New ICT infrastructure and reference architecture to support Operations in future PI Logistics NETworks

D1.1 PI-aligned digital and physical interconnectivity models and standards

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Glossary of terms and abbreviations used

Abbreviation/Term	Description
ALICE	Alliance for Logistics Innovation through Collaboration in Europe. Logistics ETP (www.etp-alice.eu)
Internet of Things (IoT)	The network of physical objects—devices, vehicles, buildings and other items—embedded with electronics, software, sensors, and network connectivity that enables these objects to collect and exchange data[1]
Shipper	Consignor, exporter, or seller (who may be the same or different parties) named in the shipping documents as the party responsible for initiating a shipment, and who may also bear the freight cost.[2]
Synchromodality	Synchronised intermodality, is the optimally flexible and sustainable deployment of different modes of transport and hubs in a network in which the user or customer is offered or can directly access to an integrated solution for his (inland) transport. It involves informed and flexible planning, booking and management, that allows to make mode and routing decisions at the individual shipment level almost in real time.[3]
UBL	OASIS Universal Business Language (UBL)
GTIN	Global Trade Item Number (GTIN)
GLN	Global Location Number (GLN)
SSCC	Serial Shipping Container Code (SSCC)
GRAI	Global Returnable Asset Identifier (GRAI)
GIAI	Global Individual Asset Identifier (GIAI)
GSRN	Global Service Relation Number (GSRN)
GDTI	Global Document Type Identifier (GDTI)
GINC	Global Identification Number for Consignment (GINC)
GSIN	Global Shipment Identification Number (GSIN)
GCN	Global Coupon Number (GCN)
CPID	Component/Part Identifier (CPID)
GMN	Global Model Number (GMN)
TDS	Tag Data Standard (TDS)
TDT	Tag Data Translation (TDT)
SLR	Systematic Literature Review
PI	Physical Internet
OLI	Open Logistics Interconnection (OLI) model
PIMS	Physical internet management systems
MHI	Material Handling Industry
FEM	European materials handling federation
BMPN	Business Process Model and Notation
CMMN	Case Management Model and Notation

Executive Summary

According to ALICE's vision for a transport system supporting sustainable and efficient logistics towards the Physical Internet and the SENSE project the Foundations Framework of the Physical Internet is based on interconnectivity, enabled through modularization as well as standardization of interfaces and protocols. A Physical Internet system is built upon three interconnectivity dimensions: (1) physical, (2) operational and (3) digital embraced by the universal interconnectivity as umbrella for these three elements.

(1) **Physical interconnectivity** is about making sure that any physical entity can flow seamlessly through the Physical Internet. Physical objects can be moved, handled and stored ubiquitously, provided that constraints due to factors such as security, climate control, etc., are respected. They can also be physically transferred from one means or mode to another seamlessly.

The state-of-the art analysis and the review of existing models and standards have been essentially concentrated on the current and emerging trends in PI Containers (all packaging levels) and on the PI hubs (bundling, automation, multimodal environment). Standards, in terms of dimensions and designs, have been developed either by the industry or by the official standardization bodies such as ISO and CEN. However, a truly integrated, interconnected and standardized PI box does not actually exist even if promising prototypes are demonstrated in ongoing projects such as Clusters 2.0 and AEROFLEX. In addition, new emerging technologies and concepts in urban and long-distance logistics might be counterproductive if both segments of the logistics are not collaborating.

The future PI network will be a reality under the condition that the current network of nodes is clearly identifiable. The elaboration of smart applications to collect information on all nodes is a pre-requisite and initiatives like railfacilitiesportal.eu should be further promoted and developed for all transport modes. The benefits of collaborative models in the hub community should be further developed and specific incentive program aiming at enhancing the collaboration should be initiated. Finally, to benefit from the full steam of the Physical Internet, new concepts for easy stuffing/un-stuffing of goods in a multimodal/intermodal PI environment should be designed for a smart transfer of goods from one mode to the other, in particular for the Road-Rail combination.

(2) **Digital Interconnectivity** ensures that physical entities, constituents and factors can seamlessly exchange meaningful information across the PI among others tracking and monitoring of objects, message passing among virtual agents and human actors and visibility about the state of demand, offer and flow. It encompasses the concepts of open global system, encapsulation, standard smart interfaces and standard collaborative protocols.

The review on current projects (such as SELIS or iCargo), on standards (GS1, UBL) and emerging trends (BPMN, AIOTI HLA) shows that there are many research projects and standardization initiatives but yet a fully integrated approach for PI is not available. The ICONET project will create a full PI-compliant stack of models taking existing standards and trends as basis. Recommendations and suggestions are addressing topics like data capture and encapsulation, data integration, B2B interoperability, service orchestration, business process interconnection and collaborative business process.

(3) **Universal interconnectivity** is the key to making the Physical Internet open, global, efficient and sustainable system. Universal interconnectivity in the Physical Internet is to be enabled through the integrated exploitation of encapsulation, interfaces and protocols. It includes the Internet of Things integrated in the automation.

The technical requirements and specifications of IoT have mainly be addressed in ICONET's D1.16. However, to be able to develop such common standardized communication protocols, the sectors are creating specific communities such as TiS for the wagon community.

The other reviewed aspect is the level of automation in logistics (warehouses/storages/hubs) and in the various transport modes. The integration of robotics solutions and automated guided vehicles into logistic processes (for example the new BASF supply chain process) is in an accelerating trend with significant investments in fully automated facilities with very few manual interventions. The handling of PI containers in a semi or fully automated mode is progressively implemented in deep-sea terminals and not all at European continental level. The transport mode 'Road' is massively investing in automation solution such as road platooning and autonomous driving as being confronted with a lack of truck drivers whereas 'Rail' is engaged in large-scale research programs in automated rail freight operations.

1 Introduction

ICONET is a 30-month project and that will significantly extend the state-of-the-art research and development around the Physical Internet (PI) concept in pursuit of a new networked architecture for interconnected logistics hubs by focusing on the following areas:

- Research, under the PI umbrella, into new business models that underpin intermodal transport, warehousing and ecommerce fulfilment.
- Development of an experimental ICT proof of concept (PoC) Infrastructure Platform to support the simulation and testing of the PI concepts.
- Development of representative PI solutions for each of the three Focus Areas for the corresponding Living Labs.

1.1 Deliverable Overview and Report Structure

This structure of this deliverable is as follows:

- Chapter 2 provides the necessary elements of the Physical Internet with a focus on the concepts of Physical, Digital and Universal Interconnectivity. The vision of the logistic players and their related roadmap and dissemination project will also be part of this section.
- Chapter 3 specifies the different analysed methodologies that could be applied within this project and explains the adopted approach for the compilation of the results and the analysis.
- Chapter 4 details the research results per PI concepts (Physical, Digital and Universal Interconnectivity).
- Chapter 5 provides the detailed analysis of the identified results of Chapter 4 per PI concepts and relevant for the ICONET project.
- Chapter 6 compiles the results in a comprehensive consolidated matrix and will serve as an input for further potential use in the other WPs and tasks of the project.

2 The Physical Internet

2.1 Introduction

The way physical objects are currently transported, handled, stored, realized, supplied and used throughout the world is not sustainable economically, environmentally and socially. This unsustainability assertion, supported through numerous symptoms outlined in this paper, reveals a harsh reality. Addressing this global unsustainability is a worldwide grand challenge, hereafter termed the Global Logistics Sustainability grand challenge.

The goal of this grand challenge is to enable the global sustainability of physical object mobility (transportation, handling), storage, realization (production, assembly, finishing, refurbishing and recycling), supply and usage. From an economical perspective, the goal is to unlock highly significant gains in global logistics, production, transportation and business productivity. From an environmental perspective, the goal is to reduce by an order of magnitude the global energy consumption, direct and indirect pollution, including greenhouse gas emission associated with logistics, production and transportation. From a societal perspective, the goal is to significantly increase the quality of life of the logistic, production and transportation workers, as well as of the overall population by making much more accessible across the world the objects and functionality they need and value.

Decades ago, the information and telecommunications community similarly faced a grand challenge. Drastically summarized, the digital world had faced a fast evolution from a world dominated by isolated large computers to a world filled with minicomputers and their workstations linked by private networks, and then to an explosive world filled with unconnected microcomputers sitting on everyone's desk. Most authorities in the community agreed that the situation was unsustainable and macroscopic solutions were needed. As the digital world was looking for a way to conceptualize how it should transform itself, it relied on a physically inspired transportation and logistics metaphor: building the information highway.

As is well known today, the digital community achieved its goal and went farther, reshaping completely the way digital computing and communication are now performed. The Digital Internet was invented, notably leading the way to the digital worldwide web and digital mobility. The reconceptualization has enabled the building of an open distributed network infrastructure that is currently revolutionizing so many facets of societal and economic reality. At the core of the paradigm shift is the Digital Internet which is about the interconnection between networks in a way transparent to the user, so allowing the transmission of formatted data packets in a standard way permitting them to transit through heterogeneous equipment respecting the TCP/IP protocol.

As the digital world exploited a physical world inspired metaphor, it is proposed that in order to meet the current grand challenge, the physical world exploit a digital Internet inspired metaphor. Even though there are fundamental differences between the physical world and the digital world, the metaphor is to be exploited to propose a vision for a sustainable and progressively deployable breakthrough solution to the global problems associated with the way physical objects are transported, handled, stored, realised, supplied and used around the world. The vision is to evolve towards a Physical Internet as a solution to the global logistics sustainability grand challenge

2.2 The ALICE roadmap

The European Technology Platform ALICE has been set-up to develop a comprehensive strategy for research, innovation and market deployment of logistics and supply chain management innovation in Europe. The platform will support and assist and advise the European Commission into the implementation of the EU Program for research: Horizon 2020 in the area of Logistics. ALICE was created in the frame of WINN project having the European Green Cars Initiative (logistics section) and EIRAC, European Intermodal Research Advisory Council, as background and supporting initiatives. ALICE was officially recognized as a European Technology Platform by the European Commission in July 2013.

In March 2017, ALICE published a vision for a transport system supporting sustainable and efficient logistics towards the Physical Internet[4]. The ALICE PI vision is based on three components (see figure 2.1): (i) The expectations of the citizens, supply chain actors and businesses aiming at increasing the overall satisfaction of all by reducing the energy consumption and CO2 emissions (ii) The challenges of the different transport modes to meeting these expectations and (iii) The Dream to transform the current supply chains networks into a truly integrated transport system for sustainable and efficient logistics.

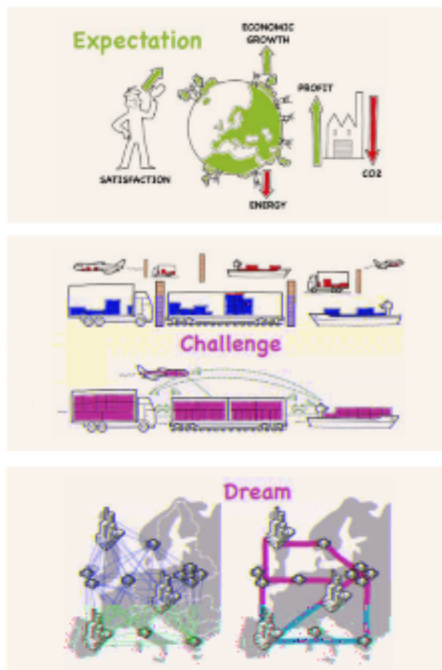


Figure 2-1 The ALICE PI vision

The ALICE roadmap identified the technological and non-technological elements that will positively impact transport in the process of reaching the dream: (1) reaching consensus among all transport and logistics stakeholders including European Commission and Member States, (2) current development on robotics for logistics and autonomous operations, (3) autonomous transport for large and small freight units, (4) Internet of Things for asset monitoring and enhanced management, (5) big data for improved forecasting and anomaly detection, (6) crowdsourcing and sharing economy towards more open and collaborative environment, and (7) fast evolution of interoperability towards easier connectivity of independent ICT systems.

On the other side, it also lists the current barriers impeding the realisation of a truly integrated system: (1) market dynamics in the logistics sector (low innovation investments), (2) lack of positive recognised business and operational models implementing horizontal collaboration, (3) lack of modular loading units for all transport modes, (4) too many regulations that hinder innovations, (5) lack of appropriate trans-shipment technologies, (6) lack of trust on sharing information services and systems and (7) Lack of appropriate standards for data collection, data collection systems for reporting commercially and socially important information as well as data quality monitoring

2.3 Accelerating the Path Towards Physical Internet -SENSE

Results from a simulation experiment with top retailers Carrefour and Casino in France and their 100 top suppliers moving from actual practice to a "Physical Internet Model" showed a potential economic benefit of 32%, a 60% reduction of greenhouse gas emissions and a potential of 50% of volume shifted from road to rail.

Accelerating the Path Towards Physical Internet -SENSE- project strategic objective is to accelerate the path towards the Physical Internet (PI), so advanced pilot implementations of the PI concept are well functioning and extended in industry practice by 2030, and hence contributing to at least 30 % reduction in congestion, emissions and energy consumption.

To that end, SENSE aims to increase the level of understanding of PI concept and the opportunities that brings to transport and logistics. By building stronger and wider support of industry, public bodies and research worlds towards the PI, we may reach consensus and enable coordinated strategic public and private investments in research and innovation embracing Physical Internet that could lead us to a new, much more efficient and sustainable paradigm.

SENSE will: 1) enhance, and stabilize a solid framework for industry, research and public bodies to share advances, barriers, opportunities and best practices regarding Physical Internet implementation, 2) build awareness and raise wide consensus on the Detailed Roadmap towards the Physical Internet developed in the frame of the project, 3) Create The Reference Knowledge Platform so the Physical Internet Community has access to recent developments including: PI implementation cases assessment, industry programs and activities, related start-ups, research and innovation projects, public initiatives and programs, and last, but not least, 4) assist and support Industry, European Commission, Member States and Regional Governments in the process of defining high impact research policies to fast track to Physical Internet.

A knowledge center, collecting all relevant information on the Physical Internet, will be soon launched and will be accessible to any registered users.

2.4 The Physical Internet foundations

A truly integrated transport system for sustainable and efficient logistics is based on an open and global system of transport and logistics assets, hubs, resources and services operated (in an open environment and framework conditions) by individual companies. They are fully visible and accessible to market players, hence creating a network of logistics networks. Coordination of logistics, transport, infrastructure and supply networks aim to move, store, supply and use physical objects throughout the world in a manner that is economically, environmentally and socially efficient, secure and sustainable. The system will be based on physical, digital, and operational interconnectivity, enabled through modularization as well as standardisation interfaces and protocols.

