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

D1.8 Simulation-based analysis of T&L and ICT innovation technologies v1

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Glossary of abbreviations used

Abbreviation / Term	Description
AI	Artificial Intelligence
API	Application Programming Interface
B2B	Business-to-Business
B2C	Business-to-Consumer
BPMN	Business Process Model and Notation
EGTN	EU-Global T&L Network
ETA	Estimated Time of Arrival
EU	European Union
GA	Grant Agreement
GTIN	Global Trade Item Number
IoT	Internet of Things
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LL	Living Lab
LMD	Last Mile Delivery
NSTR	Uniform Nomenclature of Goods for Transport Statistics
NUTS	Nomenclature of Territorial Units for Statistics
PI	Physical Internet
SKU	Stock Keeping Unit
SSCC	Serial Shipping Container Code
TENT-T	Trans-European Transport Network
UC	Use Case
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
WP	Work Package

1 Executive Summary

The objective of the research reported in this deliverable is (a) to define the impact of ICT and T&L innovation on EGTN, (b) to assess the impact of emerging concepts and technologies on freight transport corridors and hubs and (c) to position emerging technologies as contributors to the Physical Internet.

Both transportation and decision making depend on the available technology, as well as the performance of the deployed transport solution. For instance, think of the maritime container and digital platforms. The first induced a drastic change in handling operations changing the transport means themselves and their operational planning as well. The second allowed booking and sharing platforms for freight transport to exists. In this case, we see that both a hardware and a communication technology changed transportation both by opening the way for new physical means as well as new decision-making solutions. On the one side, adoption of technology and ICT solutions is moderated by several factors (geographical, economic, social, etc.), leading to a different degree of implementation and, as a result, changed performance. On the other side, successful technological adoptions can result in macroscopic changes in the performances of transportation networks and supply chains.

In the context of PLANET, the intention is to assess how innovation can impact the development of the EGTN concept. How do new technologies impact corridor performance? How does the context where a certain ICT innovation is deployed affect the adoption and the impact of the innovation itself? We address these questions by crafting a prototype PLANET integrated modelling capability, by building on top of the work done in previous deliverables which listed the models and modelling scenarios (such as D1.2) and by combining the effort and perspectives of different modelling partners and the Position Papers' authors.

With the goal of supporting the development of the EGTN concept, this deliverable reports the first steps taken in building PLANET's integrated modelling capability aiming at answering the opening set of three research questions. Concretely, this deliverable: 1) showcases a multi-model quantitative pipeline based on a LL that shows how microscopic (operational) and macroscopic (generalized utility) models can be jointly deployed to assess quantitatively the effect of technology at the macroscopic level; 2) considers and models the effect of containerized commodities having multiple entry points on national transport chains; 3) supports the development of the EGTN concept by estimating the impact of integrated innovations in a TEN-T networks setting.

This deliverable sets up the cornerstone for PLANET's joint planning capability which is a pipeline of quantitative models inspiring the *innovation*, *impact* and *integrated* attributes of the EGTN concept. This prototype made its first run and showed that multiple complex models can be successfully integrated. This is a two-fold result: first, it paved the way for further model integrations and enhancements, leading to the evaluation of different IT and T&L innovations in various scenarios; second, it provided an approach to address and model a range of operational contexts, future scenario logics and a range of emerging technologies.

As a final remark, what has been developed in the current deliverable will be continued and reported in Deliverable D1.9. The research work reported here is in progress, preliminary results have been obtained and the feasibility of the approach has been proved.

2 Introduction

2.1 Mapping PLANET Outputs

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

Table 1: Adherence to PLANET's GA Deliverable & Tasks Descriptions

PLANET GA Component Title	PLANET GA Component Outline	Respective Document Chapter(s)	Remarks
DELIVERABLE			
D1.8 Simulation-based analysis of T&L and ICT innovation technologies v1	**Description of quantitative models** that will help simulation-based analysis of T&L and ICT innovation technologies in EGTN simulation scenarios; this will (partly) be disseminated as a public compendium. (Report) **Model analysis of how ICT and T&L** innovations facilitate the EGTN (Report).	Chapter 6.3 – describes the quantitative models Chapter 7 explains how the results of the integrated model facilitate the EGTN	This whole document is the deliverable. The components highlighted in the GA outline are chiefly container in reported in the two referenced chapters.
TASKS			
ST1.4.1 Preparatory activities for the simulation	Preparatory activities for the simulation will build upon the scenarios formulated in T1.1 **(D1.2-Ch 5)** in order to **detail the research questions for applying the ICT and T&L innovations model.** More specifically, the scenario analyses of emerging technologies will be translated into **concise plans for modelling and simulation.** The results of the analysis of forthcoming legislative & policy initiatives (T1.3) will be integrated in the simulation plans to the extent that are expected to have an impact on the ICT and T&L innovations. Furthermore, the required data sets will be prepared which will contain information about corridor flows, node capacities, services and actors.	Chapter 4.1 -relation between scenarios and research questions Chapter 6.1 – plan for modelling and simulation	The results from task T1.3 have not been included in this version of the deliverable.

ST1.4.2 Impact assessment of T&L and ICT innovation technologies	Impact assessment of T&L and ICT innovation technologies will apply the quantitative models to EGTN simulation scenarios to **establish a comparative evaluation of potential benefits** from innovations considered (autonomous vehicles, warehousing automation, advances in Sensors, IoT, Blockchain, 3D printing for some product types, hyperloop) and to define the factors affecting their selection in EGTN corridors. This will connect with some of the findings of T1.5. It will also provide input to WP4, in particular T4.3.	Chapter 7.2 – comparison of the potential of different innovations	This is an anticipated result that can be obtained from the pipeline evaluation. The final version of this deliverable (D1.9) will contain the actual results.
ST1.4.3 Enhanced synchromodality and PI models for EGTN	Enhanced synchromodality and PI models for EGTN: **This subtask will research and develop synchromodality and PI models for EGTN**, extending the simulation scenarios of ST1.1.2 if necessary, to gauge the impact of PI and the role of the enabling technologies and innovations therein. These models will support WP2 components and modelling applications for the roadmaps.	Chapter 6.3.1 – PI model in a EGTN setting Chapter 6.5 - EGTN Synchromodality Model Requirements	The PI model developed as part of the PLANET integrated modelling approach EGTN. Currently, the focus has been on defining the requirements of an application of the Synchromodal model in the context of the EGTN. Thus, combining a microscopic (schedule) with a macroscopic (reliability) measure at the planning level.

2.2 Deliverable Overview and Report Structure

The remainder of this deliverable is organized as follows:

- **Section 3** defines the context for this deliverable, in particular the focal aspects that have been considered to define the prototype PLANET integrated modelling capability.
- **Section 4** provides the research questions for this deliverable.
- **Section 5** contains the literature review related to the various models considered
- **Section 6** explains the main contribution to this deliverable defining the prototype PLANET integrated modelling capability.
- **Section 7** provides the results from the deployment of the PLANET integrated modelling capability and the impact of the Cargoloop on the PI concept

- **Section 8** concludes the document.

3 Context definition: T&L and ICT innovation impact on EGTN.

This section provides background and context information supporting the development of the research questions in Section 4 and of the PLANET integrated modelling capability in Section 6.

3.1 EGTN definition

What follows is a re-elaboration of the EGTN definition obtained from the on-going work in T1.5 (by CERTH/UIRR). The definition provided here focuses on these aspects of the EGTN concept that are of importance for the current deliverable, and their relation to the modelling approach will be elaborated later in Section 6.

The EGTN concept can be understood as an advanced European strategy vision that implies the development of the Smart, Green and Integrated Transport and Logistics Network of the future. Its purpose is to efficiently interconnect infrastructure (TEN-T, Rail-Freight Corridors, etc.) with geopolitical developments, as well as to optimize the use of current & emerging transport modes and technological solutions. As efficiency and geo-economic developments do not necessarily lead to inclusivity and enhanced quality of life, the EGTN concept should be provided with the instruments to ensure equitable inclusivity of all T&L participants, increasing the prosperity of nations, preserving the environment, and enhancing Citizens' quality of life.

Being an advanced version of the TEN-T network concept, the EGTN concept is composed of several functional elements capable of:

1. strategy definition
2. strategy implementation
3. strategy possible outcomes (digital & physical infrastructures, new operational methods etc.)
4. strategy monitoring
5. maximization of strategy impact.

From this component/capacity perspective, PLANET defines the Attributes of the future EGTN. An attribute is a feature that the EGTN, as a strategic vision, should manifest. To clarify by comparison to a closely related concept, the TEN-T concept does not imply geo-economic awareness as it is limited in its scope to within-corridor logics. The EGTN concept challenges such assumption.

PLANET defines the following Attributes for the EGTN concept:

- Geo-economics aware: A European T&L network that is aware of the geo-economics aspects driving the development of new trade routes and flows to/from Europe and their impact on the TEN-T;
- **Innovation**: A European T&L network that takes advantage of the potential of innovative logistics concepts (e.g., PI) and enabling technological innovations (Industry 4.0, blockchain, IoT, 3D printing, etc.) in its operation
- **Impact**: A T&L network that is more economically, environmentally and socially sustainable than the existing TEN-T
- **Integrated**: An EU T&L network integrated with the global network both in terms of hard & soft infrastructure
- Inclusive: Accessible to disadvantaged regions, supporting the development of workforce skills & knowledge.

Focal of this deliverable are the **innovation**, **impact** and **integrated** attributes, considered both individually, as separate characteristics, and jointly, in their combination:

- **innovation** is considered by modelling advanced and innovative T&L concepts (PI, for instance) and ICT (AI).

- **impact** is considered by focusing on KPI at the different levels of aggregation and seen from different stakeholders.
- **integration** is considered by building models based on integrated transport corridors and integrated operations.

The three attributes are jointly considered in the modelling to create understanding of the EGTN concept.

To satisfy the above attributes PLANET goes beyond strategic transport studies and beyond transport ICT research, by rigorously modelling, analyzing and assessing T&L interactions and dynamics. The aim is to generate and exercise the most important future scenarios from a T&L perspective. The EGTN technology workstream performed within this deliverable is not aimed at producing a 'platform' but instead focuses on a blueprint and best practices to help T&L actors to define and implement a clear digital strategy.

The technical EGTN dimension comprises the merging of the project's two main research and development streams: 1) modelling and simulation leading to increased understanding and design of EGTN, and 2) provision of an ICT infrastructure that can be used for implementing EGTN solutions. The first point is focal in the research pursued in this deliverable and led to the development of a prototype model integration.

The EGTN concept is structured in the form of three interactive layers: the infrastructural, the technological and the governance layer. For each one of these layers their detailed specifications need to be defined in order for EGTN to be realized. It is a focus in D1.8 to consider and model the infrastructural and technological layers by means of quantitative models and simulations.

3.1.1 Geography, Actors & Stakeholders and T&L processes

With the aim of seeking relevant use cases, we consider geographical settings, actors, stakeholders and T&L processes that are aligned with the LLs. In this deliverable, the research focus and modelling result is chiefly aligned with the scenario and setting of LL1. We plan to extend the approach to the other LLs in D1.9. We highlight in Section 6.1, the process we followed for LL1 and that can be applied for the other LLs.

By focusing on a LL instead of devising an artificial case, we consider technologies (with the exception of the Cargoloop) that are currently being evaluated and found relevant by the stakeholders within the LL.

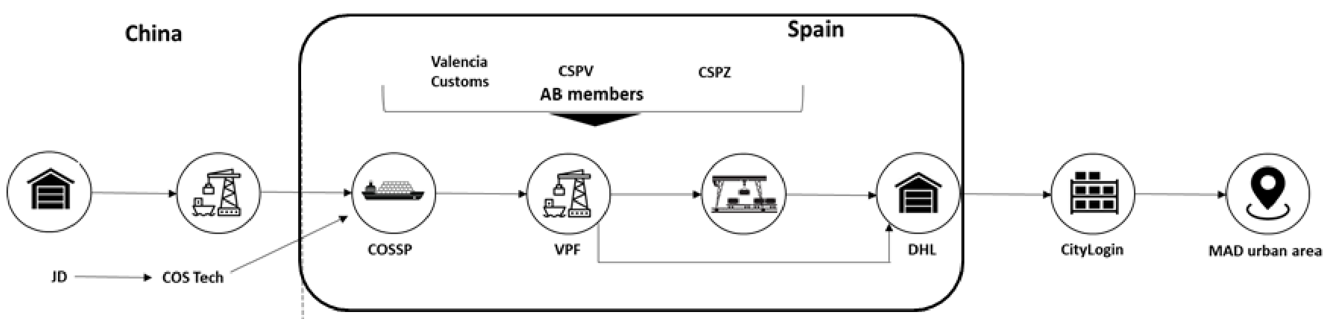


Figure 1 An example transport chain described in LL1 and the modelling focus.

