research (applied and academic) and development (by IT-oriented companies) will be needed to fully define the valorisation potential.

We expect the following value to emerge from future PI research:

- Increased utilisation of logistic assets, decreasing both direct costs and external impact
- Increased reliability of the overall logistic system
- Increased view on and optimisation potential of logistic movements for infrastructure managers
- Easier administrative tasks, both within companies and towards the government

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