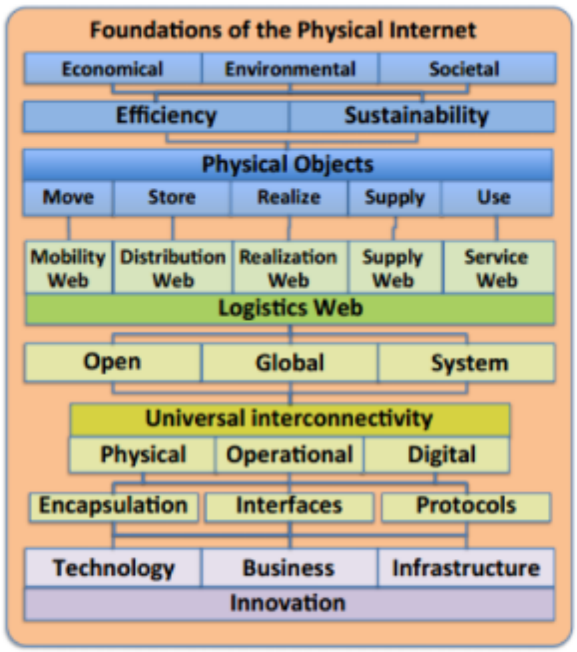


Figure 2-2 The Foundations Framework for the Physical Internet

Figure 2-2 provides a general overview of the framework pillars for the Physical Internet[5]:

- *Logistics Web Enabler*: In general, a web can be defined as a set of interconnected actors and networks. In the Physical Internet context, the types of actors and networks can be characterized, leading to define a web as a set of interconnected physical, digital, human, organizational and social agents and networks. A logistics web is defined as a web aiming to serve logistics needs of people, organizations, communities and/or society. A Logistics Web is a logistics web that is both open and global.
- *Interconnectivity*: it refers to the quality of a system to have its components seamlessly interconnected, easing the movement of physical entities from one another, their storage or treatment within any of its capable constituents, and the flow of responsibility sharing and contracting between actors. The PI system will consist of three interconnectivity elements: (1) physical, (2) operational and (3) digital. The Universal interconnectivity in the Physical Internet, as umbrella of the three other elements is to be enabled through the integrated exploitation of encapsulation interfaces and protocols.
- *Standard smart interfaces*: Interfaces are critical for achieving efficient and sustainable universal interconnectivity. Four types of interfaces have paramount importance in the Physical Internet: fixtures, devices, nodes, and platforms.
- *Innovation*: PI as enabling and enabler of innovation in the IoT ecosystem

2.4.1 Physical interconnectivity

Physical interconnectivity is about making sure that any physical entity can flow seamlessly through the Physical Internet. Physical objects can be moved, handled and stored ubiquitously, provided that constraints due to factors such as security, climate control, etc., are respected. They can also be physically transferred from one means or mode to another seamlessly. Therefore, the role of the PI hub will be essential and is part of the assets to be analysed in the framework of the physical interconnectivity.

On the large side (box level), physical logistics systems today exploit the world-standards such as 20- and 40-foot in the maritime container transport and 13,60m long loading units in the European continental market. On the small side (parcel), the standardization is deployed and exploited by logistics actors such as DHL, FedEx, Purolator and UPS.

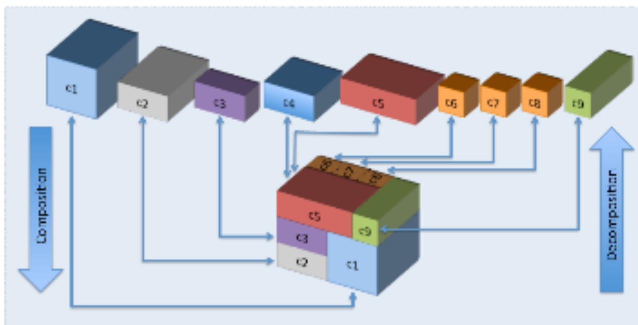


Figure 2-3 Illustrating the PI containers

The Physical Internet generalizes and significantly extends this practice by encapsulating physical objects in physical packets or containers (hereafter termed π-containers so as to differentiate them from current containers), packets, boxes and so on. These π-containers are world-standard, smart, ecofriendly and modular. They are modularized and standardized worldwide in terms of dimensions, functions and fixtures (see figure 2-3).

2.4.2 Digital interconnectivity

Digital interconnectivity ensures that physical entities, constituents and factors can seamlessly exchange meaningful information across the PI, fast knowledge and fact-based decision-making in action (Montreuil2012*)*. Digital interconnectivity includes, among others:

- Tracking and monitoring of objects within the PI.
- Message passing among virtual agents and human actors within the PI.
- Visibility about the state of demand, offer and flow.

To achieve a successful Digital interconnectivity, there is a set of PI foundations to be covered:

Table 2-1 π-Foundations related to Digital Interconnectivity

π-Foundation	Description
Open Global System	A PI system cannot be a private, closed, member-only system. The actors have to design PI solutions so that it is easy for any other actor to access and use its services.
Encapsulation	PI requires the exchange of data among participants. This way, it is mandatory to handle information encapsulated in standard data packets.
Standard Smart Interfaces	This foundation is related to the capability of exchange and collaborates among π-fixtures, π-devices, π-nodes and π-platforms.
Standard collaborative protocols	Finally, it is required the existence of a service or message-based schema to support the business process execution.

According to the Modulushca architecture (ModulushcaURL), there are four layers to be considered: business, logistics, transport and physical. In terms of Digital interconnectivity, the main issues to be solved per layer are:

Table 2-2 Issues to be covered for Digital Interconnectivity in Modulushca architecture layer

Layer	Description
Business	• Usage of technological standards to automate execution of business process • BP orchestration • BP choreography • Case management
Logistics	• Integration to ERP and corporate systems • Usage of technological standards to automate data exchange • Definition of software integration interfaces and protocols • Software Integration architectures: client-server, event process chains, enterprise integration patters, enterprise service buses, peer-to-peer networks
Transport	• Encapsulation of source and destination fields • Usage of technological standards to automate data capture (barcodes, RFID)
Physical	• Identification of assets • Identification of participants • Usage of technological standards to automate data capture (barcodes, RFID)

2.4.3 Operational interconnectivity

Operational interconnectivity is about ensuring that in-the-field operational processes as well as the business processes are seamlessly interlaced so that it is easy and efficient for users to exploit Physical Internet for fulfilling their logistics needs and for Physical Internet constituents to seamlessly collaborate in serving the logistics users of Physical Internet users. This includes designing and using standardised business contracts and incoterm-type modalities as well as implementing and respecting operational protocols. This aspect will not be further analysed in the framework of the ICONET project.

2.4.4 Universal interconnectivity

Interconnectivity refers to the quality of a system to have its components seamlessly interconnected, easing the movement of physical entities from one another, their storage or treatment within any of its capable constituents, and the flow of responsibility sharing and contracting between actors. The fourth foundation of the

3 Methodology

This section exposes the methodology followed for conducting the review. The first subsection introduces the existing approaches to perform literature reviews. Then the ICONET process for D1.1 is exposed. The first stage of the process, the analysis of previous reviews as a tertiary study is shown. Finally, the review methodology is detailed.

3.1 Approaches for Systematic Reviews

One of the most common tasks in the research community is to analyse the state-of-the-art of a research topic. Publications, in form of research papers, conference proceedings, project deliverables or white papers are the data source for this task which is known as *literature review*. Depending on the purpose of the analysis, there are several approaches:

- **Literature Reviews**: basically they are a keyword based search in a set of databases for primary studies on a research topic, following some guidelines (Denyer2009) (Rowley2004).
- **Domain specific reviews**: the application of literature reviews to a concrete domain, for example, supply chain (Seuring2012) (Saenz2015).
- **Systematic Literature Reviews** (SLRs): they aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology (Kitchenham2009). SLRs are focused on gathering and synthesizing evidence (Petersen2015).
- **Systematic Mapping Studies** (SMSs): it is used to structure a research area through classification and counting contributions in relation to the categories of that classification (Petersen2015).
- **Tertiary Studies**: it is the application of SLR to reviews in order to answer wider research questions where there are many reviews in the field (Kitchenham2009).

This deliverable aims to provide a comprehensive overview of current and emerging standards for digital and physical interconnectivity in the PI. For this reason, we have followed an **SLR-based approach**, customised to the project's needs.

According to (Kitchenham2009), an SLR is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Individual studies contributing to a systematic review are called *primary* studies; a systematic review is a form of *secondary* study. Some of the features that differentiate a systematic review from a conventional expert literature review are:

- Systematic reviews start by defining a review protocol that specifies the research question being addressed and the methods that will be used to perform the review.
- Systematic reviews are based on a defined search strategy that aims to detect as much of the relevant literature as possible.
- Systematic reviews document their search strategy so that readers can assess their rigor and the completeness and repeatability of the process (bearing in mind that searches of digital libraries are almost impossible to replicate).
- Systematic reviews require explicit inclusion and exclusion criteria to assess each potential primary study.
- Systematic reviews specify the information to be obtained from each primary study including quality criteria by which to evaluate each primary study.

3.2 Review process

This section exposes the main review process. SLR guidelines have been criticized by several authors due to the great dependence on keywords selected for the search (Wohlin2014). To reduce this potential risk, we have conducted as a first step a **tertiary study** on the field of Physical Internet (PI) in general, in order to identify the main keywords and data sources to be used during the SLR.

Then, the review process follows the stages of planning, conducting and reporting defined by (Kitchenham2009).

- **Planning**: when the review method is defined, in terms of research question formulation, search strategy, inclusion and exclusion criteria and data schema.
- **Conducting**: when the SLR is executed and searches are performed. Primary studies are retrieved and analysed according to inclusion criteria defined and, data are saved in the schema for future discussion. In this stage an iterative method is followed so that new studies are included by citation of primary studies included what is known as a snowball effect (Wohlin2014).
- **Reporting**: finally, with all primary studies included, a synthesis is obtained and conclusions to specific research questions are reported.

The global review process is then a customisation of the SLR (Kitchenham2009) and the improvements proposed by (Wohlin2014), considering that as PI is a novel concept, a substantial number of initiatives are not reported in academic research papers but white papers, project deliverables and reports (Treiblmaier2016). This way, in the SLR, not only research publication paper databases will be included but also research projects, standardization and industry initiatives.

The general process is summarized in the following Figure 3-1:

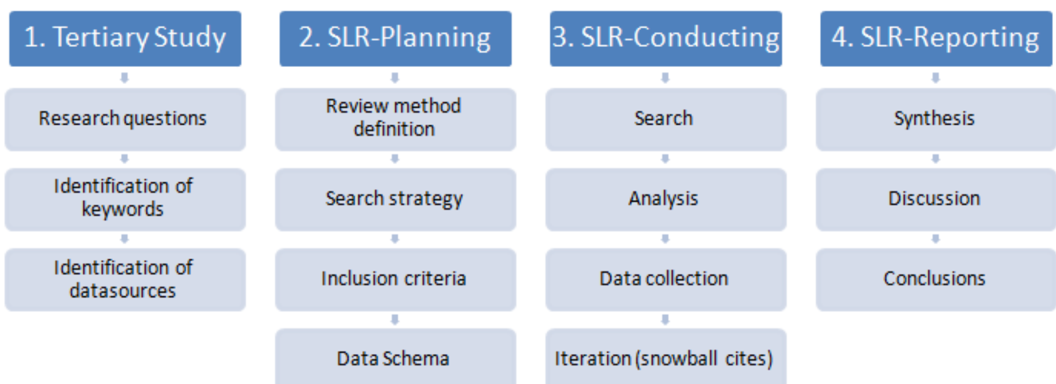


Table 3-1 Review Process Overview

3.3 Tertiary Study

3.3.1 Introduction

This first stage focuses on the identification of relevant keywords and data sources that may drive the SLR search. For this purpose, we have followed guidelines for a Tertiary Study, which is in fact the application of a SLR that includes only previous reviews.

3.3.2 Methodology

This way this section is structured following the same issues that the SLR method, so that RQs, search strategy, inclusion and exclusion criteria, data collection, results and analysis will be detailed.

R

This review stage aims to answer the following Research Questions:

Table 3-2 Research Questions of the Tertiary Study

RQ	Definition
RQ1	Is there any literature review of the state-of-the-art regarding interconnectivity in the PI?
RQ2	What are the main keywords to look for current and emerging initiatives for interconnectivity in the PI?
RQ3	What are the main data sources to look for current and emerging initiatives for interconnectivity in the PI?

S

To this end, we have looked for reviews in the field of "Physical Internet", so that we have used this keyword term as search criteria in combination with other words and several search fields. Depending on the number of the results, we have redefined the keyword search in order to improve the search according to our purposes. The following table summarises the main manual searches performed:

Table 3-3 Search Strategy of the Tertiary Study

Database	Source	Keyword Search	Search fields
Google Scholar	https://scholar.google.es	*"physical internet review"*	Title, Abstract, Keywords
		In title: "physical internet" AND review	Title
Science Direct	https://www.sciencedirect.com/	*"physical internet" AND review*	Title, Abstract, Keywords
		"physical internet"	Title
Elsevier's Scopus	https://www.scopus.com	*"physical internet" AND review*	Title, Abstract, Keywords
		"physical internet"	Title

I

The following table summarizes the inclusion criteria, both for reviews and for primary studies that may be considered in the next stage, and the exclusion criteria, as follows:

Table 3-4 Inclusion and Exclusion criteria of the Tertiary Study

Inclusion Criteria – Review	Inclusion Criteria – Primary Study to include in the next stage	Exclusion Criteria
English text Full Text access PI reviews From 2011 to 2019 Logistic reviews that includes trends or conclusions relevant to PI Interconnectivity problems	English text Full Text access From 2011 to 2019 Primary studies that includes models, proposals, initiatives or solutions relevant to PI Interconnectivity field	No English text No full access available Duplicated studies Previous to 2011 Concrete PI studies not related to interconnectivity problems

As a customization of the tertiary study methodology, we have modified the inclusion criteria so that we will include for a quick review primary studies that may suggest relevant information to the research questions. This way, although these papers will be considered in the next stage, these papers will be registered for data collection to identify keywords and data sources.

D

For each review we have retrieved the following information as data collection schema:

Table 3-5 Data collection schema of the Tertiary Study

Info	Definition
Publication Info	Publication title, author, book, journal, conference or technical paper where the study was published
Year	Review year
Review Method	Only for review papers: Review methodology
Number of studies included	Only for review papers: Number of primary studies included in the review
Main keywords	Main keywords to be considered for interconnectivity in the PI
Main data sources	Main data sources (relevant projects, standardization organizations) to be considered
Primary studies to be included	Reference to primary studies to be taken into account in the next stage
Other info to be taken into account	Other relevant information

3.3.3 Results

This section exposes the results of this stage. The following table summarises the number of papers found in each database, the papers included and their references, as well as the references of the primary studies to be considered in the next stage according to inclusion criteria.

Table 3-6 Search Results of the Tertiary Study

Database	Number of Papers Found	Number of Papers Included	Review References
Google Scholar	22 + 132	5	(Sternberg2017), (Treiblmaier2016), (Pan2017), (Maslaric2016), (Domanski2018)
Science Direct	151 + 12	0	-
Elsevier's Scopus	9 + 61	1	(Sternberg2017)

These reviews have included the following methods and studies:

Table 3-7 Detailed Results of the Tertiary Study

Year	Review Method	Number of studies analysed	Reference
2016	Short Systematic Literature review, method not defined	40	(Maslaric2016)
2016	Systematic Literature review: search term "physical internet"; search databases: Google scholar, Esmerald, PROQUEST, EBSCO, IPIC conference, ALICE website	101	(Treiblmaier2016)
2017	Systematic Literature review: search term "physical internet" AND (logistics OR transport OR supply OR distribution); search databases: Google scholar, Web of Knowledge	46	(Sternberg2017)

2017	Special issue of International Journal of Production Research	10	(Pan2017)
2018	Systematic Literature review: search term “physical internet”; search databases: Web of Science, Scopus	162	(Domanski2018)

Once the first reviews were included, they were analysed and potential primary studies cited in the review were considered for the research questions in this first stage. Then, following the snowball effect, new primary studies were included in several iterations. Table 3.-8 below shows the summary of the studies that have been taken into account in this stage:

Table 3-8 Primary Studies considered in the Tertiary Study

Year	Title	Reference
2012	An open logistics interconnection model for the Physical Internet	(Montreuil2012)
2013	Physical Internet Foundations	(Montreuil2013)
2017	Internet of things and supply chain management: a literature review	(BenDaya2017)
2018	An information framework for internet of things services in physical internet	(TranDang2018)
2018	Removiendo los pilares de la logística: physical internet	(Paz2018)
2018	Literature review of Industry 4.0 and related technologies	(Oztemel2018)
2019	The Physical Internet	(Ballot2019)

3.3.4 Discussion

This section exposes the main conclusions of the tertiary review in order to answer the RQs.