Figure 1 shows the complete transport chain for containerized goods from mainland China to Madrid urban area and the operational context modelled within the PLANET integrated capability in the highlight box. Namely, we consider an intercontinental container transport chain starting in China and ending in the Spanish inland. We consider maritime container transport, terminal operations at ports and inland transport by means of rail or truck. Transport operations modelled are port selection for the ocean liner, inland movements of container by scheduled rail service or by truck and transshipment across different modes (maritime to road or rail). Further details are provided in Section 6.3.

It is important to observe, that the stakeholders and processes currently considered cover the EGTN scope at the corridor level. Note that the inclusion of intercontinental flow is novel and extends the current view of a corridor within a TEN-T network – which is limited to intra-European transport. The port selection problem plays an important role as it represents the decision-making problem of a stakeholder evaluating various points of entry to the European territory. Despite being in its first stage, such a framework is a clear step forward towards a geo-economically aware EGTN.

3.1.2 Type of decision-making problem modelled

Table 1 summarizes the focal type of decision-making problems considered in the process described in Figure 1. In this table, we compare the aim of the LL and how this has been considered in defining the PLANET modelling approach. Overall, the specific goals of the LL/UC are generalized and translated into an appropriate model.

Table 1 Type of decision-making problem considered in the PLANET integrated modelling capability

LLs / UC aim	Consideration within the PLANET modelling approach
Real-time decision-making approach ● Implement PI and AI for inland transport optimization based on customer instruction. ● Give intelligence to terminals for dynamic routing considering network capacity, transport mode, service level and costs. ● Changing maritime routes & container inland transport re-routing	● PI multi-agent simulation. As such a multi-agent simulation models different stakeholders and processes as independent agents that follow a pre-specified logic and interact to each other. ● Port Call decision model. This optimization model captures the operational decision of an ocean liner onto which ports to enter the European territory.
Import from Shanghai to Barcelona ports. ● AI to take decision on changing POD and evaluate new alternatives. ● Alternative analysis in terms of economic costs and times: ● Vessel waits at the port until the slot is released. ● Change port rotation.	● AI (forecasting model) is integrated with the Port Call decision model to guide container vessels in the simulation. This is a data analytics model used to estimate the value of AI deployment in the operations.

3.1.3 EGTN KPI in the PLANET integrated modelling capability

Because the scope of the EGTN concept spans from innovation (that is deployed at the operational level) to geo-economical awareness (that requires macroscopic and aggregated considerations), we consider KPIs both at microscopic and macroscopic level. The KPIs we consider are listed in Table 2:

Table 2 EGTN KPIs

Microscopic KPI	Macroscopic KPI
• Capacity at terminals • Number of deliveries at destination • Predicted congestion at port terminals (i.e., prediction of the congestion at the port terminal as a measure of the expected saturation of the terminal) • Average time spent at sea (i.e., average of the duration of the container time at sea) • Distribution of total lead time (i.e., distribution of the total transport time from origin to destination)	• Shipment reliability (i.e., average container lead time from origin to destination) • Modal split (i.e., fraction of containers moved by each mode of transport available) • Rail transport fill rate (i.e., fraction of total rail capacity that has been utilized).

The choice of such KPIs is motivated by both the current stage of the modelling capability (in particular, what is being represented) and the need to interact with the Terminal model (c.f., Section 6.3.4) which provides insights at the aggregated level.

More KPIs are planned to be introduced after an internal revision between the modelling partners. In particular:

1. PLCI (Port liner shipping connectivity index) from UNCTAD for the considered ports. This KPI acts as an important indicator for Port selection from the point of view of a liner shipping company.
2. Inland Terminal Connectivity Index as developed by Position Paper 1. This KPI – being developed as part of PLANET – provides insights into the connectivity of a terminal beyond what is being represented by a modelled network.

3.2 T&L and ICT innovations

This section briefly presents the technologies and innovations considered in the PLANET integrated modelling capability that are familiar within PLANET (e.g., Blockchain, Physical Internet, AI, Optimization, etc.) and presents in detail the Hyperloop for freight transport, the Cargoloop, in Section 3.2.1.

Table 3 provides a summary of the technologies/innovations considered. Moreover, the table provides a list of the features of the concept considered that have been successfully modelled. Indeed, the concepts reported have a larger scope and higher degree of complexity than what was decided to model in the first definition of the joint model.

Table 3 Technologies and innovation considered in the joint PLANET modelling capability

Technology /Innovation	Characteristics considered in the PLANET integrated modelling capability	Technology description
Blockchain	• Limited. The impact has been modelled so far, rather than the	Blockchain, as a distributed ledger technology, is considered secure by design and is an example of a distributed database system with high fault

	precise operations the technology facilitates.	tolerance. As such it has been employed to facilitate custom clearance transactions where security and reliability of information is key (Okazaki, 2018).
Physical Internet	• Integrated transport planning. • Full visibility in the transport chain.	The Physical Internet is a recent concept proposing a self-arranging transport system inspired by the Internet. It assumes standardized modular transport protocols and real-time adaptability of transport plans and open logistical infrastructure (Montreuil, 2011; Montreuil et al., 2012) .Section 5.1 provides a detailed presentation of the PI concept.
Artificial Intelligence	• Predictive models • Neural networks	AI, or Artificial Intelligence, is a set of algorithms and machine implementations addressing a large class of problems that have been seen – until now – as solvable by human intelligence only. Out of the metaphor, Artificial Intelligence is used here for prediction of a certain quantity of interest given noisy historical data (IRE & 1961, n.d.; Nilsson, 2014). Further explanations can be found in Section 5.3.
Optimization for decision making	• Linear programming model	Under the umbrella term of *optimization*, which collects a set of quantitative methodologies to support decision making, we focus on one of the most studied and successful ones: Linear Programming. This is a method that, after constructing a mathematical model allows to find *optimal solutions* quickly (Dantzig, 2002). Section 5.2 details the model considered.

3.2.1 Cargoloop

In what follows, we provide a longer description of the Cargoloop technology as it appears first described in this deliverable.

The Cargoloop is envisaged as a new cargo transport mode and a comprehensive logistics solution for moving small and medium, standardized, and configurable shipment units.

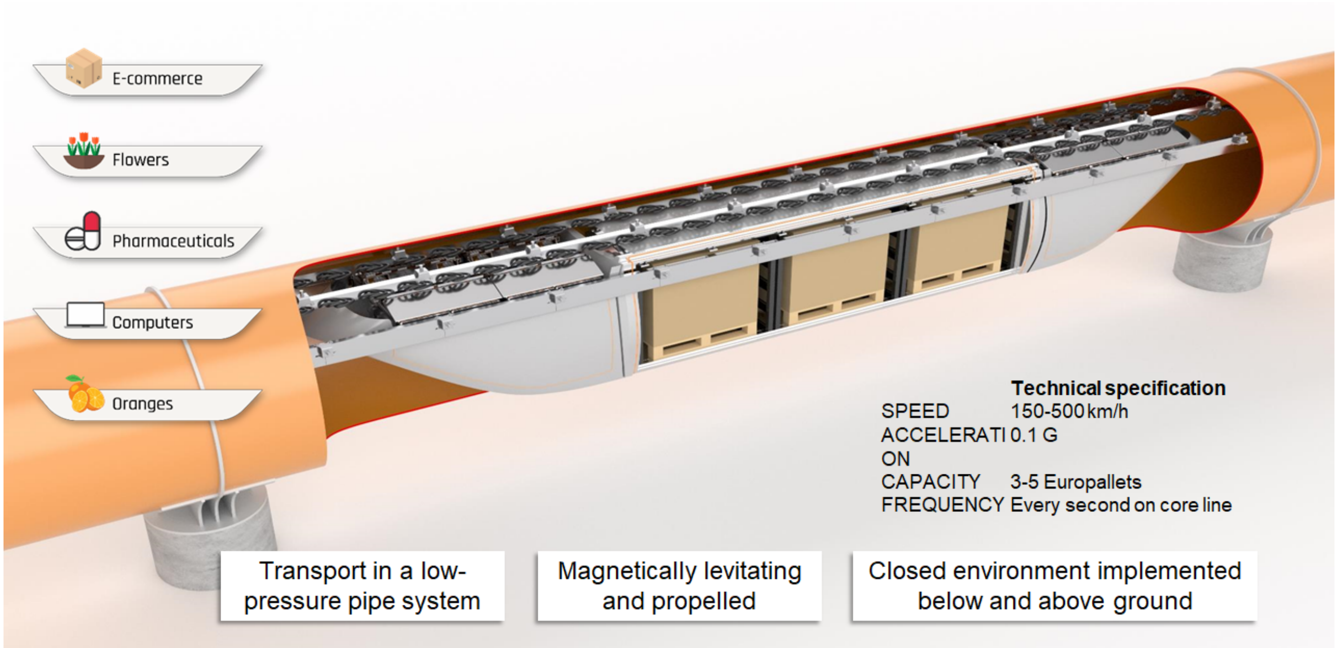


Figure 2 The Cargoloop with commodity target and technical specifications.

The Cargoloop provides:

- Short transit times enabling same-day delivery within any 2,000 km radius circle.
- On-demand capacity.
- Seamless interfaces with other transport networks and last/first mile services.
- Fully traceable and continuous operations in controlled environment.
- Lean infrastructure enabling easy integration into production, distribution and demand centers.
- Lower costs and emission levels than any other comparable transport option.

As the shipments of small and medium cargo units are an emerging challenge for the logistics market, which have not yet been fully addressed by the transport industry, the Cargoloop is envisaged as a complementary solution addressing this niche and releasing operational stress on the existing cargo transport modes.

The Cargoloop unique combination of features is addressed primarily towards a range of time-sensitive, demand-sensitive and high-value products, such as fresh food, horticultural products, pharmaceuticals, e-commerce, fashion, electronics, and high technology equipment. The Cargoloop solution directly addresses the current and future challenges of these industries by:

- Radically improving agility and efficiency of logistics operations for just-in-time and on-demand deliveries of small and medium sized shipments and packages, while minimizing their costs and carbon footprint
- Unlocking new market opportunities and economies of scale for time-sensitive and demand-sensitive products (reducing market access times, increasing geographical coverage, enabling new types of services and products)
- Enabling cost-effective transition to digital and automated logistics operations to increase responsiveness to demand volatility and changing customer requirements (logistics as a service, automated fulfilment, packaging modularization, physical internet)
- Cargoloop also brings benefits for other market segments, by creating opportunities for supply chain optimization and automation, increasing the coverage of existing logistics facilities, and reducing the need for capital investments in new or expanded facilities.

Benefits of the Cargoloop do not end at advantages experienced by its users and realizing the Cargoloop is also expected to bring a range of positive socioeconomic and environmental impacts.

- Relieving congestion, improving safety, and reducing the maintenance needs of existing transport networks by providing a new transport solution for moving existing and future freight volumes,
- Improving efficiency of public infrastructure investments by providing viable cost-effective alternative to expansion of the existing transport networks,
- Improving livability of densely populated areas by introducing a new transport infrastructure which due to its size minimizes the spatial footprint necessary to increase the capacity of the whole transport system,

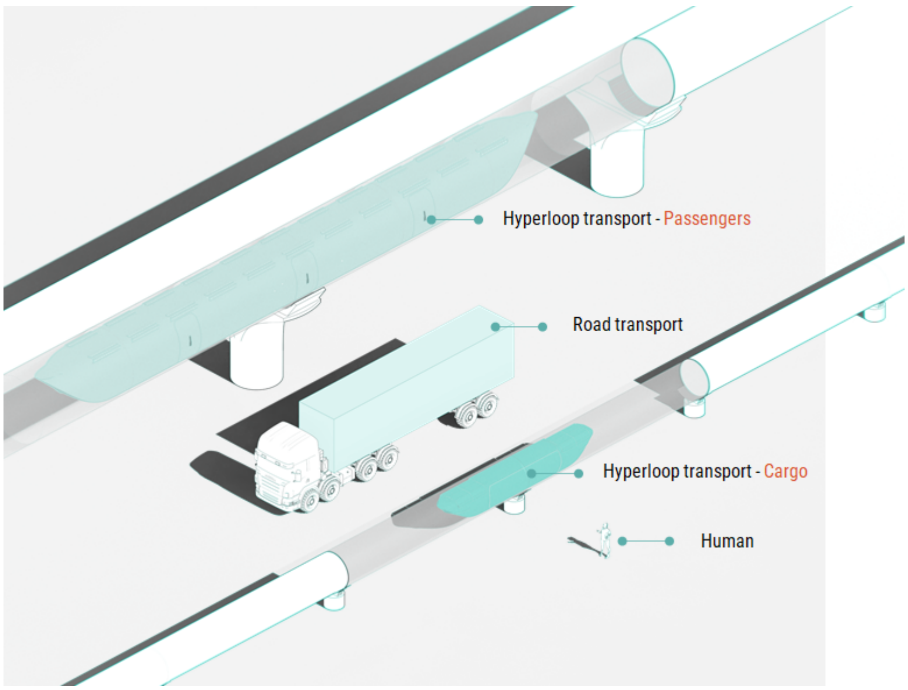


Figure 3 Cargoloop' s infrastructural footprint

- Improving environmental performance of transportation by providing an emission free and energy efficient cargo transport solution,
- Accelerating innovation by enabling faster uptake of automation and digitalization,
- Increasing productivity and resiliency of the economy by enabling faster transit of products between manufacturing facilities and the market.

The Cargoloop network is envisioned as a continental network enabling seamless and traceable transport of cargo. The Core Cargoloop links will connect major logistics and industrial centers and form the Core Cargoloop Network. They will provide high-speed, high-capacity services combined with almost continuous 24/7, highly reliable, traceable, and agile operations, and redefine the long-distance cargo transportation of small and medium sized standardized shipments.

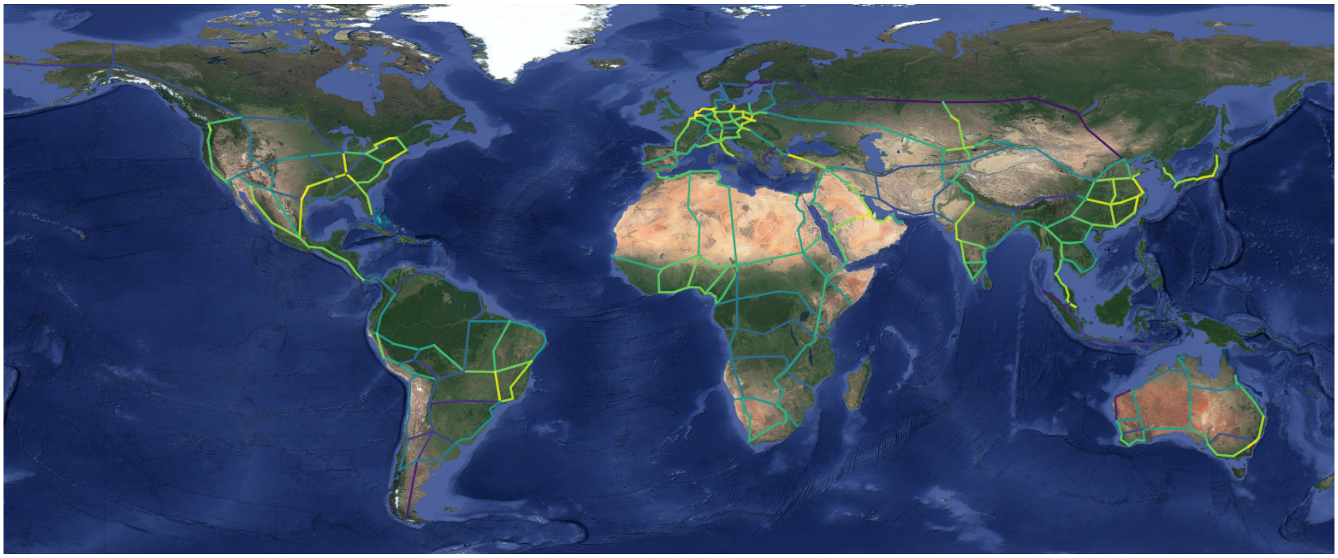


Figure 4 The Cargoloop core link system at the planetary level.

Furthermore, the Core links system is completely standardized, guaranteeing the full potential of the network by making it interoperable. The Core links will be those currently experiencing heavy cargo flows and requiring breakthrough transportation and infrastructure solutions to solve transport, logistics and socioeconomic problems, such as congestion, inefficiency, lack of reliability and pollution.

3.2.2 Impact of technology on T&L processes

The expected impact of each of the technologies considered in the setting of Figure 1 – the focus of the PLANET integrated modelling capability - is summarized in Table 4. The impact as expected from stakeholder is compared with what is being modelled in the PLANET integrated modelling capability.

Table 4 Impact of technology on T&L processes

Technology	Impact on the business processes as from LL description	Modelled impact
Blockchain	• Time reduction in administrative processes • Secure business-to-business data exchange • Facilitate collaboration	• Time reduction on custom declaration processing. This translates onto faster container processing at terminal.
Physical Internet	• Autonomous decision per container at each node. • Open logistics environment to share capacity data to improve the use of assets.	• Open logistics system: all available asset is fully visible and can be used without boundaries of ownership. This allows for global optimization of the system independently of individual stakeholders' incentives.

Artificial Intelligence	• Selection of the best means of transport according to timetable, capacity.	• Forecasted congestion at a port used in combination with the Port call optimization model. Thanks to historical information, this model forecasts demand at a port which is then compared with the capacity. By doing so a measure of congestion can be estimated.
Optimization for decision making	• Port call decision. If there is congestion in a port (wait to port clear) or opt for another port of entry.	• The same as the expected from LL description. Because ocean liners have high daily operating costs, it is important to reduce waiting time at ports in the event of a congested port. This decision is modelled by means of the port call decision model.

3.3 Definition of the Physical Internet

In order to answer the last research question, we provide here a description of the Physical Internet together with a discussion of the latest ALICE PI roadmap (Ballot et al., 2020).

The Physical Internet (PI) is considered to be the visionary paradigm supplying an integrated approach to address logistics integration and collaboration issues, and to pave the road forward to deploying efficient supply chains. The PI is a game-changing vision challenging the status-quo in the logistics industry. Indeed, in a scenario in which all Physical Internet potential efficiencies are achieved, the forecasted 300% increase in transport demand could be achieved with only 50% increase in assets[2]. The Alice platform has published a document with a comprehensive roadmap towards the Physical Internet. The roadmap sketches a path from now to 2040 showing important milestones, required technologies and first implementation opportunities for the PI. Advanced pilot implementations of the Physical Internet concept are expected to be operational and common in industry practice by 2030, contributing to a 30% reduction in congestion, emissions, and energy consumption from the transport sector.

[2] http://www.etp-logistics.eu/wp-content/uploads/2020/11/Roadmap-to-Physical-Intenet-Executive-Version_Final.pdf

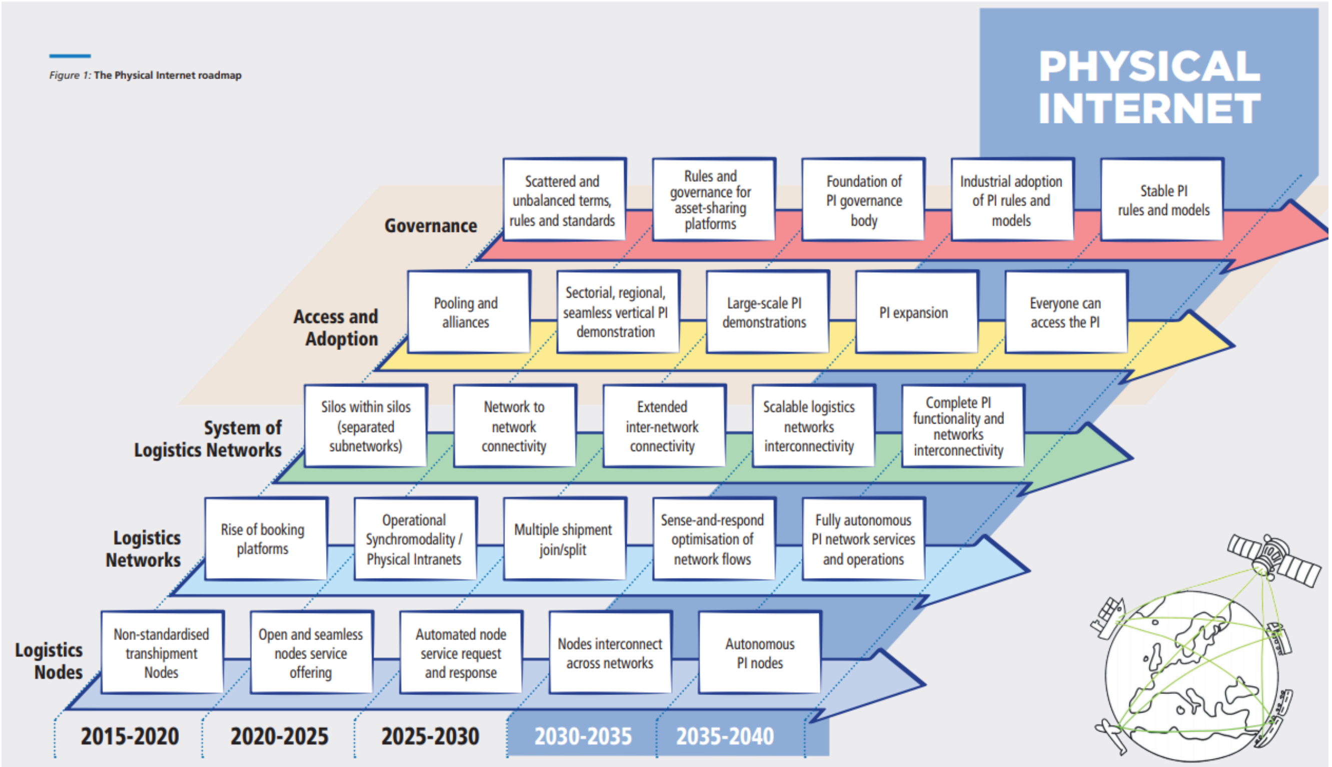


Figure 5 The ALICE roadmap towards the Physical Internet. The circled characteristics are the ones currently modelled by the PLANET integrated modelling capability.

Inspired by the metaphor of Digital Internet, the Physical Internet (PI) aims to integrate logistics networks into an open and interconnected global system through standard containers and routing protocols (Ballot et al., 2014)The Physical Internet is a global logistics system in which products are transported in standardized, modular containers as efficiently and effortlessly between continents as in the case of Digital Internet transferring information between servers.

Physical Internet is an open framework also from the point of view of the use of the resources. The use of open warehouses and transport networks looks for a systemic load consolidation and optimization in which the capacity in the logistics sites and transport networks could be more available for the use of stakeholders in a more optimized way: reducing energy consumption, environmental emissions, and economic cost.

Figure 5 shows the steps towards a full deployment of the Physical Internet as proposed in the ALICE roadmap towards the Physical Internet. The figure shows different stages of maturity on a quinquennial timeline for each of the five levels related to Infrastructure, Access and Adoption and Governance. The PLANET integrated modelling approach considers only circled elements which are related to the development of the PI concept for the near future. The description of the "Operational Synchromodality/ Physical Intranets" reported Figure 6 (sourced from the ALICE roadmap) matches well with the model proposed in this deliverable and shows that we are modelling the near future of the PI.