RQ I *PI*

After the first search stage, more than 350 papers have been identified and title, abstract and keywords have been reviewed.

Five (5) reviews have been included, which adds a total of three hundred fifty-nine (359) primary studies, without any reference to interconnectivity reviews.

RQ

PI

The following table summarises the main terms or keywords used regarding interconnectivity in the PI extracted from the data schema of included reviews:

Table 3-9 Main terms related to interconnectivity, outcomes of the Tertiary Study Reviews

Main terms related to interconnectivity		Reference
✓ Interconnected logistics ✓ Digital interconnectivity ✓ Universal interconnectivity	✓ Physical interconnectivity ✓ Operative interconnectivity ✓ Interconnected open logistics network	(Maslaric2016)
✓ Interconnectivity ✓ Interconnected global logistics systems	✓ Interoperability between PI components	(Treiblmaier2016)
✓ Universal interconnectivity ✓ Unified multi-tier framework	✓ Open global supply web	(Sternberg2017)
✓ Interconnected logistic services ✓ Interconnected logistics	✓ Open Logistics Interconnection (OLI) model	(Pan2017)
✓ Information systems for interconnected logistics	✓ Interconnected logistic networks	(Domanski2018)

The following table summarizes the main terms or keywords used regarding interconnectivity in the primary studies included:

Table 3-10 Main terms related to interconnectivity, outcomes of the Tertiary Study Primary Studies

Main terms related to interconnectivity		Reference
✓ Digital internet ✓ Information sharing ✓ Interconnected network ✓ Full digital visibility ✓ Internet of things ✓ Industry 4.0 ✓ Interconnected logistic services ✓ Interconnection ready ✓ Intelligent freight-transportation ✓ Physical internet management systems (PIMS)	✓ Service Oriented Architectures ✓ Interoperability ✓ Standardized set of protocols ✓ Smart collaboration Interface ✓ Global interconnectivity ✓ Unified multi-tier framework ✓ Logistics Interconnection model ✓ Omnichannel logistics ✓ Interconnected global logistics system ✓ Interoperability between PI components ✓ PI digital challenges	(Montreuil2012), (Montreuil2013), (BenDaya2017), (TranDang2018), (Oztemel2018), (Ballot2019)

If we sort the keywords depending on the number of occurrences, the following figure depicts the outcomes:

Figure 3-1 Number of occurrences of main keywords in the Tertiary Study

RQ

PI

The following table summarises the main data sources cited for interconnectivity in the PI extracted from the data schema of included reviews:

Table 3-11 Data sources related to interconnectivity

The following table summarises the main data sources cited for interconnectivity in the primary studies:

Table 3-12 Main data sources related to interconnectivity, outcomes of the Tertiary Study Primary Studies

Main data sources related to interconnectivity		Reference
✓ Simple Links project ✓ iCargo project ✓ InBin project ✓ Traxens project ✓ CO3 project ✓ Tiger project ✓ Comcis project ✓ Citropine project ✓ Co-gistic project ✓ Chill-on project ✓ Cluster 2.0 project ✓ Logicmatic project ✓ Movility4EU project ✓ Modulushca project ✓ Smart rail project ✓ CELDi project	✓ EPC Global Standard (GS1 2013) ✓ Material Handling Industry ✓ ALICE ETP ✓ OASIS group ✓ W3C ✓ PI manifiesto	(Montreuil2012), (Montreuil2013), (BenDaya2017), (TranDang2018), (Oztemel2018), (Ballot2019)

3.3.5 Conclusions

According to the review analysis presented in the previous section, the following table shows the main conclusions that will drive the next step.

Table 3-13 Main conclusions of the Tertiary Study

RQ	Conclusion
RQ1: Is there any literature review of the state-of-the-art regarding interconnectivity in the PI?	In order to conclude that, to the best of our knowledge, **there is no review** or survey or state-of-the-art regarding interconnectivity in the PI
RQ2: What are the main keywords to look for current and emerging initiatives for interconnectivity in the PI?	In order to conclude that, the best keyword is the combination of several words: **Interconnection OR interconnectivity OR interconnected**
RQ3: What are the main data sources to look for current and emerging initiatives for interconnectivity in the PI?	In order to conclude that, the review should contain a search on **publications**, but also: ✓ Look for related **EU projects** ✓ Look for publications of **ALICE ETP** ✓ Look for **standardization** groups (OASIS, W3C, GS1)

3.4 Systematic Literature Review based Methodology

This section presents the methodology followed to perform the SLR according to (Kitchenham2009) guidelines.

3.4.1 Research questions

As a general purpose, this deliverable aims to answer the following Research Questions:

RQ: What are the current and emerging solutions for digital and physical interconnectivity in the PI?

This general RQ has been detailed, in the area of physical, digital and universal interconnectivity in the PI, as follows:

Table 3-14 Research Questions of the Systematic Literature Review

RQ	Definition
RQ1	What are the contributions of **EU research projects** (in the area of physical, digital & universal interconnectivity in the PI)?
RQ2	What are the **standardization** proposals (in the area of physical, digital and universal interconnectivity in the PI)?
RQ3	What are the **emerging research** proposals (in the area of physical, digital and universal interconnectivity in the PI)?

3.4.2 Search strategy

Taking into account the conclusions of the Tertiary Study explained in the previous section, we have followed a keyword-based search on three different data sources:

Table 3-15 Search Data sources of the Systematic Literature Review

RQ	Search Data source
RQ1	CORDIS EU research projects under FP7 (2007-2013) open dataset (CordisFP7), CORDIS EU research projects under Horizon 2020 (2014-2020) open dataset (CordisH2020)
RQ2	European materials handling federation (FEM), Material Handling Industry (MHI), European Technology Platform ALICE (ALICE), GS1 (GS1), Google Scholar, Science Direct, Elsevier's Scopus
RQ3	Google Scholar, Science Direct, Elsevier's Scopus

Additionally, all results given from the Tertiary Study will be directly added to the search results of this stage.

The concrete search strategy for each data source is detailed as follows.

S EU P

For EU projects, we have searched "physical internet" on title or objective fields at CORDIS EU Research Projects platform under FP7 and H2020 open datasheet (CordisFP7), (CordisH2020).

Table 3-16 Search Data sources for searching EU Projects in the Systematic Literature Review

Database	Keyword Search	Search fields
CORDIS EU research projects under FP7 (2007-2013) open dataset (CordisFP7)	*"physical internet"*	Title, Objective
CORDIS EU research projects under Horizon 2020 (2014-2020) open dataset (CordisH2020)	*"physical internet"*	Title, Objective

S S

For standards, we have searched "physical internet" on title and standard on title or abstract or keywords in scientific publications, as well as, in the main standardization or physical internet associations like (ALICE), (FEM), (GS1) and (MHI). Additionally, we have added manually standards results coming from EU projects.

Table 3-17 Search Data sources for searching standards in the Systematic Literature Review

Database	Source	Keyword Search	Search fields
European materials handling federation (FEM)	http://www.etp-logistics.eu/	"standards"	All website
Material Handling Industry (MHI)	http://www.mhi.org	"standards"	All website
European Technology Platform ALICE (ALICE)	https://scholar.google.es	"standards"	All website
GS1 (GS1)	https://www.gs1.org	"standards"	All website

S E R

For emerging technologies, considering the Tertiary Review conclusions presented in Section 3.3.5, we have performed the following search strategy:

Table 3-18 Search Data sources for emerging research proposals in the Systematic Literature Review

Database	Source	Keyword Search	Search fields
Google Scholar	https://scholar.google.es	*In title: "physical internet" in title: interconnection*	Title
		In title: "physical internet" in title: interconnectivity	Title
		In title: "physical internet" intitle: interconnected	Title
Science Direct	https://www.sciencedirect.com/	*"physical internet" AND (interconnection OR interconnectivity OR interconnected)*	Title, Abstract, Keywords
Elsevier's Scopus	https://www.scopus.com	*"physical internet" AND (interconnection OR interconnectivity OR interconnected)*	Title, Abstract, Keywords

3.4.3 Inclusion and exclusion criteria

This section presents the inclusion and exclusion criteria for the search results:

I EU P

The following table summarises the inclusion criteria for EU Projects search results:

Table 3-19 Inclusion and Exclusion criteria for EU Projects in the Systematic Literature Review

Inclusion Criteria	Exclusion Criteria
FP7-H2020, EU Project Access to its deliverables or proposals Projects that propose any method, practice, tool or initiative related to physical or digital or universal interconnectivity in the PI	<FP7 EU Projects Website is down No access to deliverables or reports Duplicated projects Projects not related to interconnectivity problems

I S

The following table summarises the inclusion criteria for standards search results:

Table 3-20 Inclusion and Exclusion criteria for standards in the Systematic Literature Review

Inclusion Criteria	Exclusion Criteria
EU or international standard Related to physical internet domain	Not applicable to physical internet Publication not available Draft, not final release

I E R

The following table summarises the inclusion criteria for publication search results:

Table 3-21 Inclusion and Exclusion criteria for publications in the Systematic Literature Review

Inclusion Criteria	Exclusion Criteria
English text Full Text access From 2011 to 2019 Peer-reviews Papers, Books, Whitepapers That proposes any method, practice, tool or initiative related to physical or digital or universal interconnectivity in the PI	No English text No full access available Project deliverables Duplicated studies Previous to 2011 Concrete PI studies not related to interconnectivity problems

3.4.4 Data collection

This section refers to the data schema retrieved for each element of the search method.

D S EU P

For each EU project we have retrieved the following information as data collection schema:

Table 3-22 Data schema for EU Projects in the Systematic Literature Review

Info	Definition
Acronym	Project acronym
Status	Project status
Title	Project Title

Program, Topics and FP	Details of EU FP
Start Date	Project starting date
End Date	Project end date
Objective	Project objective
Interconnectivity info	PI-Interconnectivity information
Physical – Digital – Universal	Checkboxes to trace what type of interconnection the project is related to

D S S

For each standard we have retrieved the following information as data collection schema:

Table 3-23Data schema for standards in the Systematic Literature Review

Info	Definition
Designation	Standard designation
Year	Standard year
Title	Standard title
Description	Standard description
Organization	Association in charge of the standard

D S E R

For each paper we have retrieved the following information as data collection schema:

Table 3-24 Data schema for publications in the Systematic Literature Review

Info	Definition
Publication Info	Publication title, author, book, journal, conference or technical paper where the study was published
Latest update	Latest standard update
Interconnectivity info	PI-Interconnectivity information
Physical – Digital – Universal	Checkboxes to trace what type of interconnection the project is related to
Other info to be taken into account	Other relevant information

4 Search Results

Section 4 presents the analytical results obtained from the search strategy performed. The analysis of the results in terms of ICONET project is detailed in Section 5.

4.1 EU research projects

This table shows the EU projects found according to the different data source, and the final inclusion regarding criteria defined in the previous sections:

Table 4-1: EU Projects Search Results Summary

Database	Potential Projects	Search Results	Included	Excluded	Exclusion criteria
(CordisFP7)	25778	1	1	0	-
(CordisH2020)	20878	4	4	0	-
Tertiary Study Results	-	16	8	7	4 not found, 3 not EU projects

These are the EU projects included in the review, sorted by start date:

Table 4-2 EU Projects Search Results Details

Acronym	FP	Title	Start Date	End Date
TIGER	FP7-TRANSPORT	Transit via Innovative Gateway concepts solving European-Intermodal Rail needs	2009-10-01	2012-09-30
CO3	FP7-TRANSPORT	Collaboration Concepts for Comodality	2011-09-01	2014-08-31
COMCIS	FP7-TRANSPORT	Collaborative Information Services for Container Management	2011-09-01	2013-08-31
iCargo	FP7-ICT	iCargo - Intelligent Cargo in Efficient and Sustainable Global Logistics Operations	2011-11-01	2015-04-30
MODULUSHCA	FP7-TRANSPORT	Modular Logistics Units in Shared Co-modal Networks	2012-10-01	2016-01-31
CO-GISTICS	CIP	Cooperative logistics for sustainable mobility of goods CO-GISTICS	2014-01-01	2016-05-31
Smart-Rail	H2020	Smart Supply Chain Oriented Rail Freight Services – Smart-Rail	2015-05-01	2018-04-30
MOBILITY4EU	H2020	Action Plan for the future of Mobility in Europe	2016-01-01	2018-12-31
LOGIMATIC	H2020	Tight integration of EGNSS and on-board sensors for port vehicle automation	2016-03-01	2019-02-28
DynaHUBS	H2020	DynaHUBs is a new application designed to kick start the development of the Physical Internet using a crowd-sourced approach	2016-08-01	2018-07-31
SELIS	H2020	Towards a Shared European Logistics Intelligent Information Space	2016-09-01	2019-08-31
CLUSTERS 2.0	H2020	Open network of hyper connected logistics clusters towards Physical Internet	2017-05-01	2020-04-30
SENSE	H2020	Accelerating the Path Towards Physical Internet	2017-10-01	2020-03-31
AEROFLEX	H2020	Aerodynamic and Flexible Trucks for Next Generation of Long-Distance Road Transport	2017-10-01	2021-03-31

4.2 Standards

This table shows standards found according to the different data source, and the final inclusion regarding criteria defined in the previous sections:

Table 4-3 Standards Search Results Summary

Database	Search Results	Included	Excluded
European materials handling federation (FEM)	0	0	0
Material Handling Industry (MHI)	28	9	18
European Technology Platform ALICE (ALICE)	0	0	0
GS1 (GS1)	29	21	8
Manually added from EU projects	1	1	0

These are the standards included in the review:

Table 4-4 Standards Search Results Details

Organization	Designation	Title
OASIS	**UBL**	OASIS Universal Business Language (UBL)
GS1	**GTIN**	Global Trade Item Number (GTIN)
GS1	**GLN**	Global Location Number (GLN)
GS1	**SSCC**	Serial Shipping Container Code (SSCC)
GS1	**GRAI**	Global Returnable Asset Identifier (GRAI)
GS1	**GIAI**	Global Individual Asset Identifier (GIAI)
GS1	**GSRN**	Global Service Relation Number (GSRN)
GS1	**GDTI**	Global Document Type Identifier (GDTI)
GS1	**GINC**	Global Identification Number for Consignment (GINC)
GS1	**GSIN**	Global Shipment Identification Number (GSIN)
GS1	**GCN**	Global Coupon Number (GCN)
GS1	**CPID**	Component/Part Identifier (CPID)
GS1	**GMN**	Global Model Number (GMN)
GS1	**EAN/UPC barcodes**	GS1 Data Capture EAN/UPC barcodes
GS1	**TDS**	Tag Data Standard (TDS)
GS1	**TDT**	Tag Data Translation (TDT)
GS1	**EDI GS1 XML**	EDI GS1 XML
GS1	**EDI EANCOM**	EDI EANCOM
GS1	**EDI GS1 UN/CEFACT XML**	EDI GS1 UN/CEFACT XML
GS1	**GDSN**	Global Data Synchronisation Network (GDSN)
GS1	**GPC**	Global Product Classification (GPC)
GS1	**EPCIS CBV**	EPCIS and Core Business Vocabulary (CBV)
GS1	**GTS**	Global Traceability Standard (GTS)
GS1	**LIM**	GS1 Logistics Interoperability Model Application Standard (GS1 LIM)
ANSI MH	**ANSI MH1-2016**	Pallet, Slip Sheets, & Other Bases for Unit Loads
ANSI MH	**ANSI MH10.8.1-2005**	Linear Bar Code & 2-Dimensional Symbols
ANSI MH	**ANSI MH10.8.12-2011**	Specification for Material Handling Component
ANSI MH	**ANSI MH10.8.15:2011**	Specification for XML Reader Output from ISO/IEC 15434
ANSI MH	**ANSI MH10.8.2-2016**	Data Identifier and Application Identifier Standard
ANSI MH	**ANSI MH10.8.3-2004**	Transfer Data Syntax for High Capacity ADC Media

GS1 standards for data exchange	List of GS1 standards related to data exchange:
	• EDI (Transaction Data)
	  o GS1 XML
	  o EANCOM
	  o GS1 UN/CEFACT XML
	• Product Data Sharing (Master Data)
	  o Global Data Synchronisation Network (GDSN)
	  o Global Product Classification (GPC)
	  o GS1 SmartSearch
	  o GS1 Digital Link
	  o GS1 Mobile Ready Hero Images
	• Visibility Event Data
	  o EPCIS and Core Business Vocabulary (CBV)
	• Verification Messaging
	  o GS1 Lightweight Verification Messaging Standard
	• Network
	  o ONS
	  o Certificate Profile

GS1 standards for traceability	Global Traceability Standard (GTS): it provides the needed framework to ensure that traceability systems are interoperable and scalable, where trading partners can easily collaborate and share information for visibility across the entire chain.
GS1 Logistics Interoperability Model Application Standard	The mission of GS1 Logistics Transport & Logistics (T&L) is to lead the development and drive the implementation of the GS1 Logistics standards to gain business benefits for global supply chains by fostering interoperability between the partners to overcome barriers of scalability and achieve visibility.
ANSI MH1-2016	This standard pertains to pallets used in the unit-load method of assembling, stacking, storing, handling, and transporting materials and products. The standards are to accomplish the following: define terminology and nomenclature associated with pallets; apply to pallets irrespective of components and materials used in their fabrication; provide a series of recommended pallet dimensions and sizes; describe procedures for pallet sampling, inspection, and testing.
ANSI MH10.8.1-2005	This standard specifies the minimum requirements for the design of labels containing linear bar code and two-dimensional symbols on transport units to convey data between trading partners, provides for traceability units to convey data between trading partners, provides guidance for the formatting on the label of data presented in linear bar code, two-dimensional symbol, or human readable form, provides specific recommendations regarding the choice of linear bar code and two-dimensional symbology, and specifies quality requirements, makes recommendations as to label placement, size, and the inclusion of free text and any appropriate graphics, provides guidance in the selection of label material.
ANSI MH10.8.12-2011	This standard specifies a transfer structure, syntax, and coding of messages and data formats when using high capacity ADC media between trading partners, specifically between suppliers and recipients, and where applicable, in support of carrier applications, such as bills of lading and carrier sortation and tracking.
ANSI MH10.8.15:2011	This standard specifies for an Automatic Identification and Data Capture (AIDC) reader manufacturer, the preferred output of an AIDC reader when processing ISO/IEC 15434 formatted data. The standard is intended to cover the processing of all AIDC media. It specifies that the output be provided in an XML format suitable for display in Internet Explorer and usable in other applications. The specifications are intended to cover the

	output from processing of all current and future Format Indicators included in ISO/IEC 15434.
ANSI MH10.8.2-2016	This standard provides a comprehensive dictionary of MH 10/SC 8 Data Identifiers and GS1 Application identifiers provides for the assignment of new Data Identifiers, as required, and provides a document detailing the correlation, or mapping, of Data Identifiers to Aplication Identifiers, where a correlation exists.
ANSI MH10.8.3-2004	This standard specifies a transfer structure, syntax, and coding of messages and data formats when using high capacity ADC media between trading partners, specifically between suppliers and recipients, and where applicable, in support of carrier applications, such as bills of lading and carrier sortation and tracking.
ANSI MH10.8.6-2013	This standard is an application standard for the marking of product packages with linear barcode and two-dimensional symbols. It defines minimum requirements for identifying product packages that are distributed outside the originating location. It specifies label data content and requirements, including data element requirements; data representation; rules for encoding of mandatory and optional elements in machine-readable symbols; and human readable information.
ANSI MH10.8.7-2005	This standard establishes machine-readable (linear, two dimensional, and composite symbols) and human readable content for direct marking and labeling of items, parts, and components. This standard provides a means for items, parts and components to be marked and read in either fixtured or handheld scanning environments at any manufacturer's facility and then read by customers purchasing items for subsequent manufacturing operations or for final end use. Intended applications include, but are not limited to, supply chain applications, e.g., inventory, distribution, manufacturing, quality control, acquisition, transportation, supply, repair, and disposal. Location and application methods of marking are not defined herein.
ANSI MH10.8.8-2006	This standard provides guidance for the use of radio-frequency identification (RFID) for the handling and tracking of packages, parcels, and flat mail. The standard identifies minimum data requirements as well as semantic and syntactical recommendations. This standard further provides specific recommendations for the air interface communications of RFID devices based on the application requirements identified by the carriers.
EN and ISO standards	ISO 1496-1, ISO 1496-2, ISO 1496-3, ISO 1496-4, ISO 1496-5 EN 283, EN 284, EN 452, EN 12406, EN 12410, EN 12641-1, EN 12641-2, EN 13853, EN 14993

4.3 Emerging Research

This table shows the emerging research papers found according to the different data source, and the final inclusion regarding criteria defined in the previous sections:

Table 4-6 Research papers Search Results Summary

Database	Search Results	Included	Excluded	Exclusion criteria
Google Scholar	10+2+0	2	8	Not interconnection related
Science Direct	8	4	4	Duplicated, Not interconnection related
Elsevier's Scopus	27	6	21	Duplicated, Not interconnection related

After the search strategy, 48 primary studies where found. Without duplicates, a total of 28 potential primary studies where identified. When inclusion and exclusion criteria were applied, a list of 10 publications was created. The number of primary studies per stage is shown in the following Figure:

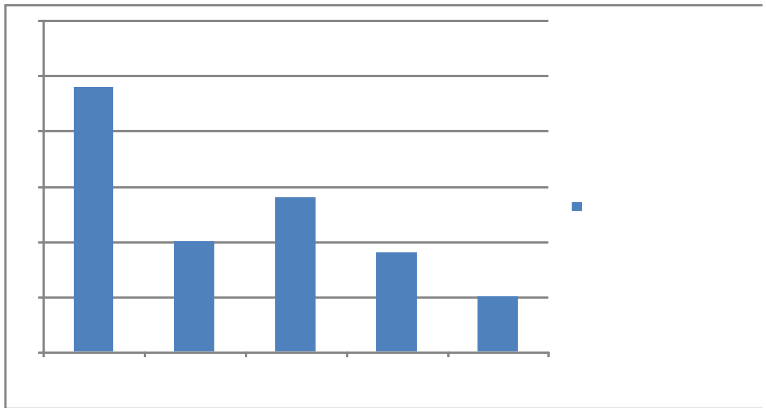


Figure 4-1 Summary of primary studies found and application of inclusion criteria

These are the emergent primary studies included in the review:

Table 4-7 Emergent Primary Studies Search Results Details

Title	Year	Authors	Journal / Conference
Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchromodal transport research	2018	Ambra, T., Caris, A. and Macharis, C.	International Journal of Production Research, pp. 1-18
A smart framework for the physical internet	2018	Mededjel, M., Belalem, G. and Neki, A.	ILS 2018 - Information Systems, Logistics and Supply Chain, Proceedings, pp. 181-190
Modelling and solution approaches for the interconnected city logistics	2017	Ben Mohamed, I., Klibi, W., Labarthe, O., Deschamps, J.-C. and Babai, M.	International Journal of Production Research. Vol. 55(9), pp. 2664-2684
Physical Internet and interconnected logistics services: research and applications	2017	Pan, S., Ballot, E., Huang, G. and Montreuil, B.	International Journal of Production Research. Vol. 55(9), pp. 2603-2609
A proposal for an open logistics interconnection reference model for a Physical Internet	2016	Colin, J.-Y., Mathieu, H. and Nakechbandi, M.	Proceedings of the 3rd IEEE International Conference on Logistics Operations Management, GOL 2016
Containers for the Physical Internet: requirements and engineering design related to FMCG logistics	2015	Landschützer, C., Ehrentraut, F. and Jodin, D.	Logistics Research. Vol. 8(1)
Modeling of Physical Internet Enabled Interconnected Modular Production	2015	Marcotte, S., Montreuil, B. and Coelho, L.	Proceedings of 2nd International Physical Internet Conference, Paris, France.
Proposition of a hybrid control architecture for the routing in a	2015	Saliez, Y., Berger, T., Bonte, T. and Trentesaux, D.	IFAC-PapersOnLine. Vol. 28(3), pp. 1978-1983

Physical Internet cross-docking hub			
Analogies between Internet network and logistics service networks: challenges involved in the interconnection	2014	Sarraj, R., Ballot, E., Pan, S. and Montreuil, B.	Journal of Intelligent Manufacturing. Vol. 25(6), pp. 1207-1219
Physical Internet foundations	2013	Montreuil, B., Meller, R. and Ballot, E.	Studies in Computational Intelligence. Vol. 472, pp. 151-166
An open logistics interconnection model for the physical internet	2012	Montreuil, B., Ballot, E. and Fontane, F.	IFAC Proceedings Volumes (IFAC-PapersOnline) Vol. 45(6 PART 1), pp. 327-332

The following Figures analyse the primary studies regarding publication year and author, where Ballot E. and Montreuil B. have the top number of papers with 4 and 5 respectively.

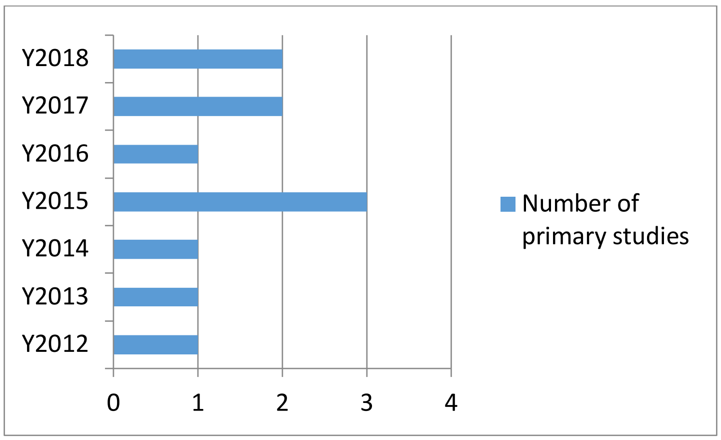


Figure 4-2 Summary of primary studies found per publication year

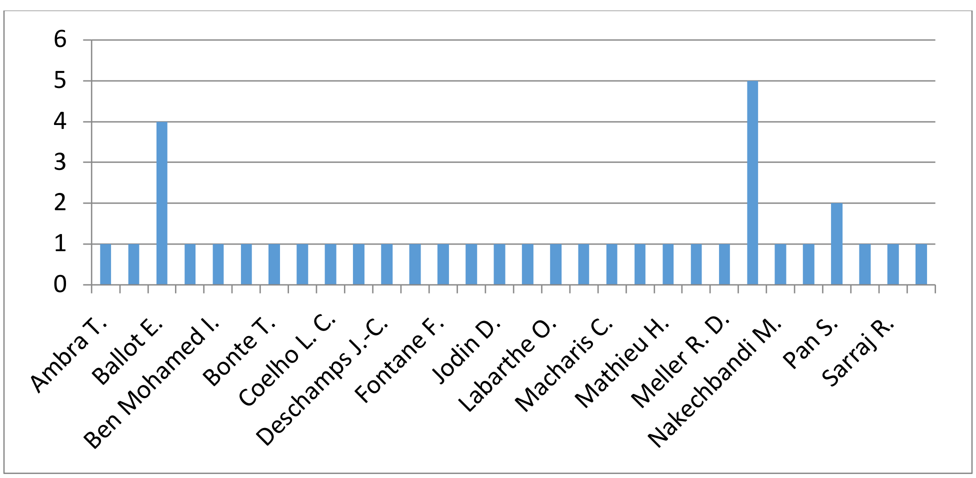


Figure 4-3 Summary of primary studies found per author

5 Analysis

This section analyses the search results regarding the identified Research Questions (RGs). The explanation of the discussion is structured according to the physical, digital and universal interconnectivity issues in the PI.

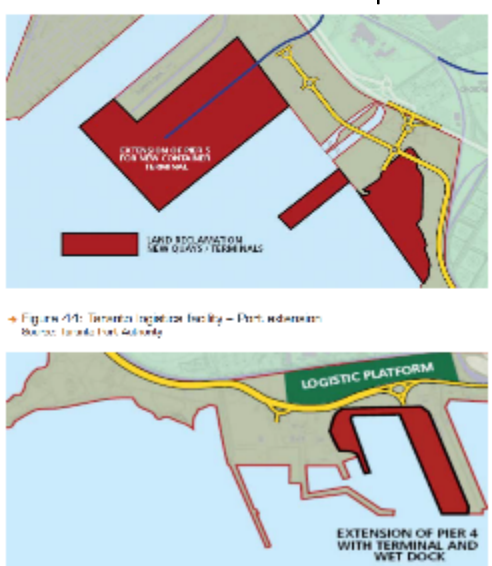
5.1 Physical Interconnectivity

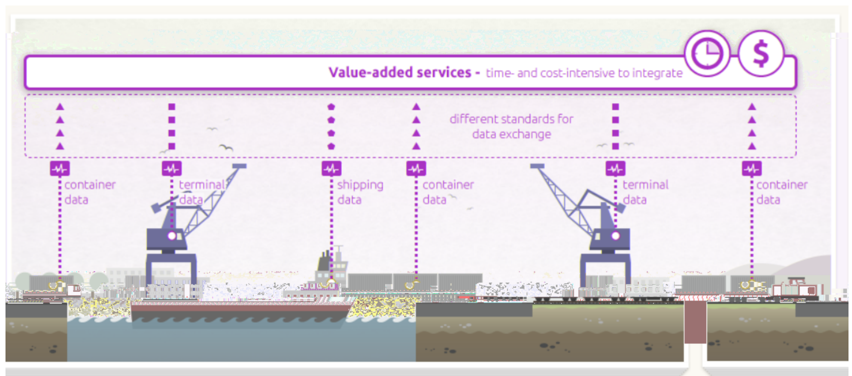
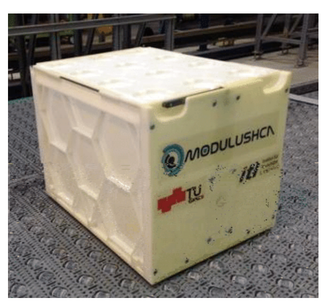
This section analyses the search results regarding Physical Interconnectivity problems, according to projects, standards and emerging research areas. Each subsection details the research done and conclusions and statements are exposed in the final subsection.