Generation 2: Operational Synchromodality / Physical Intranets (2020 – 2025)

Concrete Benefits

(Full) load flexibility; booking of door-to-door services (not only single modes); more resilient and flexible use of logistics networks; use of transport modes with less emissions, faster integration of suppliers and customers.

The second generation will entail a continuation and consolidation of the current trend. Logistics Service Providers and Freight forwarders start to be digital platforms for service management and offering. Major logistics service providers and forwarders will develop internal connections between their departments responsible for different modes and logistics services (e.g., warehousing, etc.) and will develop systems and technologies to create full visibility and management capability to access resources (owned or contracted) seamlessly, into the so-called "physical intranets". These will allow managing flows and services in a more seamless way by shifting freight quickly between modes of transport, using common waybills and synchronised schedules, internal to the company or their close partners, use empty transport capacity[12] or relocate inventory positions closer to consumption.

Figure 6 ALICE-ETP, 2020. Roadmap to the Physical Internet

4 Research questions

4.1 Modelling scenarios

When devising a quantitative model, it is important to select a few settings of primal interest among the many alternatives that the modeler is presented with. We refer to these settings by modelling scenarios. A modelling scenario is a specific situation that is represented in abstract terms by the model. For our purpose in this deliverable, the modelling scenarios have been developed for the focal process given in Figure 1 have been sourced from D1.2 and adapted to the context of this deliverable in Table 5. Note that the last two rows have been added as a result of the reflections in Table 3 which listed the technologies considered in this deliverable.

By means of a summary,

1. Each scenario implies a selection of technologies to consider that is motivated by LL1.
2. The scenarios define, as well, the freight transport corridors and hubs to consider.
3. The to-be scenarios position some technologies as contributors to the PI.

Table 5 Modelling scenarios for the PLANET integrated modelling capability

Simulation	Scenarios	Description
PI Maritime Network Asia (China) – Europe (Valencia, Madrid)	**AS IS (current)**	Ocean Liner's Oceanic routes from China to Spain. Pre-defined container movements by truck & rail to customer warehouses.
	TO BE (PI network)	Containers arrive at VLC port, intelligent real-time decision for movements to warehouse.

		Terminals provide optimized dynamic routing of containers through the network (Intelligent algorithms based on AI).
PI Node (Distribution warehouse)	**AS IS (current)**	Container from Valencia Port arrives at Warehouse, container is unloaded, and then deliver pallet/parcels to destination with standard truck/van. Manual operation in warehouse with fixed rules (i.e. static allocation of products to zones in the warehouse).
	TO BE (PI network)	Containers arrives at automated warehouse, where pallet units are defined. Modelling the warehouse human resources, based on inflow/ outflow predictions. Pallets are then sent to Madrid city hubs where parcels are created for final customers in Madrid city. Track & trace delivery using Sustainable vehicles. Automated operations in the warehouse (AGVs...). Smart Decision Making: Adapting the flows of goods to the situation in the warehouse (digital clones).
Artificial Intelligence	**AS IS (current)**	Little to no forecasting for quantities of interest into current decision making that is chiefly guided by expert knowledge and simple expressions.
	TO BE (AI adoption)	Deployment of Artificial Intelligence methods for supervised learning tailored to the specific quantity of interest. Estimation and Forecasting are adopted in multiple aspects of a single decision-making procedure.
Automated decision making	**AS IS (current)**	Decisions are made without support from mathematical models. Decisions are not *optimized*, but status-quo and current practice prevails without support from quantitative models and methods.
	TO BE (Optimization Adoption)	Optimization models are used to support (and drive) decision making in complex problems. Various decisions at different levels are supported for automated decision-making models.

4.2 RQ1: defining the impact of ICT and T&L innovation to EGTN

The EGTN concept challenges the current assumptions of the European TEN-T networks and, in particular, it relates European inland freight matters with global trade flows and geo-political changes. Some technologies impact this interface between inland and *out-land* decisions and flows. For instance, Blockchain is expected to lead to faster border crossings allowing for more dynamic decision making from the stakeholders facing the decision of which point of entry to consider. As a result, inland flows are affected in their volumes, pressure on infrastructure and speed by Blockchain.

The situation depicted in the previous example is generalized to the other technologies considered in Section 3.2. As our goal is to quantitatively define the impact of ICT and T&L innovation on the EGTN concept, we contribute to the development of the technological layer of the EGTN. Such layer consists of the digital infrastructure of EGTN which aims to realize the innovation attribute of EGTN through leveraging emerging technologies and supporting its operation under the PI paradigm.

4.3 RQ2: assessing the impact of emerging concepts & tech on freight transport corridors and hubs

The impact of technology can be disruptive, leading to sudden and extraordinary changes, on business and operations or not, for instance when adoption is slow or limited and the technology is not mature or understood fully yet. As technology is seen as a driving force for the future of Transport and Logistic in Europe, it is important to assess its impact on the physical transport infrastructure. This motivates the second research question of this deliverable which aims at filling the knowledge gap between tool-technology utilization and macroscopic effect of the tool itself. The technologies considered in PLANET will be modelled and considered in the freight transport corridor defined in Section 3.

4.4 RQ3: positioning emerging tech as contributor to PI

From a policy-maker perspective, it is of interest to understand which emerging technologies should be supported further in their development and adoption. Because of the long-term vision of a Physical Internet, the supporting choice is (partially) driven by an understanding of which technologies (or combinations of) best contributes to the development of the Physical Internet.

In spite of the task's usual quantitative approach, this research question is going to be addressed in a qualitative fashion. Devising a quantitative model is deemed as an unviable option because of the complex task of defining a *degree of contribution* of a technology to the Physical Internet concept. Still, we propose a simple method to address this question by evaluating the magnitude of a technology impact as a sorting criterion to define how a technology contributes to the establishing of the PI concept. This is a novel approach and makes use of the PLANET integrated modelling capability that is the main contribution of the deliverable.

5 Literature review

This is a short overview of the main literature related to the modelling components of the Planet integrated modelling approach. Given the nature of this report, the literature here reviewed is meant to provide a minimal background to the different components that constitute the pipeline developed later in Section 6, or that are planned to be included in future work.

5.1 Physical internet

Supply chain simulation is a scientific method by which users employ a model to observe the operation of an entire supply chain and conduct ‘’what-if’’ analyses for multiple scenarios. There are several kinds of supply chain simulation methods, including agent-based simulation. This kind of simulation uses an agent or agent group to represent supply chain entities and uses agent interactions to represent communication and coordination between entities. According to their objectives, resources, and knowledge, agents make decisions by themselves and interact with other agents to achieve the overall objective of the multi-agent system. In this natural way, the supply chain is simulated[3].

Agent-based modeling uses a bottom-up modeling approach and is widely considered as a valuable approach for decision support in supply chains (Julka, Karimi, et al., 2002; Julka, Srinivasan, et al., 2002; Mele et al., 2007; Petrovic et al., 1998; Thierry et al., n.d.; van Dam et al., 2009). Each entity in the system is modeled as an "agent" that has its own states and interests and makes decisions based on a series of rules (Bonabeau, 2002) . Agents are also able to interact with each other, perceive their environment, and respond to changes. Agent based models are flexible and scalable. The complexities of models can be manipulated by modifying the number of agents and the rules for their actions and/or reactions, learning, and interaction[4].

In this project, a model has been developed from the basic elements (model agents) of the Physical Internet:

- Nodes: the nodes in the PI network represent the places, (i.e.: warehouses) where goods are stored, transferred or manipulated between movements in the network. In the model, the main nodes are seaports and dry ports.
- Transporters: the transporters convey or handle containers within and between the nodes of the Physical Internet. In this model, the main inland transporters are trucks and trains, which ship containers between inland nodes. On the other hand, vessels agents ship containers from deep sea to seaports.
- Orders: an order is the element of information that causes products to move within PI. The order is associated with a set of containers, which must be transported from a point of origin to one (or several) destinations.
- Containers: the container is fundamental for the Physical Internet; it is the metaphor of the Digital Internet. By analogy with data packets, the goods are encapsulated in intelligent containers of easy-to-interconnect modular dimensions, called PI Containers, designed to flow efficiently in hyper connected networks of logistics services.

5.2 Port selection model

Containerized trade accounts for more than 40% of the total maritime trade in terms of tonnes loaded, as in 2019 approximately 152 m TEUs were loaded(UNCTAD, 2020). The large volume and high value of cargo transported by containerships has driven significant research towards methods for improving the efficiency of fleet and port operators. Containerized trade research can be broken down into three main themes as proposed by , focusing on:

- container routing that is related to the optimal flow movement of laden and empty containers,
- fleet management that looks into operational decisions of ship assignment and scheduling, and,
- network design that looks into choosing optimal porst and combining them to create the operational infrastructure for shipping.

Increasing vertical integration between shipping companies, terminal operators and inland logistics has intensified since 2010 as companies look to expand their services, reduce their exposure to volatile rates and integrate their operations leading to end-to-end logistics. UNCTAD(2020) and Tran & Haasis (2013) report that 21 port operators control 80% of global terminal operations with COSCO accounting for roughly 14% of the

[3] Long, Q., & Zhang, W. (2014). An integrated framework for agent-based inventory–production–transportation modeling and distributed simulation of supply chains. Information Sciences, 277, 567-581.

[4] Sha, M., & Srinivasan, R. (2016). Fleet sizing in chemical supply chains using agent-based simulation. Computers & Chemical Engineering, 84, 180-198.

global port throughput. Therefore, a new research focus for operational optimization across multiple modes and terminal operations is required.

Container routing problems typically assume a set of pre-defined routes, and a decision is required to be made for the optimal allocation of a slot to maximise profit. Zeng et al. introduce the principle of slot assignment equilibrium which reflects a reasonable distribution of containers among visited port and full utilisation of containers. To account for transhipment features, Bell et al. propose a model that minimises the total sailing time and container dwell time at ports whereas ensures container balance to the repositioning of empty ones.

A typical fleet management problem, assigns vessels to predetermined shipping routes, aiming to optimise the offered capacity to anticipated demand. Fleet management problems often incorporate purchase or leasing of vessels to address demand requirements, while considering the maritime network constraints such as canal and port draught limits. Wang & Meng (2012) expand the typical fleet management problem by also considering traffic uncertainty and volatility in customer demand.

Maritime network design problems look into optimally selecting ports and combining them economically to create an infrastructure for shipping operation. Focusing on single routes, Pearson (1988) evaluates the effect on total cost of switching from Southampton, UK to either Tilbury or Felixstowe, in essence seeking an optimal balance between the longer sea distance, but superior handling performance of the two latter ports. Performance indicators used include that of port time, travel time and total maritime and inland cost. Adaptations of the network design problem exist for considering empty containers repositioning, comprehensive cost functions as well as multiple routes, linking network utility functions with route design (Bell et al., 2019).

5.3 Predictive modelling

Forecasting for container throughput has been ongoing since the 1980s and substantial developments have been made in this field since then. However, most common forecasting methods such as Autoregressive Integrated Moving Average (ARIMA), Seasonal ARIMA, regression analysis and exponential smoothing all work under the assumption of a linear trend (Yang et al, 2020). The time series for container flow consists of nonlinear trends which makes it difficult to forecast effectively and so novel techniques are being explored to predict trends more accurately.

Genetic programming has been shown to outperform decomposition methods and SARIMA methods to forecast Taiwan's container throughput(Chen & Chen, 2010). A vector error correction method based on a vector autoregression to predict the container transportation volume was introduced by(Syafi'i & Takebayashi, 2005). An improved gray Verhulst model proposed by (Guo et al., 2005) indicated that it achieved high prediction accuracy and also retained the strengths and characteristics of the gray system model. (Gosasang, Veerachai CHANDRAPRAKAIKUL & KIATTISIN, 2011) showed that multilayer perceptron (MLP) forecasting outperformed linear regression (LR) forecasting models with multivariate data to forecast cargo throughput; the models were compared in terms of their root mean squared errors (RMSEs) and mean absolute errors (MAEs).

The data provided by COSCO Spain for daily container volumes at ports is a nonlinear time series which makes it hard for regression and nonlinear fitting models to explore the time series relationship. However, Recurrent Neural Network (RNN) are a class of deep learning algorithms that can generate memory states of past values when learning temporal sequences with inherent dependencies. Long short-term memory neural network (LSTM) take RNN's a step further by overcoming the vanishing gradients problem usually caused by RNN.

LSTM models are widely used in predictive modelling especially for sequential time series data. For prediction of the volume of containers arriving at a given port, a multivariate stacked LSTM model was implemented using Python. This model is trained on historical data provided by COSCO Spain for the number of containers arriving at Valencia port from their vessels. It outputs the predicted flow of containers for the next day in order to better facilitate transport planning.

5.4 Synchromodality

Container transport in the hinterland of a port is executed using different transport means and is organized into various unified solutions. Indeed, a shipment could be arranged via a slow and cheap barge connection, or on a train that is both faster and more expensive than a barge, or on a truck that is fast and extremely flexible, but at the same time the most expensive mode. It is also possible to execute shipments that involve a sequence of different modes to exploit their characteristics. The combined use of heterogeneous modes leads to the definition of integrated transport solutions. We focus on intermodal and synchromodal transport. Those types of arrangements distinguish themselves from the so-called unimodal transport of containers using a single mode, often truck.

Intermodal transport can be broadly defined as "the transportation of [people or] freight from their origin to their destination by a sequence of at least two transportation modes" (Crainic & Bektas, 2007). One of the main characteristics of intermodal transport is the integration of transport modes to compose a whole journey. "Integration" often refers to "the active coordination and alignment of the modes of transport" (Reis, 2015), with the former describing the harmonious functioning necessary to move containers effectively from one mode to the other, and the latter indicating a unified approach to the formulation of the transport solution.

Synchromodal transport has emerged from an enhanced integration of transport modes and adds "adaptive mode choice" to the concept of intermodal transport (Behdani et al., 2016; Tavasszy, L., Van der Lugt, L., Janssen, G., & Hagdom - Van der Meijden, 2010). While integration between complementary and sequential services lays the groundwork for improved performance of the overall transport system, adaptive mode choice requires that transport modes are chosen along the deployment of the transport service. As a result, organization and coordination of transport blend together to take advantage of up-to-date information as decisions are taken closer to execution (Reis, 2015). Despite those two characteristics of synchromodal transport will be exploited in this work, we do not adhere to any of the already provided definitions of concept. Indeed, we will consider transport solutions that respect those two requirements only as they are common of the definitions available in the literature. We refer to (Singh et al., 2016) for a review and discussion of the different definitions of synchromodality available.

While intermodal transport has been studied for more than twenty years, synchromodal transport has received much attention only in recent years, both in the academic community and in industry. Between the academic studies, (Behdani et al., 2016) shows that the benefits of a synchromodal approach to schedule design can lead to costs savings of more than 20%, while (van Riessen et al., 2015)states the challenges and opportunities of taking the perspective of a central planner willing to deploy synchromodal transport solutions. Regarding opportunities, synchromodal transport should improve upon the current practice both in terms of costs savings and in terms of service level (both reliability and flexibility). Prospective challenges mainly relate to achieving the required level of planning flexibility and formulating suitable transport plans. Considering the industrial initiatives, the deep-sea terminal operating company ECT offers synchromodal transport solutions in the hinterland of the port of Rotterdam, and Platform Synchromodaliteit aims at the development and diffusion of synchromodal transport between the participating logistics partners (Maersk, ECT, Wayz, etc.).

Synchromodal transport has received such sudden attention because it should improve service level and network-wise performances (as costs, reliability and CO2 emissions) through an educated understanding of cooperation (information sharing, in particular) between multiple stakeholders. Two elements can be highlighted, namely the improved service level and focus on cooperation. Both aspects appeal to practitioners who are confronted daily with the unexpressed potential of cooperation.

6 Model definition

In this section, we define the prototype of the PLANET integrated modelling capability. The development of a prototype was decided with the aim of quickly provide a combination of quantitative models that could be showcased to other task leaders within WP1. This allowed for a joint development of the prototype which was enriched with several perspectives. The prototype took the shape of a pipeline, i.e., a combination of models where data are exchanged in a Input/Output sequence. In this section, we will often refer to the pipeline as this was found to be a descriptive and accepted concept.

Moreover, we elaborate on the modelling requirements for an application of synchromodality within the EGTN.

In what follows, we first describe the approach followed in defining the prototype as it provides the guide to a proven path to enrich the model further. We then define the modelling use case and show the details of the various models used. Finally, we describe the synchromodality enhancement for EGTN.

6.1 Workflow towards pipeline definition

The pipeline we developed was the result of several workshops between all partners involved in this task. The approach follows the following steps, some of which are reported in Figure 7:

1. Selection of a modelling use case based on LL from D1.2,
2. Selection of the relevant models for the modelling use case and context considered,
3. The modelling use case has been formalized aiming at a secure and well-motivated interface between the models
4. Relevant modelling scenarios have been selected, tuned to the modelling possibilities while tuning the modelling towards the modelling scenarios.
5. The first pipeline concept has been elaborated (cf. Figure 8).
6. The pipeline has been tested on artificial data.

The Figure 7 shows also the planned workflow together with the relation to previous deliverables and WPs.

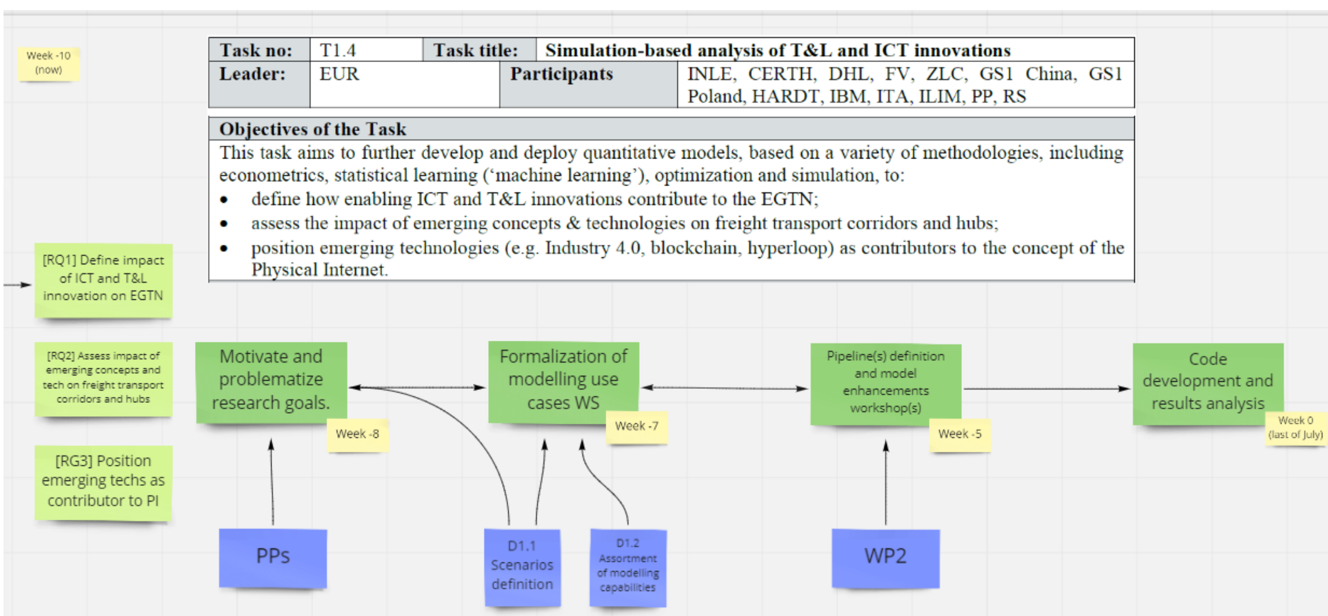


Figure 7 Planned workflow to define the pipeline.

Figure 8 provides a high-level description of the pipeline. It shows how, starting from a simple instance, two separate scenarios have been considered for modelling. On the two scenarios a combination of models (still to be defined at this stage) is executed outputting values related to the KPIs defined in Section 3.1.3. This output is then processed and presented to a macroscopic model (in our case the terminal model). The pre-processing pipe step was required to transform the output of the model execution into valid, and meaningful, input for the macroscopic model.

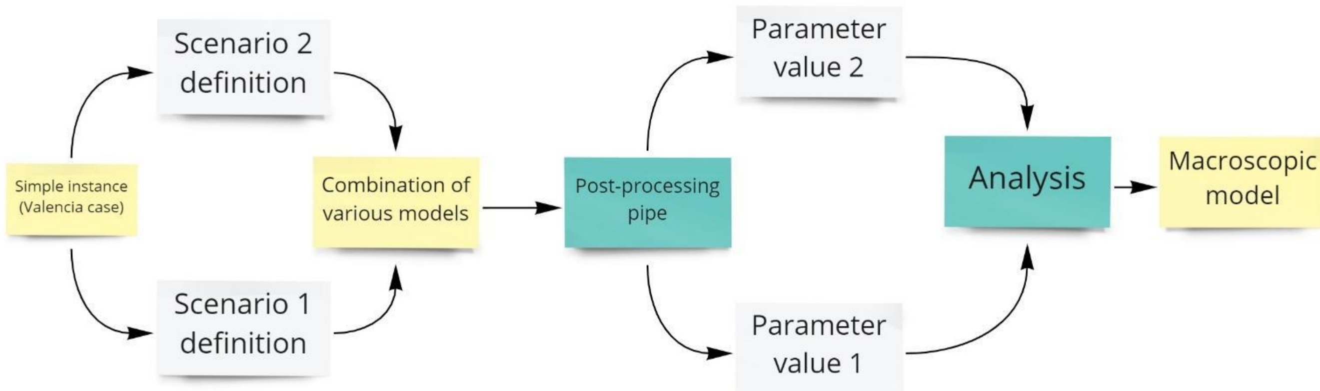


Figure 8 Pipeline high-level definition

6.2 Modelling use cases

A **modelling use case** is a specific situation in which a model could potentially be used. For our purposes, it provides main user (stakeholder interested in the analysis), context of application (logistic setting of interest), research question (declination of the D1.4 RQs to the context) and evaluation scenarios of interest.

The modelling use case is related to a specific pipeline. By **pipeline**, we mean a sequence of models run in sequence in such a way that the output of one will be the input of another. For our use here, a pipeline should substantiate a modelling use case. In other words, for each modelling use case, we devise a pipeline. A pipeline is written in a certain programming language.

In Table 6, we formalize a template for a generic modelling use case which is composed of several features that are explained in the Table itself. We provide an example answer for each of these features which describe the pipeline developed in this deliverable. The answers provided are a summary of the content of Section 3, and subsections there, which explained the context in more detail.

Table 6 Modelling Use Case template and information for PLANET integrated modeling capability

Feature	Explanation	Answer (for the developed pipeline)
Modelling use case title:	A title for the modelling use case	Prototypical PLANET integrated modelling capability
Narrative presentation:	Explain what is are the problems being modelled and how this is being done.	Containerized cargo from China to inland Spain can enter the Mediterranean coasts of Spain via several ports. Congestion at the ports impact the decision of the ocean liner shipping company which results in different hinterland connections being used. In this setting, several technologies impact decision-making. Having as a base a multi-agent simulation, AI and Optimization models are integrated to

		evaluate the impact of emerging technologies on T&L processes. Final, a macroscopic model analyses long-term changes in flows deriving from the operational results.
PLANET partners involved:	List of partners name involved in the modelling use case	EUR, IBM, ITA, VLTN (modelling) All other parties involved in the task (, review and
Model stakeholders:	List the main stakeholders considered in the model	Ocean liner, port authorities, port terminal operators, trucking companies, rail operator, hub operators.
Involved models (reference to D1.2):	List the models involved (as defined in D1.2 or additional ones)	PI simulation, Forecasting model, Port call selection model
Focal technologies and innovations:	List the technologies considered in the modelling use case	Physical Internet, Artificial Intelligence, Optimization, Blockchain
Modelling scenarios:	Describe the scenarios at a high-level	As is situation vs PI deployment

6.3 PLANET integrated modelling capability – Pipeline

The modelling use case defined in the Section 6.2, and summarized in Table 6, has been translated in the pipeline depicted in Figure 9. Each component of the pipeline is described in a separate section (cf. Sections 6.3.1,6.3.2, 6.3.3 and 6.3.4), in what follows we describe the pipeline by explaining how the models interact and show the relation with the EGTN concept.