5.1.1 Projects

The following Table summarises the main contributions to take into consideration regarding physical interconnectivity:

Table 5-1 EU Projects Contributions to Physical Interconnectivity

Acronym	Contributions to Physical Interconnectivity
TIGER *Hubs and Nodes*	TIGER is the acronym of "Transit via Innovative Gateway concepts solving European - intermodal Rail needs". TIGER Project is a Large Scale Integrated Collaborative Project for the development of Rail transport in competitive and co-modal freight logistics chains. The WP2 conducts a survey on the logistic concepts for each demonstrator. It includes a comprehensive catalogue of the existing infrastructures, terminals, equipment, procedures and processes. New designs, production layouts and re-engineered solutions have been applied in order to arrive for each demonstrator at identifying the most effective and efficient solutions keeping into consideration both the geographical location, the natural barriers, the morphology of the territory and the operational constraints dictated by bottlenecks or other local Infrastructural impediments.  Figure 5-1 Notion of nodes/hubs and integration of logistics platform The WP3 aims at identifying for each demonstrator the necessary tools and means capable of fulfilling the desired objectives. These Tools and Means varied between Infrastructure investments, bottlenecks corrections and adaptations, ICT and intelligent management systems, signaling, production management and control, Logistics chain optimization processes, integrated systems implementation, different organizational layouts, systems

	re-engineering, new intermodal chains, new booking systems, new equipment, just to mention the most relevant signifying the variety of the applicative fields.
COMCIS *PI containers (data)*	COMCIS is a collaborative project between multiple transport and logistics actors that generates situational awareness along global supply chains in support of enhanced logistics services. COMCIS supplies business tools that can eliminate uncertainties and raise efficiency, especially when sensitive cargo is involved. COMCIS demonstrates “Collaborative Information Services for Container Management” and ensures that such services can be used in real-world operations. COMCIS provides three distinct generic value propositions: (1) Data consolidation (2) Data standardization and (3) Data aggregation.  Figure 5-2 COMCIS Value-added services
MODULUSHCA *PI Containers*	The objective of MODULUSHCA was to achieve the first genuine contribution to the development of interconnected logistics at the European level, in close coordination with North American partners and the international Physical Internet Initiative. The goal of the project was to enable operating with developed iso-modular logistics units of sizes adequate for real modal and co-modal flows of fast-moving consumer goods (FMCG), providing a basis for an interconnected logistics system for 2030. In the MODULUSHCA project, a first step towards modular boxes for the FMCG market has been made. This includes the assessment of requirements in surveys, decision for a material, optimisation of truck fill with the perfect sizes for the boxes and the actual development and manufacturing of the boxes.  Figure 5-3 Moduluscha boxes Work started with an analysis for defining an initial set of M-box exterior dimensions for the FMCG sector utilizing road-based transportation. The 0.8m x 1.2m x 2.4m M-box platform has been used as input into the next phase of the project that further defined the M-box. In particular, wall thickness dimensions have been determined to see what, if any impact, they should have on the initial M-box exterior dimension set presented here.

CO-GISTICS	CO-GISTICS is the first European project fully dedicated to the deployment of cooperative intelligent transport systems (C-ITS) focused on logistics. CO-GISTICS services are deployed in 7 European logistics hubs. CO-GISTICS is deploying the following 5 services: (1) Intelligent Truck Parking and Delivery Areas Management, (2) Cargo Transport Optimisation, (3) CO2 Footprint Monitoring and Estimation, (4) Priority and Speed Advice and (5) Eco-drive Support.
Smart-Rail *Asset Monitoring and predictability*	The SMART-RAIL project looks at the European rail freight system as a whole, integrating existing and new knowledge that originates from various parts of this system. This integrated knowledge will support collaborations across the European market so that systems can further innovate and optimize their operations. The objective of one of the demonstrators is to increase reliability of services, in the event of (un)planned disruptions on the network and to increase the visibility of rail freight transport in the supply chain. A logistic control tower for freight transport on multi -modal corridors including rail links realising more transparency about alternatives in the multimodal network has been developed. The term "Control Tower" is being used in many supply chain circles to describe an end-to-end holistic view of the supply chain and near real time information and decision making. The essence of the control tower concept is to provide supply chain visibility across divisions, countries and modalities. The heart of the control tower is an information hub supported by a set of detailed decision-making rules and a trained team of operators. The big advantage of this central information hub is that it gathers and integrates data from a variety of sources and subsequently distributes it in a consistent format. This integrated overview allows the control tower operator to detect risks or opportunities at an earlier stage.
MOBILITY4EU *Roles of Hubs*	The Mobility4EU Action Plan for Transport in Europe in 2013 details measures that address technical topics especially referring to societal aspects and issues for multi stakeholder interaction, as e.g. policy, user acceptance, standardization and collaboration. This Action Plan is structured around six main areas: (1) Low / Zero Emission Mobility, (2) Automation and connected transport, (3) Safety and (cyber)-security in transport, (4) Mobility planning, (5) Cross-modal / cross border transport, and, (6) Putting the user in the centre. The following recommendations are worth to mention in the context of ICONET project: • Define roles of hubs and warehouses in automated transport. • Bring stakeholders together to discuss requirements of hubs and modal interfaces of all sizes and support local + regional authorities in the planning of hubs. • Define main corridors to connect hubs and requirements to make them smart and sustainable. • Explore the organization of hubs for accommodating automation in seamless travel. • Publish the Inventory of Assets, a database of accessibility at hubs.
LOGIMATIC *Automation and Monitoring*	LOGIMATIC aims at implementing and validating an accurate localization and navigation system to automate the Straddle Carrier operations in an enhanced container chain management in port yards, thus increasing the efficiency of this type of operations, speeding up the tasks, enabling resource and space optimization and allowing operations at night. The core of the project is a cost-effective, real-time positioning system that primary relies on a combination of a multi-constellation GNSS receiver augmented by EGNOS and equipped with onboard [illegible]

	system for monitoring purposes and to exchange action plans and progress reports of their daily tasks. The following technologies will be tested and validated: - Novel hybrid positioning system: implement a tight integration of GNSS and multiple sensors to provide reliable real time location estimation to enable autonomous driving of straddle carriers in realistic scenarios. - Novel GNSS Cyber-Security Module: develop a software prototype able to evaluate the integrity of GNSS signals by exploiting ad-hoc algorithms and spoofing detection methods (e.g. received signal strength (RSS) monitoring) and predictable characteristics of the navigation signal. - Novel GIS-Based Yard Transport Logistics planning and monitoring system: improve the planning of straddle carrier movements within the yard and an overall monitoring of yard logistics (real-time scheduling and execution level). The validation plan includes a combination of certain System acceptance tests such as: - Different types of routes to be assigned and correctly followed by the straddle carrier (e.g. "L", "Z" "π", straight route etc.). - Automatic handling of different types of containers: 40 feet vs 20 feet. - Automatic handling of containers at different stacking height: e.g. Picking a container stacked on the ground or in the upper position (when stacking two-high) - Loading (picking) a container by the straddle carrier. - Unloading the container on the ground with specific precision. - Different combinations of the above. See video: https://youtu.be/W8696Npida0
DynaHUBS *Urban Logistics (parcels)*	DynaHUBs is a community-driven, door-to-door freight delivery platform where equals are serving each other. For the consortium, fetching and delivering is fun. It gives it a social status and strengthens our local community and friendships. Its business model provides a novel way of connecting routes and increases capacity for door-to-door cargo and freight logistics. DynaHUBs provides virtual meeting points that form a Physical Internet on the existing transportation infrastructure, enabling users to: • Switch between different modes of transport, • Cancel unnecessary journeys, • Shorten routes, and • Share capacity between vehicles, goods and people within the 'Physical Internet'. See video: https://www.youtube.com/watch?time_continue=44&v=J_YRE4OAsRU.
CLUSTERS 2.0 *Modular loading units (PI containers)*	The objective of Cluster 2.0 is to leverage the full potential of European Logistics Clusters for a sustainable, efficient and fully integrated transport system as defined by the ALICE roadmap. It has identified three living labs: (1) Proximity Terminal Network & Cluster Community System, (2) Symbiotic Network of Logistics Clusters and (3) Innovative Cluster Handling Technology. The ambition of the third Living Lab is to prove the use of New Modal Load Units (NMLU's) in the supply chain efficiency based on standard fixed size flexible load units capable of supporting modal shift and micro hub distribution. NMLU prototypes will be designed and developed, as well as handling technology. It is an objective to develop modular load unit container prototypes which must fill optimally a 13,6m trailer and a row of modular load units must also fit to the 20, 40 or 45 feet container dimensions, which will be authorized and homologated to be used for both road and rail transportation. Once developed and homologated, these modular intermodal container prototypes will be tested in real business environment. The test will consist on:

<table>
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loading modular intermodal container prototypes within a live warehousing environment,
shipping the modular intermodal container prototype from the warehouse to an intermodal terminal,
transferring the modular intermodal container prototype to a train using the Innovatrain terminal concept,
transporting the modular intermodal container prototype by rail, and
transferring the modular intermodal container prototype back from the train to the truck.

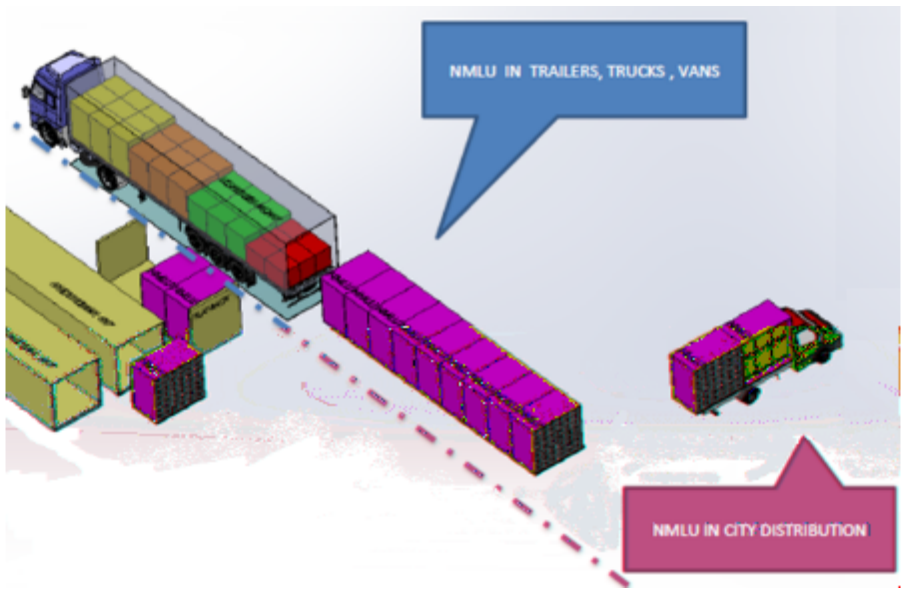
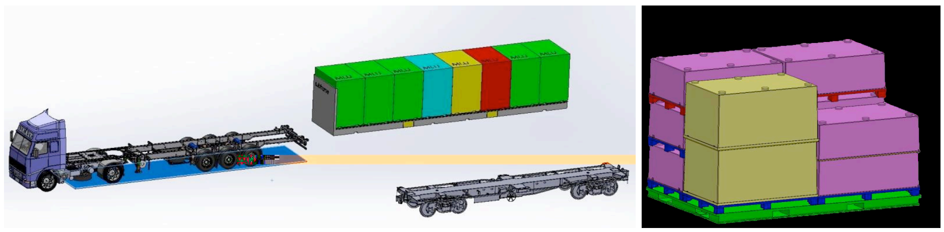


Figure 5-4 NMLU concept in Clusters 2.0

n this first period of the project, the NMLU concept has been developed and the 4 scenarios are detailed, describing several use cases for each of them:

Warehousing: The part will be executed at the P&G warehouse of Crailsheim (DE) for modular intermodal container prototype loading, the Innovatrain terminal in Oesingen (CH) for modular intermodal container prototype transfer and the road leg between Crailsheim and Oesingen.
Intermodal transportation (truck and train): (A) Intermodal Truck / Train transport. JDR has a intermodal control center at Venlo. This is also a cross dock location where LTL freight is being combined into FCL freight. From this location daily truck transport to the rail terminal in Venlo are being carried out. From the rail terminal Venlo TX Logistik operates and controls the train to Milano. (B) Intermodal transfer between truck and train. INNOVA will test the modal transfer from truck to train and backwards.
City distribution: (A) Truck with bundled NMLU’s can be used in two ways; Truck carries out transportation. Truck uses smart loading and unloading zone and metamorphizes to distribution point for city distribution with cargobikes (B) Test the function as an independent ‘micro hub’ incorporated in activities of urban distribution.
Airport distribution: Additionally, the LL will be executed in Brussels airport terminal, where WFS and DHL can ship NMLU units to CityDepot for city distribution testing.

</td></tr>
<tr><td>AEROFLEX</td><td>The AEROFLEX project aims to develop and demonstrate new technologies, concepts and architectures for complete vehicles that are energy efficient, safe, comfortable,</td></tr>
</table>

Smart modular loading units	configurable and cost-effective, while ensuring that the varying needs of customers are satisfied by being flexible and adaptable with respect to the continuously changing operational conditions. The objective of WP4 on Smart Loading Units is to investigate the potential to improve transport efficiency by flexible solutions for load optimization and load efficiency of vehicle combinations, considering the use of single trucks, tractor and semitrailer combinations (16.5 m), and truck, dolly and semitrailer combinations (25.25 m). The WP aims to develop and design solutions for prioritized transport segments where transport flows are considerable and where the impact of efficiency improvements is high. One of the identified use cases is focusing on the possibility to demonstrate a multimodal use case based on the first results of Clusters 2.0.  Figure 5-5 AEROFLEX Smart Modular Loading Units The idea is to create a sub-container, the NMLU that can be fixed on a subframe that has the same interfaces and outer dimensions as a 45-ft container. This subframe can be taken from or placed on a train in one transshipment movement. The subframe can also be placed on a standard container chassis. The basic idea is that companies who do not have the volume to fill a wagon load, but need a long distance shipment, combine their NMLU's in one shipment. The trailer with subframe makes a milkrun along the contributing pick up points. The NMLU's can be loaded and unloaded automatically on the subframe. The trailer drives to the port and the complete subframe with NMLU's is craned on the train.

5.1.2 PI Boxes: standards

I

Different packaging materials are used for different packaging purposes. There are basically three (3) levels of packaging: primary, secondary and tertiary (see figure 5.1 for examples). Primary packaging is critical for branding and protection on the shelves. Secondary packaging is critical for protection and branding during transit. All these packaging might be considered as a PI-container in the context of the Physical Internet.

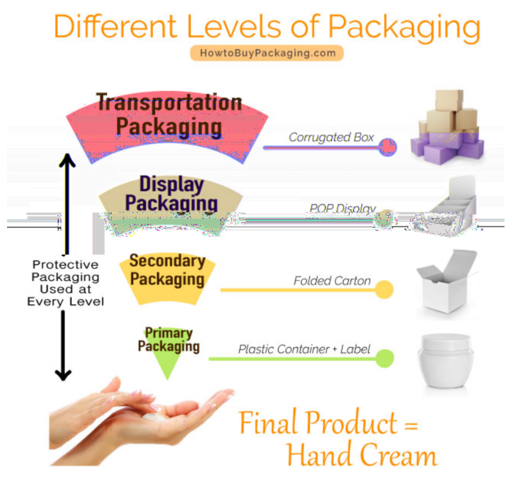


Figure 5-6 Levels of packaging

- Primary packaging at manufacturer:
    - The packaging that most closely touches a product, often referred to as "retail packaging."
    - Its main goals are to protect the product and inform or attract a customer.
    - What's considered to be primary packaging depends on the product. For example, a pop can is primary packaging (because it's the primary way to carry around soda), while a corrugated box containing a camera and its accessories is also primary packaging (because it's the primary way to purchase it).
- Secondary packaging (cartons, crates, nestable boxes, GS1 box):
    - The packaging used to ship products already in primary packaging.
    - Its main goals are to protect products and provide branding during shipping.
    - It's also used as display packaging in retail locations such as grocery stores.
    - Examples of secondary packaging include 12-packs of soda cans, the corrugated box that a half-dozen camera boxes ship in, and the display stand for a newly-released Blu-Ray movie.
- Tertiary Packaging (pallets, roll containers):
    - The packaging used most often by warehouses to ship secondary packaging.
    - Its mail goal is to properly protect shipments during their time in transit.
    - Tertiary packaging is typically not seen by consumers.
    - Examples include the pallets that bulk shipments are placed on, corrugated pads used to separate layers of boxes and stretch wrap used to secure stacks of cartons.

A quaternary packaging is used to facilitate the loading/unloading of tertiary packages to/from ships, trains and trucks. This category covers all types of intermodal loading units (containers, swap bodies, road units such as semi-trailers and road trains).

P

Primary packaging is the material in direct contact with the product contents whereas secondary and tertiary packaging are used to protect, group, handle, store and ship the primary packages.

Primary packaging solutions should emphasize both utility and appearance. Utility is important because if the packaging is defective, it may directly impact the end user's ability to use the product. In the case of food products, users will almost always be forced to throw away product with defective primary packaging. In the case of non-perishable products, defective primary packaging can still result in lost or damaged product, affecting the user's ability to utilize the product.

Aside from protecting your product until it reaches the end user, primary packaging can serve another very important role. It is a key location for placing company's logo, slogan, and other information that will help identify and distinguish your brand. Marketing by using the primary packaging as a place to display this information is both commonplace and extremely effective: consider the efforts of soda manufacturers. It is commonplace to see not only the product's brand, but promotional materials for other products printed on soda cans. By utilizing all space where a consumer's eye is sure to fail, soda manufacturers have tapped into a lucrative marketing opportunity by using primary packaging as a billboard.

Primary packaging is subject for some specific categories of products to strict rules and requirements as for example for pharmaceutical products or foods transported in special packaging such as bottles, cans or jars (see list of ISO standards https://www.iso.org/ics/55/x/). In terms of physical dimensions, EN and ISO standards may impose measurements in terms of overall height, width and length and the permissible quantity of substances for the standardised packaging.

In any case (with or without standards), the primary packaging will strongly influence the design of the secondary packaging, that might be also standardizes depending on the types of primary packaging. One packaging that fits all purposes will never been possible.

S

Cartons

Both folding carton and corrugated are widely used in the packaging world and visible every day in the retail aisles. Folding carton is made out of paperboard that is printed, laminated, cut, folded and glued. Corrugated is made from two outer linerboard sheets with a fluted sheet (the familiar squiggle) sandwiched between. It comes in many thicknesses and styles. Corrugated packaging offers structural support to products that are heavy or unevenly distributed within the box.

Figure 5-7 Types of cartons

The European Federation of Corrugated Board Manufacturers (FEFCO) is a non-profit organisation representing the interests of the industry across Europe and addressing a wide range of issues, from technical topics to economical questions. It regroups twenty-four (24 the customer and the supplier, regardless of language and other differences. The FEFCO code is adopted for worldwide use by the International Corrugated Case Association (ICCA).

The following list provides the most common outer dimensions (length x width x height) of folding cartons:

- 150x150x80 mm,
- 190x150x140 mm,
- 200x150x90 mm,
- 240x130x130 mm,
- 250x175x100 mm,
- 250x200x140 mm,
- 260x170x120 mm,
- 300x200x200 mm,
- 300x215x140 mm,
- 300x200x100 mm,
- 300x200x150 mm.

Crates

A crate is a large container that helps to store and move the items together. These are made of plastic y & wood generally, but crates are also made up of steel and aluminum. Plastic Crates are tough and durable but wooden crates are customized as per the item dimension. These are used to transport or store large, items with different volume. Steel & aluminum crates are made for a particular purpose. Plastic Crates are most saleable and can also be customized often like milk crates, crates for carrying cold drinks etc. Crates can be stacked and/or folded.

Figure 5-8 Types of crates

Some standards for specific wood and plastic crates have been developed by the sector but no ISO or EN standard has been developed so far. Figure xx provides examples of possible dimensions for plastic crates (food).

Figure 5-9 Possible dimensions for nestable plastic crates

T

Pallets

Wooden pallets typically consist of three or four stringers that support several deck boards, on top of which goods are placed. In a pallet measurement the first number is the stringer length and the second is the deck board length. Square or nearly square pallets help a load resist tipping. Two-way pallets are designed to be lifted by the deck boards. The standard North American pallet, or GMA pallet, has stringers of 48 inches and deck boards of 40 inches. Four-way pallets, or pallets for heavy loads (or general-purpose systems that might have heavy loads) are best lifted by their more rigid stringers. These pallets are usually heavier, bigger and more durable than two-way pallets. Pallet users want pallets to easily pass through buildings, to stack and fit in racks, to be accessible to forklifts and pallet jacks and to function in automated warehouses. To avoid shipping air, pallets should also pack tightly inside intermodal containers and vans.

No universally accepted standards for pallet dimensions exist. Companies and organizations utilize hundreds of different pallet sizes around the globe. While no single dimensional standard governs pallet production, a few different sizes are widely used.

ISO pallets

Dimensions (W × L) millimetres	Dimensions (W × L) inches	Wasted floor, ISO container	Region most used in
1016 × 1219	40.00 × 48.00	3.7% (20 pallets in 40 ft ISO)	North America
1000 × 1200	39.37 × 47.24	6.7%	Europe, Asia; similar to 40" × 48".
1165 × 1165	45.9 × 45.9	8.1%	Australia
1067 × 1067	42.00 × 42.00	11.5%	North America, Europe, Asia
1100 × 1100	43.30 × 43.30	14%	Asia
800 × 1200	31.50 × 47.24	15.2%	Europe; fits many doorways

Figure 5-10 ISO Pallets (dimensions)

European pallets

The EUR-pallet - Euro-pallet or EPAL-pallet - must use at least 78 nails of a specific type that are subject to a prescribed nailing pattern. The final pallet weighs 20 to 25 kg. Only dry wood may be used, to reduce the risk of mold.

EUR-pallet type	Dimensions (W × L)		ISO pallet alternative
EUR, EUR 1	800 mm × 1,200 mm	31.50 in × 47.24 in	ISO1, same size as EUR
EUR 2	1,200 mm × 1,000 mm	47.24 in × 39.37 in	ISO2
EUR 3	1,000 mm × 1,200 mm	39.37 in × 47.24 in	
EUR 6	800 mm × 600 mm	31.50 in × 23.62 in	ISO0, half the size of EUR

Figure 5-11 EUR pallets (dimensions)

Each EUR-pallet bears a number of quality marks:

- On the left corner leg the EPAL logo is shown. Originally this was used for the railway company designation that was eligible to control the Euro-pallet production. Since the control was moved to the EPAL, many framework agreements require the EPAL logo.
- On the central leg the code of the producer company is shown along with the signature of the verifier and the name of the railway company that installed the verifier. If the EUR-pallet has been repaired already, then a round verification nail is put in the central chunk. The last numbers designate the production year and possibly the type of wood.
- On the right corner leg the EUR logo is shown. The EPAL and EUR logos are encircled in an oval that resembles the nationality sticker for cars.

Figure 17 provides illustration of the most used pallets for the transport of packed primary goods in quaternary containers (described in in chapter 5.2.1.5).

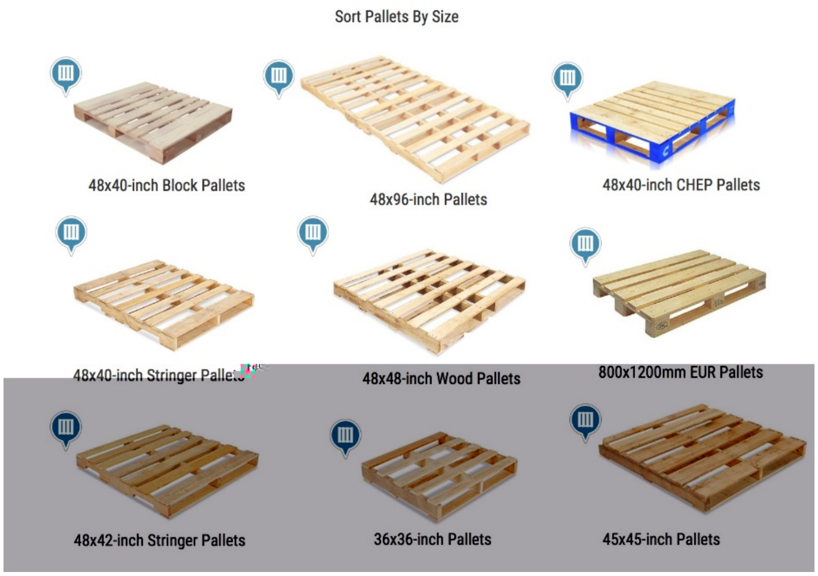


Figure 5-12 Types of pallets (examples)

Post Pallets

Post pallets are fully welded steel constructions, ideal for use in warehouses. They are extensively used a lot in automotive and are made out of a steel base pallet with 4 posts.

There are 7 different sizes available for this product:

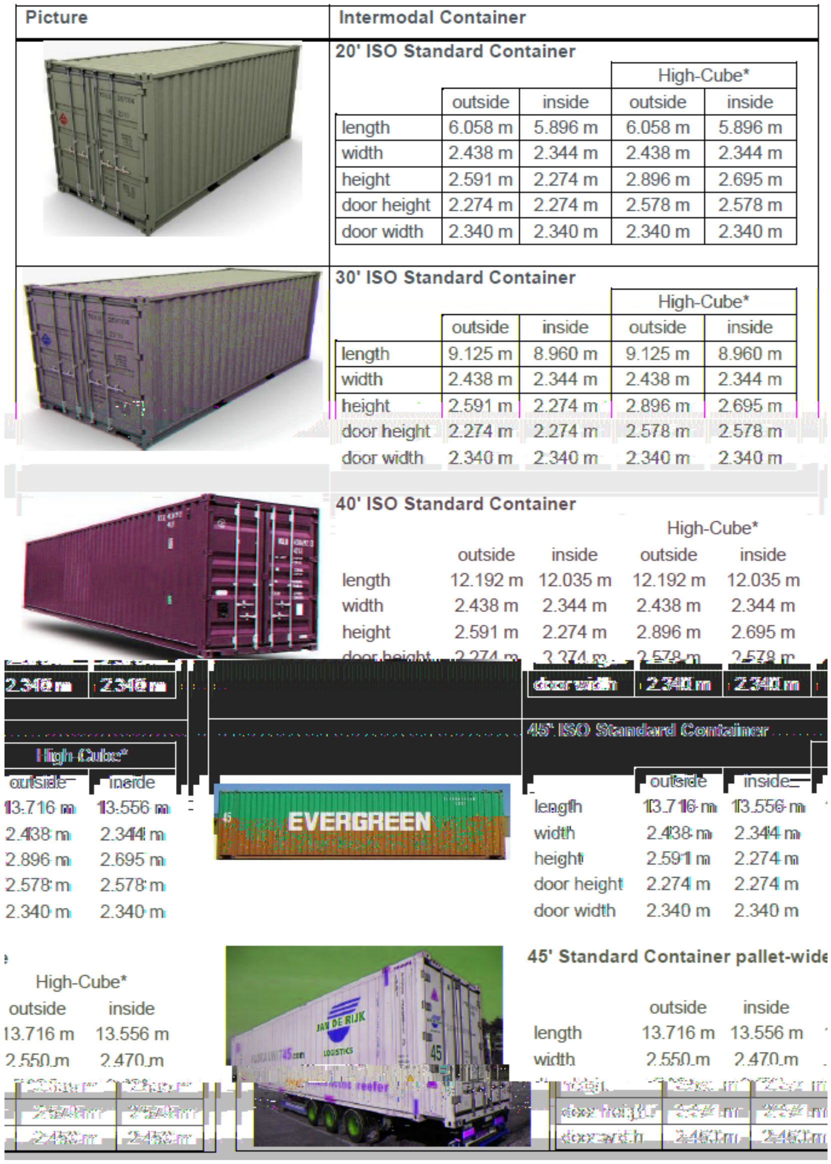
- 610mm Wide x 610mm Deep x 455mm High (PP1)
- 915mm Wide x 610mm Deep x 455mm High (PP2)
- 915mm Wide x 610mm Deep x 610mm High (PP3)
- 915mm Wide x 915mm Deep x 610mm High (PP4)
- 915mm Wide x 915mm Deep x 760mm High (PP5)
- 1220mm Wide x 915mm Deep x 610mm High (PP6)
- 1220mm Wide x 915mm Deep x 760mm High (PP7)

Figure 5-13 Post pallets

Q

ISO Standard Containers

An intermodal container is a large standardized shipping container, designed and built for intermodal freight transport, meaning these containers can be used across different modes of transport – from ship to rail to truck – without unloading and reloading their cargo. Intermodal containers are primarily used to store and transport materials and products efficiently and securely in the global containerized intermodal freight transport system, but smaller numbers are in regional use as well. These containers are known under a number of names, such as simply container, cargo or freight container, ISO container, shipping, sea or ocean container.



Picture	Intermodal Container				
	20' ISO Standard Container				
				High-Cube*	
		outside	inside	outside	inside
	length	6.058 m	5.896 m	6.058 m	5.896 m
	width	2.438 m	2.344 m	2.438 m	2.344 m
	height	2.591 m	2.274 m	2.896 m	2.695 m
	door height	2.274 m	2.274 m	2.578 m	2.578 m
	door width	2.340 m	2.340 m	2.340 m	2.340 m
	30' ISO Standard Container				
				High-Cube*	
		outside	inside	outside	inside
	length	9.125 m	8.960 m	9.125 m	8.960 m
	width	2.438 m	2.344 m	2.438 m	2.344 m
	height	2.591 m	2.274 m	2.896 m	2.695 m
	door height	2.274 m	2.274 m	2.578 m	2.578 m
	door width	2.340 m	2.340 m	2.340 m	2.340 m
	40' ISO Standard Container				
				High-Cube*	
		outside	inside	outside	inside
	length	12.192 m	12.035 m	12.192 m	12.035 m
	width	2.438 m	2.344 m	2.438 m	2.344 m
	height	2.591 m	2.274 m	2.896 m	2.695 m
	door height	2.274 m	2.274 m	2.578 m	2.578 m
	door width	2.340 m	2.340 m	2.340 m	2.340 m
	45' ISO Standard Container				
				High-Cube*	
		outside	inside	outside	inside
	length	13.716 m	13.556 m	13.716 m	13.556 m
	width	2.438 m	2.344 m	2.438 m	2.344 m
	height	2.591 m	2.274 m	2.896 m	2.695 m
	door height	2.274 m	2.274 m	2.578 m	2.578 m
	door width	2.340 m	2.340 m	2.340 m	2.340 m
	45' Standard Container pallet-wide				
				High-Cube*	
		outside	inside	outside	inside
	length	13.716 m	13.556 m	13.716 m	13.556 m
	width	2.550 m	2.470 m	2.550 m	2.470 m
	height	[illegible]	[illegible]	[illegible]	[illegible]
	door height	[illegible]	[illegible]	[illegible]	[illegible]
	door width	[illegible]	[illegible]	[illegible]	[illegible]

Figure 5-14 ISO Containers (dimensions)

Intermodal containers exist in many types and a number of standardized sizes, but ninety percent (90%) of the global container fleet are so-called "dry freight" or "general purpose" containers, durable closed steel boxes, mostly of either twenty or forty foot (6 or 12m) standard length. The common heights are 8 feet 6 inches (2.6 m) and 9 feet 6 inches (2.9 m) – the latter are known as High Cube or Hi-Cube containers.