Figure 9 depicts a graph with yellow boxes representing data and azure ones representing models that are connected by several arrows. An arrow from a data box to a model box means that data is used an input by the model, while an arrow from a model box to a data box means that output from the model is stored in a dataset. Each model box is also accompanied by a logo to represent the main capability of that model and can be neglected (it is a visual feature). Snapshots of data and red arrows show precisely where each model interacts and proves the positive result of the dry-run of the prototype. Maps show the output of the Terminal model. As a final remark, the red lock icon next to the “COSCO data” box shows that some real (and confidential) data have been used in the pipeline.

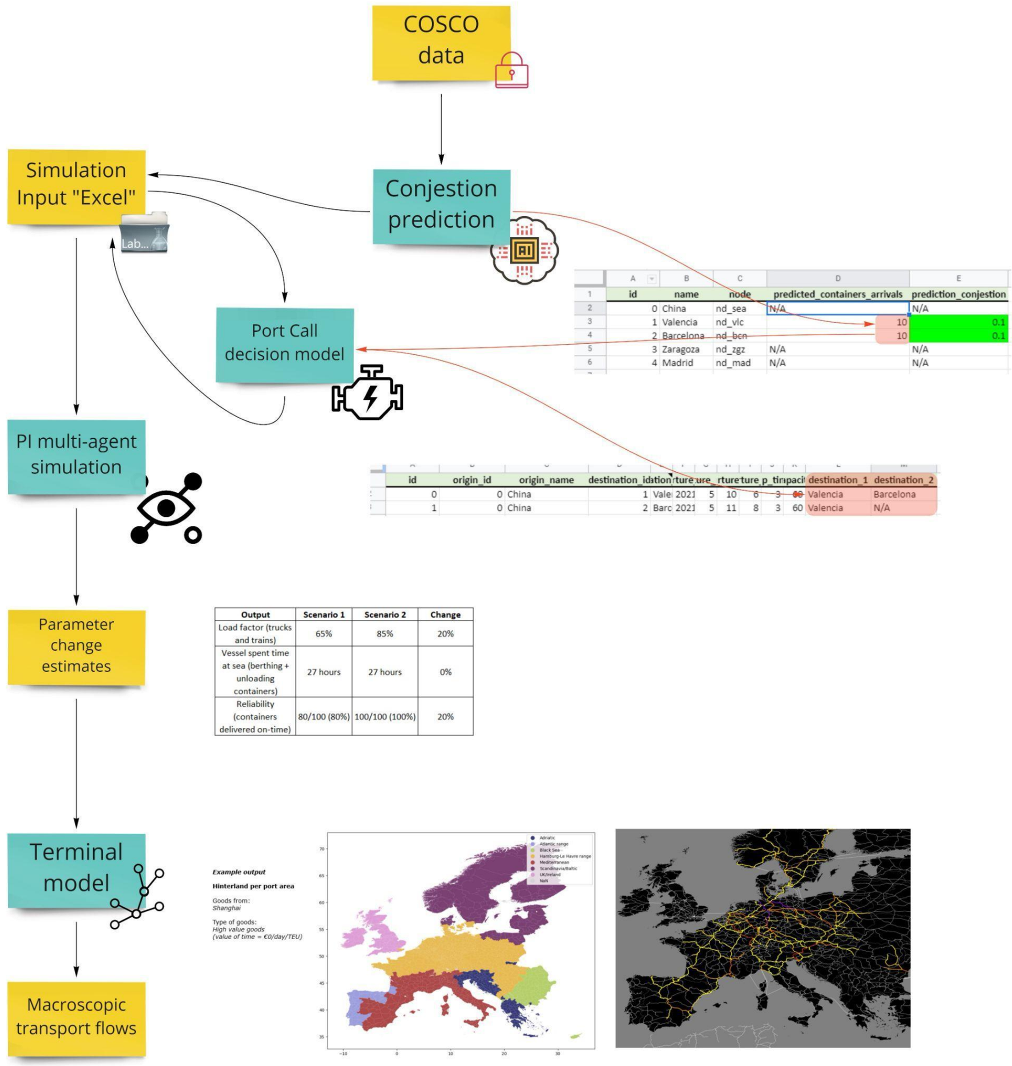


Figure 9 The prototype pipeline - The PLANET integrated modeling capability

After this presentation of the elements of Figure 9, we can describe the flow of information. Starting from COSCO data, the Congestion prediction model (cf. Section 6.3.3) forecasts by means of AI the number of containers predicted at each port. After a – for now – simple calculation of the congestion at the port based on an estimated port capacity level, the congestion level is provided to the Simulation Input "Excel" spreadsheet. This document contains all specifications of transport means, technologies and demand information required to execute the multi-agent simulation. Before starting the simulation, it is the turn of the Port Call decision model (cf. Section 6.3.2) that, using the predicted congestion, computes the optimal port call for the ocean liners. The decision is then stored back in the Simulation Input "Excel" and serves as input for the PI multi-agent simulation. (cf. Section 6.3.1) This model generates an instance of the network described in Section 3.1.1 (cf. Figure 1) and executes a multi-agent simulation where the a prespecified scenario is executed by simulating all transport and transshipment operations. As a result of this simulation, the KPIs defined in Section 3.1.3 (cf. Table 2) are computed. By comparing two scenarios run, the parameter changes relevant for the Terminal model (cf. Section 6.3.4) are computed. Finally, an execution of the Terminal model allows for an estimation of the macroscopic effect of technology.

After the presentation of the prototype PLANET integrated modelling capability, the pipeline just presented, we show how this is related to EGTN concept and, more precisely, to the Attributes selected in Section 3.1 (i.e., Innovation, Impact and Integrated). First, the containerized cargo flow that is considered crosses the EU boarder with a decision on which points of entry to use. This is a fundamental feature to qualify this modelling effort for the EGTN concept within PLANET. Indeed, this allows for an understanding of the impact of planetary/global decisions at the local level. Second, several emerging technologies are considered in a concerted deployment and their effect at the macroscopic level is computed. This relates to the Innovation and Impact Attributes of the EGTN concept as it allows to evaluate the impact of innovation at the EGTN level. Moreover, the integration of different processes and the integration of different technologies with these processes clearly relates to the Integration Attribute of the EGTN. This prototype PLANET integrated modelling capability – which serves as a thought experiment (!) – shows that the several Attributes of the EGTN concept interact with each other, and that such interaction should be considered as well.

The following sections provide a detailed description of each of the models considered in the Pipeline.

6.3.1 PI multi-agent simulation

Figure 10 shows an overview of the main view of the PI multi-agent simulation. The model is composed of 5 main nodes: deep sea, Valencia, Barcelona, Zaragoza and Madrid. The blue nodes correspond to seaports and the yellow nodes to dry ports.

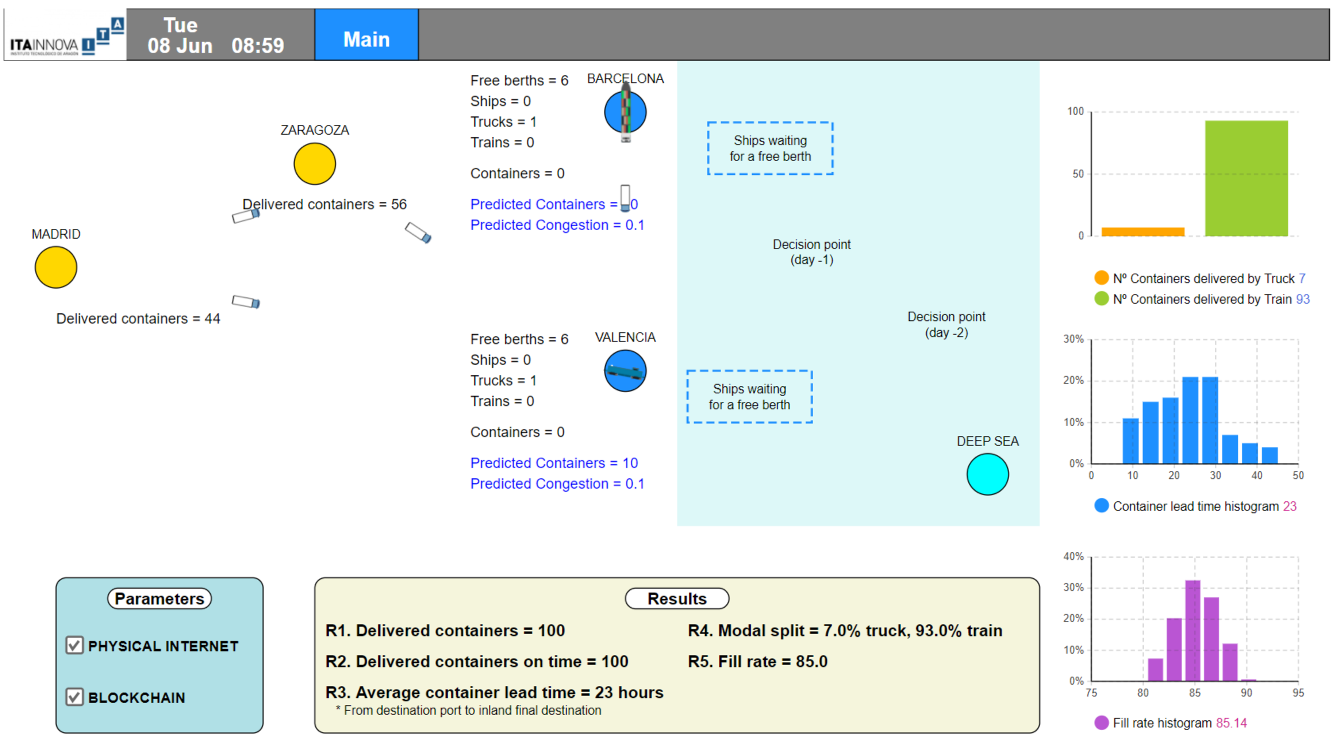


Figure 10 Multi-Agent Simulation overview

At a given time, vessels carrying containers depart from the deep sea. They have two decision points (day -2, day -1) as they approach the seaports, and can choose which one (Valencia and/or Barcelona) to go. Once the containers arrive at the port, they are unloaded.

On the other hand, there is a fleet of transports (trucks and trains) that run circular routes with a given schedule. When they arrive at one of the seaports, they load containers and transport them to their final destination (dry port).

Each agent in the model (nodes, vessels, transports, containers) is modelled by statecharts that capture the actual process sequence of that agent. Communication between agents is done by messages, which allows triggering transitions that make an agent take a decision or move from one state to another.

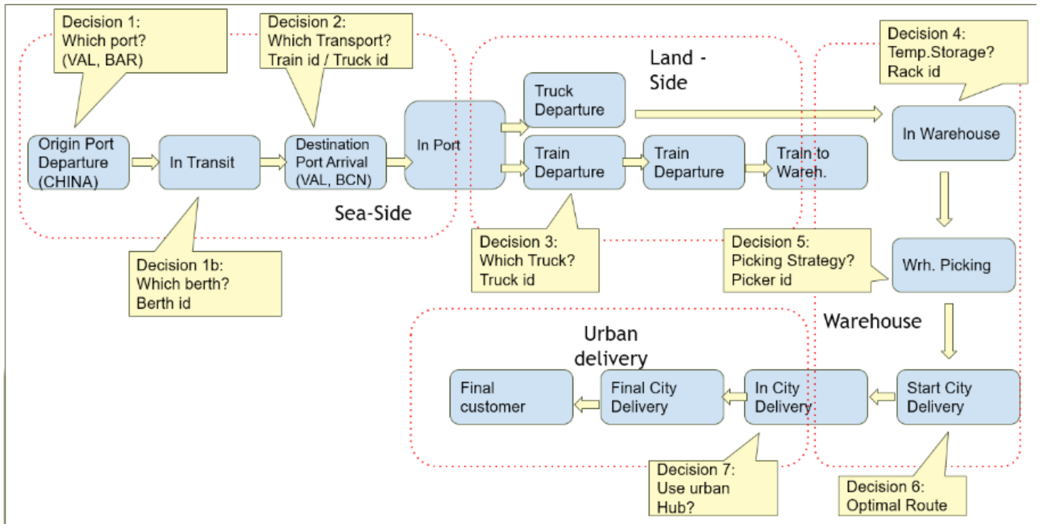


Figure 11 Detailed process flow modelled by the multi-agent simulation

During the simulation, the model allows the collection of statistics (numerical indicators, graphs, histograms etc.) such as the number of containers delivered, how many containers have been delivered on time, the containers lead time, the fill rate of the transports or the modal split, among others. In addition, the model allows different scenarios to be parameterized, evaluating for example the impact of applying or not applying technologies such as blockchain in certain processes or considering the adoption of PI.