Swap bodies

A swap body is one of the standard freight containers for road and rail transport. This container type may also be called exchangeable container or interchangeable unit. Swap bodies take advantage of the large number of trailers used to carry standard ISO containers. The design of swap bodies and roller container is optimized to minimize empty weight, saving on trucking fuel cost (less dead weight to be transported), and cost of built of reloading terminals.

Picture	Description		
	EU SWAP BODYS		
	**C745 Swap Body steel / curtain side / max 18 Europallets**		
		outside	inside
	length	7.450 m	7.300 m
	width	2.550 m	2.470 m
	height	2.750 m	2.525 m
	door height	2.500 m	2.500 m
	door width	2.440 m	2.440 m
	**C745 Swap Body "cool-chain" / max 17 Europallets**		
		outside	inside
	length	7.450 m	7.240 m
	width	2.600 m	2.490 m
	height	2.740 m	2.400 m
	door height	2.550 m	2.550 m
	door width	2.490 m	2.490 m
	**C782 Swap Body steel / curtain side / max 18 Europallets**		
		outside	inside
	length	7.820 m	7.670 m
	width	2.550 m	2.470 m
	height	2.750 m	2.525 m
	door height	2.500 m	2.500 m
	door width	2.440 m	2.440 m
	**A1370 - 45' Swap body (pallet wide) / max 34 Europallets**		
		outside	inside
	length	13.716 m	13.620 m
	width	2.550 m	2.470 m
	height	2.725 m	2.550 m
	door height	2.475 m	2.475 m
	door width	2.460 m	2.460 m

Figure 5-15 Dimensions of swap-bodies

As a consequence, swap bodies do not have upper corner fittings, are generally not stackable, and must be lifted by the bottom frame. Swap bodies normally have the same external dimensions for the bottom corner fittings as ISO shipping containers, so that they can be placed on the same kinds of trucks, trailers and railroad cars designed for shipping containers. However, to optimize the carriage of pallets, wide bodies are often scaled to the maximum width allowed for standard road trucks and railroad cars and to a different length accommodating a quantity of European-pool pallets (0.8 m × 1.2 m or 31.5 in × 47.2 in) without leaving empty space.

Basic standardization is set with EN 283, EN 284 and EN 452 for construction and design, as well as EN 13044 for marking and identification. The panel responsible for developing standards is CEN/TC 119. The outcome of this panel has not yet provided any contribution to automation, as handling the swap bodies is a traditional haulage business with truck drivers involved.

5.1.3 PI Nodes / Hubs

I *E*

Terminals play an important role in European Intermodal Transport. In the first place, they serve as the transhipment point between at least two different transport modes and goods are consolidated in terminals for the further distribution. But terminals often fulfil further important features for the (combined) transport services like warehousing, cleaning of loading units or packaging of goods. For the development of new loading units (such as PI containers), it is also important to consider the different type of terminals and the requirements of the relevant stakeholders.

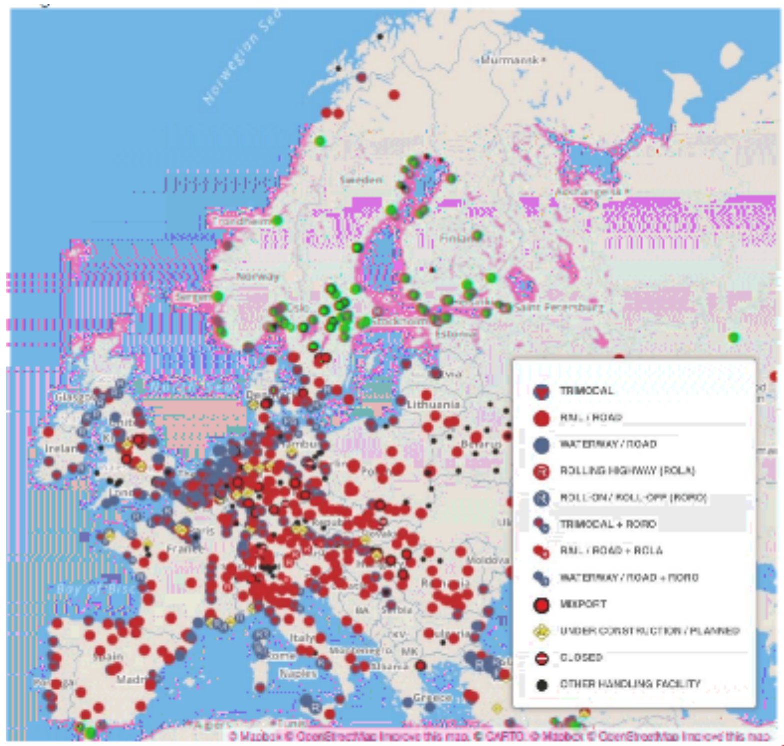


Figure 5-16 Map of terminals/hubs in Europe

Terminals for the combined transport can be classified according to the amount of connected transport modes and the type of transport mode. There are bimodal terminals which combine two different transport modes like rail/road or inland waterway/road and trimodal terminals, which combine the three transport modes road, rail and inland waterway. Figure 5-15 shows the availability of the different type of public accessible combined transport terminals in Europe. There are also private terminals owned by large transport service providers where the access for other companies is restricted. Today, there are over 1,000 hubs/terminals, but the availability varies geographically. The terminal density is high especially in Germany and the Benelux countries because of its central European position and their proximity to the deep-sea ports for intercontinental and hinterland transport.

According to European legislation[6], the operators of railway-related hubs must publish static and dynamic data on their service facilities. A European initiative started to develop a common European solution to collect on one single interface all facilities' information (www.railfacilitiesportal.eu).The categorisation of a hub can be defined according to the following principles:

- They can be divided in technologies for loading units which are suitable for crane-handling and those, which are not suitable for crane-handling. The technologies can further be divided into terminal based and or waggon-based technologies. Figure 22 illustrates all possible options.

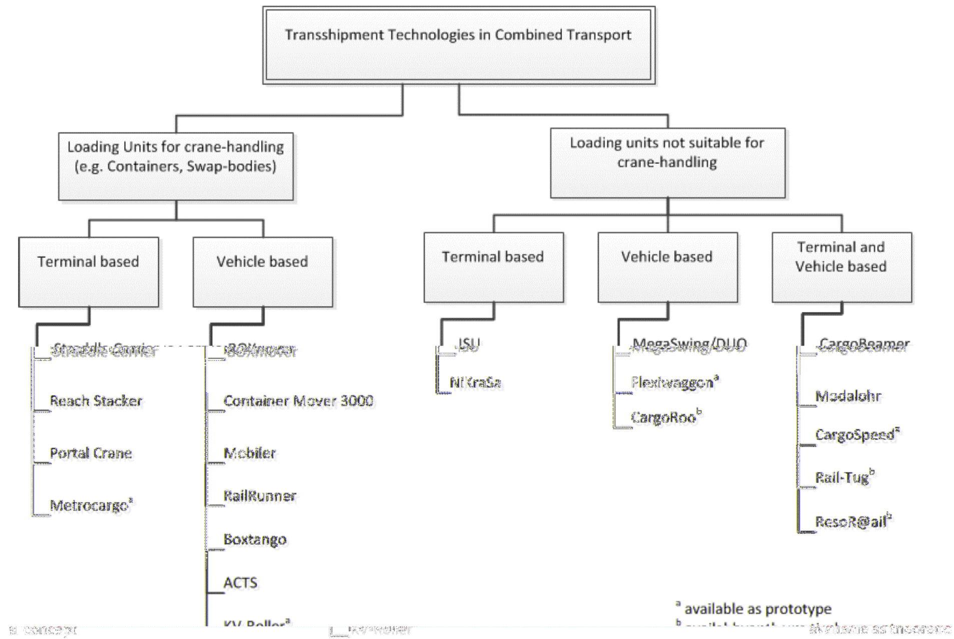


Figure 5-17 Types of terminals (by technologies)

- The terminals/hubs can be split according to their geographic location services and functions in the supply chain: (1) sea port as directly located at the sea or a river with mainly maritime logistics services (2) dry port as terminal located near the coast and connected with a sea port via road/rail/inland waterway mainly for consolidation and distribution services, (3) inland terminals with tail, road and inland waterway connection for continental logistics services and (4) freight centres, located near the first three categories, providing complementary logistics services (warehousing, maintenance, repair work). Figure 23 represent the possible interactions between all types of inland services and their possible functions and services.

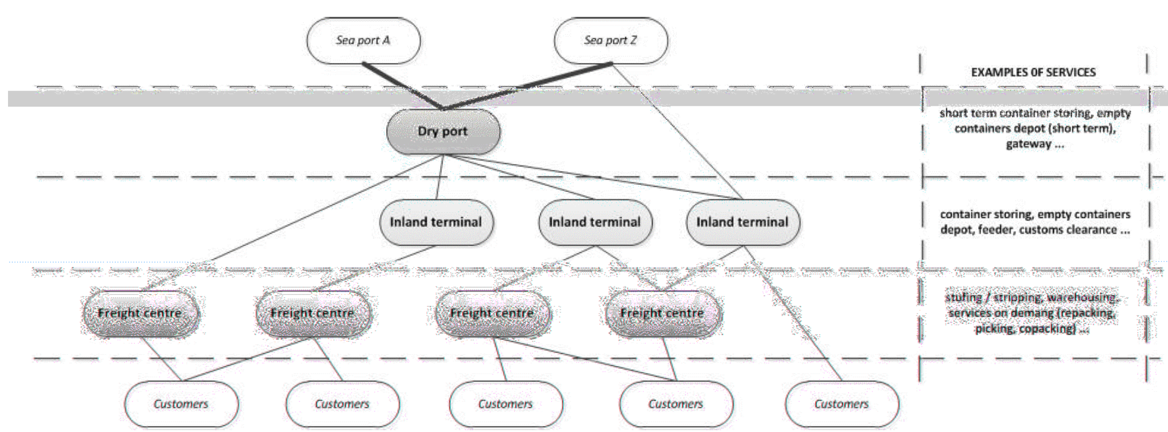


Figure 5-18 Types of inland terminals (by function)

The following chapter will integrate those identified elements into the context of a PI hub in intermodal transport, in particular for the Road-Rail combination.

H *PI*

Introduction

The central idea of the Physical Internet is the interconnection of networks, which leads to a network of networks. But the means of this interconnection need to be defined. The Physical Internet is a global logistics system based on the interconnection of logistics networks by a standardized set of collaboration protocols, modular containers and smart interfaces for increased efficiency and sustainability The Physical Internet imposes more unloading/reloading work for transhipment through the hubs (the physical routers) so as to benefit from shipments of small-size π-containers.

PI hubs are a central pillar of the future PI. PI Hubs act as nodes where π--containers switch from one logistics service to another. Hubs act as gateways between two logistics networks, change of transport mode and change of vehicle (transloading/transhipping). This section of the report covers the following aspects: (1) localisation and functions of the PI hubs, (2) a road-rail hub towards a new approach to multimodality, (3) a framework for inbound and outbound logistics activities in a logistics hubs, (4) the possible design of a PI hub, and, (5) catalogue of technologies that can support receiving, storing an picking PI containers in a PI hub.

Localisation; types and functions of hubs

The efficiency of hubs designed especially for PI-containers of various sizes is therefore of major importance to the performance of the entire system. This efficiency is determined at several levels, notably in the routing algorithms that shall group the flows on their best routes whilst saturating the means of transportation and complying with lead-times. It is also determined in the actual realization of hubs of various scales specifically designed for crossdocking PI-containers of various ranges of sizes. Although in the case of shipping containers, the twist-lock has established itself as the means of locking them when anchoring them to the floor and when stacking them, there is presently no widespread solution for units of intermediate sizes or for containers of small sizes. These mechanisms and their efficacy will be crucial to the different necessary hubs.

In the digital world, an Internet router has little in common with the router found between two large autonomous systems, each operated by an access supplier, or at the entry of submarine cables. In the same manner, according to the size of π -containers accepted, the modes of transportation at play and even the level of traffic, technological solutions that are doubtless very different need to be envisaged. On an urban level, the π - container sizes will mostly be small. However, when it is a case of using maritime, rail or waterway corridors, only π-containers in the large size category will be present. The interfaces between the modes of transportation will also require specific hubs to interconnect their mode-specific features.

Hub types	Ship	Train	Barge	Aircraft	Truck	Light vehicle	Manual*
Ship	L: ✓ M: S:	L: ✓ M: S:	L: ✓ M: S:	∅	L: ✓ M: ✓ S:	∅	∅
Train		L: ✓ M: S:	L: ✓ M: S:	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	∅
Barge			L: ✓ M: S:	∅	L: ✓ M: ✓ S:	L: ✓ M: ✓ S:	∅
Aircraft				L: M: ✓ S: ✓	L: M: ✓ S: ✓	L: M: ✓ S: ✓	L: M: S: ✓
Truck					L: ✓ M: ✓ S: ✓	L: ✓ M: ✓ S: ✓	L: ✓ M: ✓ S: ✓
Light vehicle						L: ✓ M: ✓ S: ✓	L: M: ✓ S: ✓
Manual*							L: M: S: ✓

*** Manual = on foot, bike, etc.**

Legend: (L = PI-container of cross-section compatible with heavy means of transportation, M = PI-container of around 1 m3, S = small PI-container/box).

Figure 5-19 Types of hubs required between modes

Based on Figure 5-18, twenty two (22) types of unimodal and bimodal hubs would be needed, without counting the additional differences linked to the scale of the traffic that would affect the design, or the different possible technologies, hence a hub of the type aircraft/train is not supposed to process isolated small PI-containers (size S) and could be designed accordingly. But a hub of the truck/light vehicle type should be able to process any size of π-containers etc. Based on this representation, it is possible to construct trimodal hubs, etc.

A road-rail hub towards a new approach to multimodality

There are already multimodal platforms designed to transfer current large containers between road and rail. However, their organization has essentially been designed according to the constraints of the rail mode and not those of the goods flows. The goods are therefore handled on dead end sidings which require numerous long and costly traction operations. The road/rail hub proposed herein, groups both the functions of cross-docking between rail and road and between trains, thus removing the need to transit through sorting centres which generate lead times and hazards, not to mention their real estate footprint.

In general, a smart automated road/rail system for freight transportation reduces human interventions and limits unloading/reloading, errors, transfers, etc. Just as the Digital Internet has enabled a large number of day-to-day information search processes to be accelerated, the Physical Internet seeks to do the same in the field of freight transportation by automating as many handling operations as possible and improving the interoperability of systems (transportation systems, sorting and routing systems, etc.). In this part, we are going to present an important component of the Physical Internet, an example of a road/rail hub, which is a flow router just as a TCP/IP router is for the Digital Internet.