The model and process just described is related to part of the Sea and Lan-side operations depicted in Figure 11. This relation between the LL's operations, previously described in Section 3.1.1, and the Multi-Agent simulation shows the practical relevancy of the PLANET integrated modelling capability.

6.3.2 Port call decision model

For a given liner shipping route, which is a sequence of port calls for a container ship, the aim of the proposed program is to decide whether to call at all ports within a subset of the route ports or not. As hinterland transport is capable of forwarding some to the containers to their hinterland destinations, the program minimizes the cost of the maritime, and hinterland transport as well as port handling and accounting for delays. In the Living Lab context, the question concerns COSCO's AEM1 route (Asia Mediterranean Route 1) that is designed to call both Valencia and Barcelona ports. Figure 12 The real case motivating the port call decision model depicts this situation: a decision between two alternatives must be taken considering both port and hinterland congestion on the route to the customer. The decision variables capture if a specific cargo shipment (container) is discharged in Valencia or Barcelona. For example, x_{pc} where p resembles the port of discharge and c the container identification, which is further tied to a specific destination. Therefore, for any container c, $x_{bc}+x_{vc}=1$. Then a binary variable indicating whether a port will be called can be defined as y_p, that will be equal to 1 if at least one container is discharged there. The point of having a y parameter is to allow for port handling and vessel queueing costs of calling an additional port to be represented.

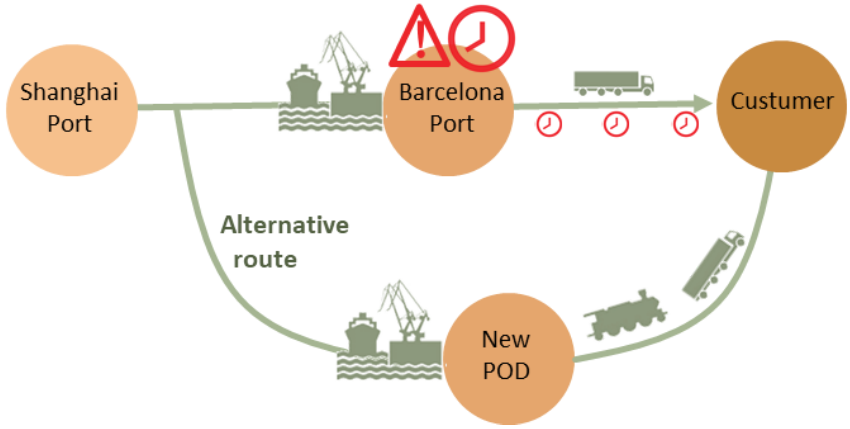


Figure 12 The real case motivating the port call decision model

In Figure 13, a simple implementation of the port call decision model is illustrated. The left column (light green) names the final destination of each container. The y variable (first line below the colored section) reflects the main decision variable of the model, which captures which of the two ports the vessel should call. When equal to 1 the port is called, and when equal to zero the port is not called. The two colored columns on the top right capture the x decision variable, which indicates where each container is discharged (1 resembles the discharge location). The figure below captures how the solution of the program changes for different port call costs. On the left, the port call cost is low for both Barcelona and Valencia, and the algorithm decides to call both, also indicating where to discharge each container. In the instance in the middle, the call cost increases substantially, representing a large queue for both ports. In this instance the algorithm chooses to call only at the port of Valencia, as the hinterland connections are closer. The third instance (right) illustrated that the decision changes if the level of congestion at the two ports is not even, and a longer queue is observed at Valencia. The program then, decides to only visit the port of Barcelona.

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

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

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

Figure 13 Port Call decision model - Comparison of different parameter settings

6.3.3 Congestion prediction

The congestion prediction model forecasts 24 hours in advance the number of containers arriving the next day at Valencia Port. Currently this model is trained on historical data based on estimated arrival times and so can be improved further if historical data on actual arrival times is available. This model is a stacked multivariate LSTM model which means it is a form of Recurrent Neural Network consisting of several deep layers stacked on top of each other and takes as input a range of features extracted from the historical data. The graph below shows results of this model when tested on 100 days, the root mean squared error is 2.11 which means prediction is off from the actual value by approximately 2 containers on average. A comparison between the actual and the predicted arrivals against the day of arrival is shown in Figure 14.

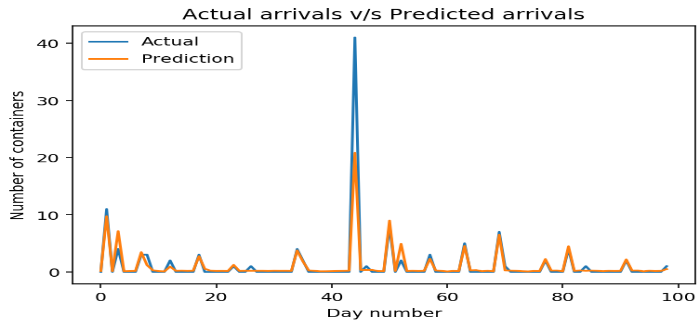


Figure 14 Congestion prediction model results

6.3.4 Terminal model

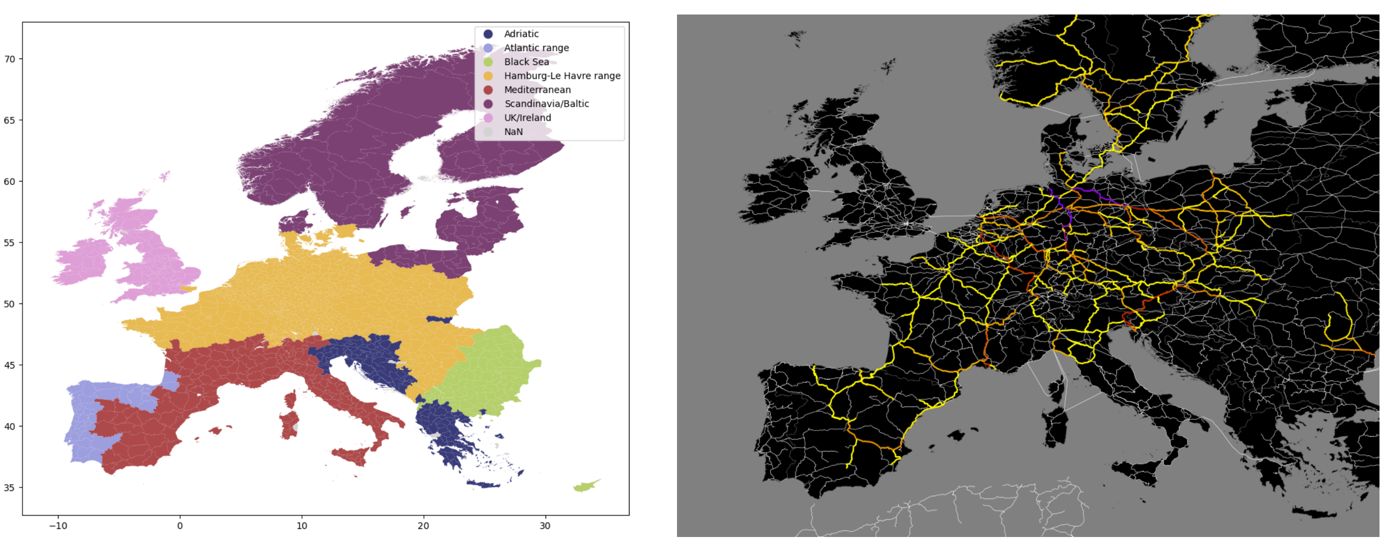
We report here the description of the Terminal model from D1.2, to make this deliverable complete. Further information on the model can be found there.

"The Terminal Model is a flexible transport model offering extensive policy and scenario evaluation options. In its core, the terminal modal calculates transport costs and time between regions for various modes of transport and different commodities. It uses a complex network (road and intermodal, including transhipment points) including associated transport cost to establish transport costs from a particular location within the study area (municipality level) to any other area within Europe (NUTS-3 level) or outside Europe.

The terminal model requires the following inputs:

- Detailed regional structure based on NUTS2006, including the neighboring countries Norway, Switzerland, Serbia, Bosnia, Albania, Montenegro, and North Macedonia. All other countries are included on the country level. For PLANET, China has been included on the province level.
- Trade data from various sources depending on the application of the model, including Statistics Netherlands for trade related to the Netherlands; ETISplus for inter-EU trade; Eurostat COMEXT for EU-extra EU trade and UNCTAD for extra-EU – extra EU trade (non-EU trade).
- Rail network & internal and external transport costs
- Road network & internal and external transport costs
- Sea network & internal and external transport costs"

Figure 15 shows an example output from the Terminal model. On the left, the hinterland region per port for a specific commodity type. On the right, the utilization of rail infrastructure for a certain import flow.



6.4 Simulation scenarios

The modelling scenarios defined in Section 4.1 have already been considered in the prototype PLANET integrated modelling capability. The scenarios defined there were needed to define a setting for the definition of the model instance required by the multi-agent simulation model and all other models. The simulation scenarios we revise here are planned as a future feature of the PLANET integrated modelling capability and relates to the non-interactive aspects of our model. For instance, they relate to geo-economical setting, adoption levels which can be represented but do not interact with the model. As such they can be considered as the narrative behind a certain setting. As these simulation scenarios are still to be elaborated further, we provide shortly here the starting point of this discussion which is a methodology for defining relevant scenarios and sourced from Position Paper 1. Figure 16 shows the approach devised in PP1 to plan scenarios and an example scenario logic. While such scenarios are quantitative, to interact with the PLANET integrated simulation capability it is required to perform an additional step where these insights are converted into representative parameter values. This is a challenging task that that will lead to model the effect that different scenarios logics have on corridor performance. Other scenarios will be developed by considering different technologies.

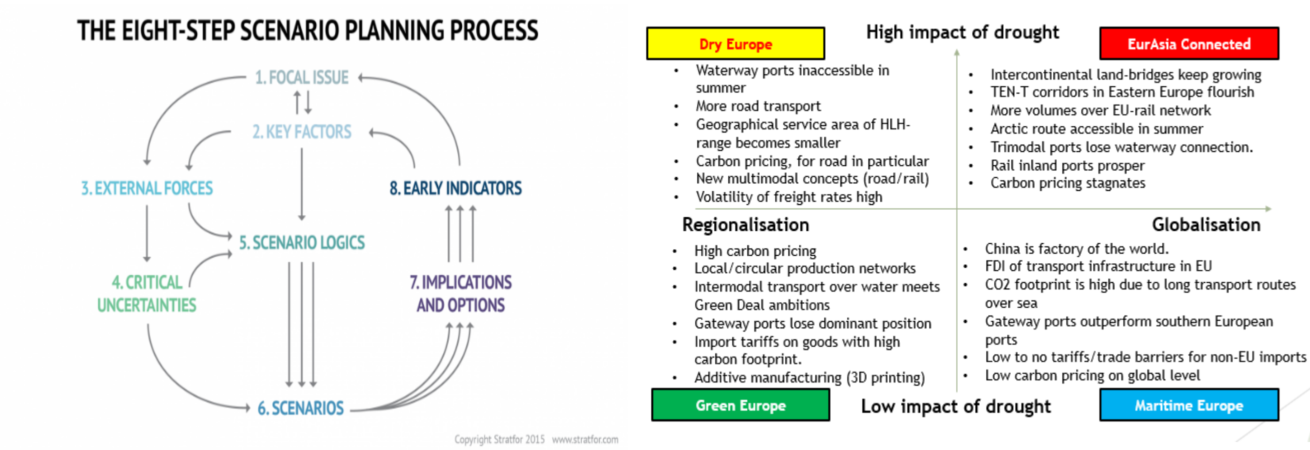


Figure 16 PositionPaper 1. Scenario planning process and example scenario

6.5 EGTN Synchromodality Model Requirements

As part of this deliverable, we present the result of several interactions with LL stakeholders aimed at defining a possible deployment of synchromodality. Outcome of such discussions, we summarize in Table 7 the business requirements to being able to test the synchromodal model.

Table 7 Synchromodal model requirements for EGTN

Synchromodal model requirement	Requirement for EGTN stakeholders and key actors	Explanation
Information on departure times and transit time distribution for all scheduled asset	**Exact schedule information for near-future departing transport services is shared**	The synchromodal model provides decision support assuming exact and reliable information on departure times. This information is

	The transit time of each transport mean is tracked and historical data on transport lead time is shared	often not available by practitioners.
Information on unit transport cost and available capacity for all scheduled transport scheduled	**Cost and capacity information for the near future is exact and shared.**	Cost and capacity are sensible information. Key to the meaningful devise of any transport plan. This information should be reliably defined and made available in real-time.
Target reliability level	**Visibility of end-customer agreed reliability**	Synchromodal transport requires a certain reliability target being set jointly by customer and network operator. While the customer might aim for the highest possible value, it is the networks operator that can define a meaningful value.
Real-time position of all containers in the network	**Real-time visibility of all containers** **Sharing of real-time information on containers position**	In order to being able to adapt transport plans, visibility on the asset and capacity to change and adjust plans is required. In many real cases this is simply not possible, thus leading to little room for the deployment of synchromodality.
Deployment of the Synchromodal (adaptive) plan	**Real-time adjustment of transport decisions for each container at each node of the network.**	Being able to adjust a transport plan is a pre-requisite of synchromodality. This is often not possible in reality, especially for inter-continental flows where different technologies are used.

7 Results

This section examines the results obtained from the first dry-run of the prototype PLANET integrated modelling capability and the sample results that are expected from an application of the pipeline. It is noteworthy, that the prototype PLANET integrated modelling capability is a result in itself. In Section 7.2, we present how future execution of the PLANET integrated modelling capability can lead to a comparative evaluation of the potential benefits from innovation. Moreover, in Section 7.3, we show by means of a qualitative reasoning what is the expected impact of Cargoloop both the PI concept and on corridors and hubs.

7.1 Pipeline model execution

In order to test that the PLANET integrated modelling capability worked, we executed all models involved in the pipeline starting from input provided by COSCO and artificial data representing cargo demand from China to mainland Spain. We obtained the results reported in Figure 17 PLANET integrated modelling capability - dry run results Figure 17 as output by the software. Scenario 1 is the baseline scenario – the AS-IS situation described in Table 5 - where no technology or innovation takes place. Scenario 2, instead, considers a deployment of all technologies - the TO-BE setting from Table 5. Of interest here, is the *Change* column which shows what is the added benefit from the adoption of technology. Even though the results are based on artificial data, one could observe an increase of load factor and reliability as a consequence of technology deployment.

These results constitute the proof that a joint modelling capability can be developed to provide a quantitative answer to the benefit of technology within the EGTN. By considering additional technologies and scenarios we aim at comparing the benefits from the deployment of different technologies as we illustrate in Section 7.2.

Output	Scenario 1	Scenario 2	Change
Load factor (trucks and trains)	65%	85%	20%
Vessel spent time at sea (berthing + unloading containers)	27 hours	27 hours	0%
Reliability (containers delivered on-time)	80/100 (80%)	100/100 (100%)	20%

Figure 17 PLANET integrated modelling capability - dry run results

The execution of the pipeline was done by asynchronously executing each step and manually transferring data among them. This operation could be done quickly due to the low computational requirements of the models in the current set up. It might be expected that, as the complexity of the models and represented processes increase, alternative ways to execute the pipeline should be found. For now, this was not a concern.

As a final remark, the pipeline and the instance represented can be improved, extended, and tuned easily, if needed. This allows to consider additional T&L settings both in terms of enriched representation of the operations and in terms of geographical context considered.

7.2 Comparative evaluation of potential benefits from innovation

The pipeline has been developed in such a way to enable a testing of various technologies on the same transport setting. By doing so, it is possible to compare the potential benefits from innovation. In what follows, we illustrate what type of analysis we plan to execute starting from the pipeline developed. The numbers shown in Figure 18 are not the result of a computation, but serves to present the mock-up idea of what should be expected from an execution of the pipeline. Figure 18 shows the evaluation of three KPIs (reliability, modal split and congestion at port) in different technology/innovation scenarios listest on the left with the baseline case where no innovation is considered first. In the various scenarios, technologies and innovations can be considered deployed either individually (as in the first rows) or jointly (note the “+” sign) as we did in the pipeline dry-run (cf. Sect 7.1). As the KPIs considered are bound to values between 0 and 1, decimal value shave been reported.

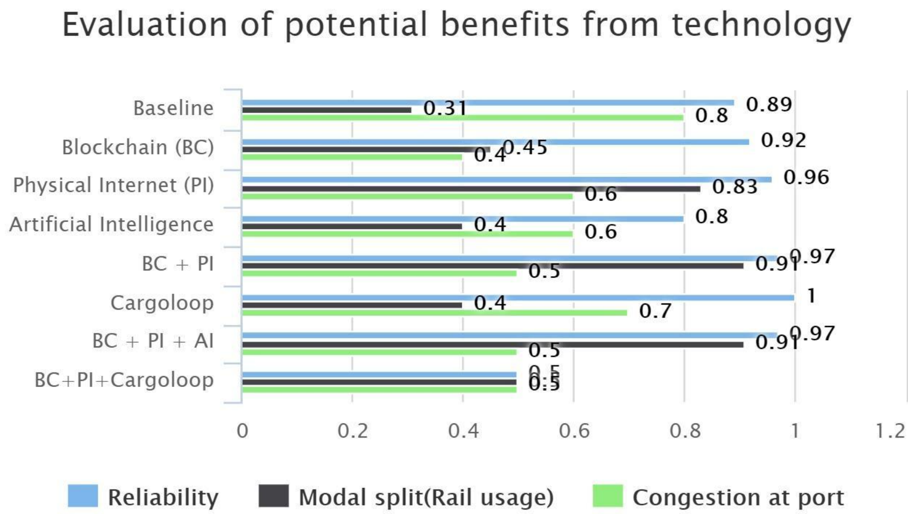


Figure 18 Comparative analysis of potential benefits from innovation. Mock-up.

As a result, from the pipeline application in different scenarios, it can be expected to obtain a result as depicted in Figure 18 where the impact of different technologies on the same EGTN instance is evaluated. It is important to observe that the pipeline as developed can assess the impact both of a single and multiple technologies being deployed. This is important to substantiate recommendations related to a concerted technology development. In Figure 18, three KPIs from the ones defined in Table 2 have been considered both at the microscopic (as congestion at port) and the macroscopic level (as reliability, i.e., fraction of containers delivered on-time, and modal split). Figure 18 is a mock-up showing how the current pipeline will assess the evaluation of potential benefits from technology. Note that for Reliability and Modal split KPIs the higher the value the better, while for Congestion at port the lower the value the better.

7.3 Cargoloop’s impact on the Physical Internet concept and on corridors and hubs (supply networks)

In this section, we discuss the relation between Cargoloop, as an emerging technology, and the Physical Internet. Because including the Cargoloop into the pipeline was not deemed possible, we opted for a qualitative reflection on the impact of this technology on the PI concept. A quantitative modelling of the Cargoloop concept is being considered.

Hyperloop as a modality for freight achieving air speeds without emissions is the only sustainable transport solution for time-sensitive shipments and therefore fills in a major gap in the physical internet vision. It will be designed to match the principles of the physical internet. It will be an open, shared network, perfectly integrated and synchronized with other modalities. The system will provide real-time tracking and accurate ETAs as the controlled environment doesn’t suffer from external influences like weather and traffic. Cargoloop hubs will be connected to existing multimodal nodes, for example at (inland) ports and airports, so time-critical shipments can be transported by hyperloop while less time-critical shipments can be transported by other modalities such as rail, barge and truck.

Furthermore, as a Cargoloop vehicle is designed to carry 3 to 5 Euro pallets at a time, it can move significantly smaller loads than trucks at a higher frequency while achieving a high load factor. This greatly improves the options for time sensitive LTL shipments to move through the networks of modalities quickly and efficiently. As the Cargoloop system and vehicle are still in development, the cargo hold can be optimized for PI containers if they prove to have a different sweet spot than currently anticipated.

A highly reliable and autonomous system like Cargoloop that is not interfered by weather, human error or other traffic, offers excellent opportunities for predictable transport. When the estimated time of arrival can be predicted to the second, the first and last mile can be planned more efficiently as well. This asks for a perfect IT integration with its users as well as solid agreements on availability and capacity while maintaining the open character of the network.

Data alignment is core to the Cargoloop concept, and this new mode of transport offers the possibility of designing a comprehensive operational and tactical control model from scratch, adhering to the principles of PI.A single hyperloop tube has the potential to transport 2 million tonnes of cargo per annum, the equivalent of hundreds of trucks per hour. That would mean a significant relief of heavy vehicle traffic on highways between Cargoloop hubs. With a well-designed network, it would eliminate the need to extend capacity on existing highways or build new ones. A European hyperloop network can also replace intra-continental air cargo (mostly used for express shipments) drastically reducing carbon footprint and other external negative effects of air transport.

8 Conclusion and future steps

This deliverable addressed the three research goals of Task T1.4 by defining and testing the first prototype of the PLANET integrated modelling capability. While this was developed to provide quantitative answers to the research questions, it resulted in a valuable thought experiment to further WP1’s understanding and development of the EGTN concept – which is central in PLANET. The main result of this deliverable is the prototype itself which is a pipeline of different models deployed in a concerted scenario. Advanced Artificial Intelligence methods like Recurrent Neural Networks, Optimization models for Port Call decision and Physical Internet Multi-Agent simulations have been successfully combined. Moreover, this deliverable reports the results of the first interactions with LL stakeholder aimed at deploying advanced synchromodal planning features.

The work summarized in this deliverable presents an approach to evaluate the impact of technology and innovation at the macroscopic level. Key and novel aspect of our approach is the modelling of technologies and innovations at the operational level and the estimation of the resulting macroscopic effect via macroscopic generalized-utility models. This approach is viable and hinges on the estimation of aggregated KPI changes due to the deployment of a certain technology. For instance, the estimated modal shift resulting from the joint deployment of PI, Blockchain and Artificial Intelligence is then fed into a macroscopic model to compute the change in entry point for certain commodity types.

With the model we developed, the innovation, impact, and integrated attributes of the EGTN concept have started to take shape. We model an integrated network considering trade flows of extra-European origin, where different innovative concepts and technologies are deployed and show the impact of technology itself on the whole network and its constituents. As a result of the model-crafting effort, we realized that these attributes should not only be considered individually, but jointly as well. Indeed, the extent to which integration is possible at the network level depends, at least nowadays, on the impact of certain ICT innovations (as PI or Blockchain). Therefore, these attributes have dependencies that needs to be explored further.

Due to the considerable research effort required, it has been decided to focus the prototype development to a single modelling use case rather than make marginal progress by addressing several cases. This shared approach paved the way to both future enhancements of the developed prototype and its application to other relevant modelling use cases. Because of this choice, a couple key modelling requirements were shifted to be investigated in Deliverable 1.9 (the final deliverable of Task T1.4): modelling city operations to extend the represented operational flow beyond containerized cargo and assessment of multiple technological innovations’ impact within the model. By taking this step further, the innovation Attribute and the Technological layer of the EGTN concept will be supported by PLANET’s integrated modelling capability.

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