We will put forward a hub concept for trains and semi-trailers, one version of which will be illustrated and whose performances will be assessed for different configurations. The underlying idea is that, in spite of the additional cost and complexity induced by the unloading/reloading, the resulting benefits in terms of overall efficiency of the system and service potential will outstrip this additional cost.

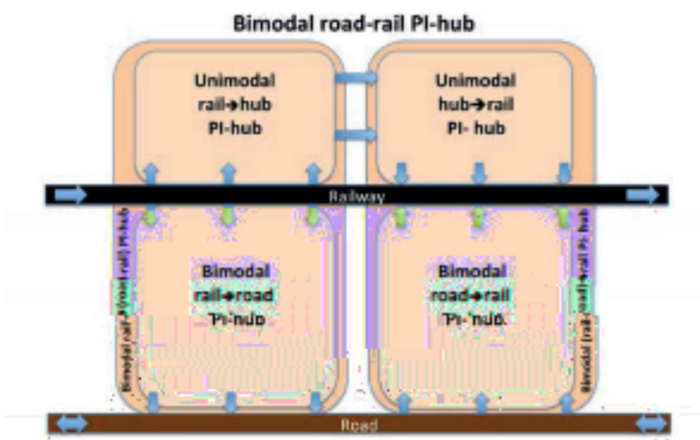


Figure 5-20 Simplified conceptual mode of road-rail PI Hub

One of the difficulties of sorting operations between rail tracks, not to mention the addition of a road exits, is the necessary crossing of "heavy" flows. This difficulty is overcome in different manners according to the sorting technologies, but what they all have in common, is starting from the principle of sorting on several tracks as at all times there is a bijection between the origin or destination and one track.

The research conducted in this field e.g. (Ballot, Montreuil, & Meller, 2014) and (Ballot, Montreuil, & Thivierge, 2012) shows both the complexity of the railcar sorting operations and the necessity of awaiting a critical size for it to be beneficial to transit via a sorting centre, which is a significant brake to adopting these technologies.

To overcome these limits, the concept presented herein, is organized around a single track and splitting the PI-hub's operations into four functional zones. In this scenario, a train is handled sequentially with at least one unloading, movement and then loading sequence, or several linked sequences, each handling just a fraction of the train. As shown in Figure 5-9, this hub is organized around a bimodal road/rail zone, a bimodal railroad zone, a unimodal post-rail zone and a unimodal pre-rail zone. These last two zones are intended for implementing container rail transfers. The bimodal and unimodal zones are arranged on either side of the rail track.

The two upper zones are intra-rail zones and the two lower zones are interfaces between road and rail. A train entering the hub first arrives at the left zone which is an unloading zone for intra-rail in the upper part and towards the road in the lower part. After moving along one zone, the train arrives at the reloading zone, either from the road in the lower half or from the rail in the upper half.

We note at this stage that there is no road-road flow on the diagram represented as it is not planned at the stage in this hub, but this unimodal flow could easily be added. The size of the zones handled simultaneously can be adjusted to deal with the growth in traffic, between dealing with one container and concurrently dealing with all containers on a train. This functional description can be implemented in different manners, from a single stacker to automated transshipment facilities.

A framework for inbound and outbound logistics activities in a logistics hub

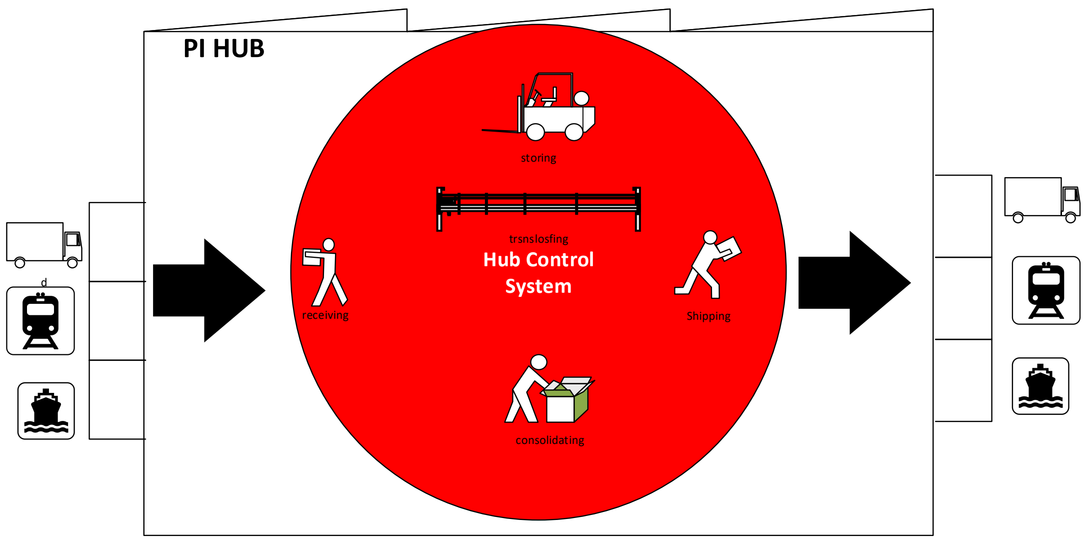


Figure 5-21 Overview of activities in a logistics PI Hub

Figure 5-20 provides a schematic overview of the inbound and outbound activities in a logistics PI Hub. According to this Figure, incoming π- containers are first identified and then directed to the correct processing pipeline depending on their type, contents and destination. Several activities are performed on the containers according to their characteristics and to the current status of PI. Π-containers may, for example, be put in temporary storage if their outbound transport is not going to take place within a certain time. π-containers may be undergone other consolidation activities, where smaller containers with the same destination are combined to match the transport capacities of the transport units. Stored containers need to be retrieved and moved to a particular area for outbound delivery.

In some cases, this activity consists of transshipment/transloading where containers are moved from an incoming transport vehicle directly to an outgoing one. Containers that have been temporarily put away are retrieved when required, by warehouse picking activities. Larger containers stored outdoors (i.e. in a container yard) need to be located and transferred to the hub operations area. In both cases, handling equipment such as forklift trucks, cranes or other loading/unloading equipment is used. Such equipment has to be compatible with the transport units used (e.g. trailers, rail wagons, etc.) and type of cargo. All handling activities will require certain levels of human input; however, increasingly replaced by robotic and other types of automation systems.

A new concept illustrated in Figure 5-21 is the hub control system which interfaces the materials handling equipment, order retrieval systems, and other distribution technologies. A hub control system can provide real-time data access about all areas/processes/objects in the hub. A hub control system can be used to optimize inventory levels, while maximizing throughput by interfacing and controlling other systems such as pick/put-to-light, robotics, and high-output conveyors. The hub control system can also direct Autonomous Guided Vehicles (AGVs) to retrieve orders while tracking inventory levels in real time.

In all cases, the PI hub must strive for efficiency and performance to match required throughput levels. Thus, the layout of the PI oriented hub must be oriented towards efficiency of operations. Hub processes and operations must also be designed for efficiency, for minimizing container movements, and for sustaining throughput rates. Hubs must also maintain quality and energy conservation and reduce labour cost.

Figure 5-22 Hub Reference Model

A reference model for hub operations can help frame the main areas processes and activities within a hub that are of importance to PI. The model shown in Figure 27, adapted from the DCRM reference model (http://en.warehouse-excellence.de/homepage/components/) can provide such a framework for analysis:

- The top level corresponds to an aggregate view of the whole hub. It contains descriptions of the hub's structure, resources, capacity, performance levels etc.
- The second level is the Process Level and includes the key processed of receiving, storing, picking, consolidating, packing and shipping the goods.
- At the third, or Task Level, the implementation of the different process tasks is shown. The process design strategy and the technologies used for implementing it are also shown. For example, the Picking process (as explained in subsequent sections) can be implemented with either the 'goods to man (picker)' or the 'man to goods' strategies. Each of these strategies is supported by technologies that are described in the next section for picking operations.

<u>A possible design for PI logistics hub</u>

Both the design of the physical infrastructure and of the processes should facilitate the efficient handling of incoming π-containers. They should be placed efficiently based on their destination, departure status, contents and physical characteristics, in order to minimise their movements inside the hub.

Depending on the above criteria, π-containers should be segregated, so that appropriate equipment types can organised into zones, and depending on the time of their departure and destination. Again, the overall goal would be to minimize handlings of the PI containers and their contents.

As in conventional transportation chains, PI demand may fluctuate. For instance, demand may be seasonal. Fluctuations can stress high-throughput environments. Scalable cost-effective technology should be deployed in the PI hub that is capable of coping with maximum demand.

The following activities should be considered:

- *Coordinated arrival of shipments.*

  PI hubs should try to coordinate the arrival of shipments/ π-containers so that it avoids congestion. Ideally PI containers should arrive just-in-time (JIT) to minimise the time they have to spend in the hub. The arrival times of PI containers with the same outbound destination should be synchronised too.

- *Optimisation of hub space.*

  The design of the distribution centres (DCs) layout tries to maximise usable floor and height space with higher ceilings and narrow aisles. This creates the need for specialized equipment to reach inventory stored at high levels. The narrow aisles also limit the types of vehicles such as forklift trucks that operate on them, and their flows (uni or bi-directional). For example very narrow aisles may not be suitable for high throughput hubs.

  PI with its range of universal size PI containers will also impose unique constraints on the space configuration of PI hubs.

- *Automation.*

  Automation includes applications such as high-speed conveyors, pick/put-to-light, auto-guided vehicles (AGVs) for storage and retrieval, voice-directed technology, wearables, radio frequency identification (RFID) scanning, and robotic applications. These technologies are reviewed in the following sections. The automation aspects of a hub will be further explained in Section 5.3 on universal interconnectivity.

5.1.4 Emerging research

P

GS1 box

Germany made a standardized box for trade delivery, the GS1 box. The reusable containers can reduce process costs in the supply chain by 20 percent (20%). The idea: instead of using umpteen different secondary and tertiary packaging made of cardboard and shrink wrap, small slow-moving devices such as deodorant or shower gel should in future be transported from the factories to the central warehouses of the chain stores in a standard container. There, the unpacking and redistribution accounted for in the dealer's own returnable boxes. The advantages of the unified system are obvious: leaner processes, lower costs, less packaging waste, a high degree of automation along the supply chain, better utilization of pallets and loading space.

The savings potential of the relevant logistical process costs is on average 20 percent (20%). It was determined in a test run last year. A total of 6,000 value-added transport crates with items from the drugstore range temporarily replaced the supply of disposable cardboard boxes. Interested manufacturers and distributors are invited to use the containers in their own processes. Drugstore items are expected to be sold in standard transport boxes

The background to the project is the often cumbersome and packaging-intensive processes involved in supplying retailers with industry. Manufacturers pack goods for transport in secondary and tertiary packaging made of cardboard and plastic. These are transported on pallets to the central warehouse. There they are unloaded, unpacked and redistributed into the merchant's own returnable boxes. This process step causes a high resource and disposal expense of disposable cartons. In the project, the companies have proven that a cross-company, standardized reusable transport system pays off. The advantages of a uniform system are obvious: streamlined processes, lower D4.1– Use cases and requirements defined for smart loading units in a multi-modal context and KPI's.

Figure 5-23 GS1 boxes

Rytle (smart urban logistics)

To transform the logistics of the last mile into the digital age, the company RYTLE developed a revolutionary telematics infrastructure, which can be used easily with a smartphone app. The company designed several concepts:

- The MovR (cargo bike to handle the BOX).
- The BOX: in order to optimize the process of delivery, a novel exchange BOX has been developed. This is packed by the logistics service provider packed with parcels and other general cargo and represents the link between HUB and MovR. The MovR-driver picks up the BOX with its contents for delivery and transports them quickly and ecologically on the last mile. The Exchange box is in Euro pallet format (L: 1.120mm W: 800mm H: 1.900mm).
- The City HUB: is characterized as a mobile depot with small space requirements and can be integrated in the cityscape in an ecological and economical manner. Due to the innovative design, the HUBs designed by RYTLE take less space visually and factually. The HUB is a refined standard-container in lightweight design, equipped with a lifting function and telematics. Dimensions: L: 3.700 mm W: 2.550 mm H: 2.100mm

Figure 5-24 - The Rytle solution for urban logistics

The concept of this project makes it possible to collect goods in a terminal outside the city (far or close), transport them in to swap bodies by train in urban railway area and transship the swap bodies through horizontal systems. The last mile delivery will be done by eco-friendly vans to the customers.
Investigation and engineering of new transshipment equipment has been done for speeding up and facilitating handling operations in urban areas, integrated with Spectrum train. The Concept will be suitable also for innovative loading units, suitable for low volumes of good. This will entail a new concept for City Logistics supported by new handling system and micro swap bodies. The Concept guarantees the possibility to transport by train LDHV goods low density high volume. It is possible to subdivide the swap bodies in micro swap bodies that are sub multiples of the big ones. In fact, in 4 micro swap bodies, it is possible to load almost the same quantity of material loaded in a big swap body. These sub multiples can go directly in delivery.
This system allows the train to go in the city center and unload the micro swap bodies for the last mile delivery.

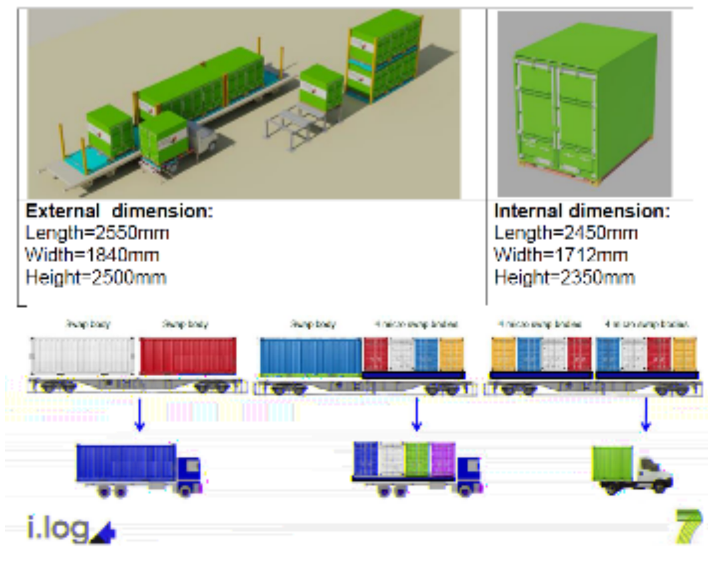


Figure 5-25 Micro swap-body

L

IOT

Internet of Things (IoT) is an umbrella of technologies that involve the networking and internet connectivity of sensors. Sensors capture and transmit information from their environment, via gateways to centralised systems for further processing and analysis. In a hub environment, sensors can capture and transmit information about both the goods, and the equipment that handle them. This is utilised by other systems (usually Cloud-based) that perform analytics to control and optimise the process, but also delivered to human task performers. Smart lift trucks equipped with sensors can stream data to their drivers and to external control systems for enhanced safety and training. Sensor-equipped lift trucks can also report problems such as collisions and send alerts when mechanical problems arise. Smart trailers for live tracking that enables end-to-end stock visibility, perishables temperature monitoring, and correct truck-trailer pairing. Other IoT applications include precise asset/inventory location for real-time tracking, positioning, guidance, and visibility.

AUTOMATIC/AUTONOMOUS DRIVING VEHICLES

Robots in DCs can be categorized into two factions: gantry robots that lift goods and auto guided vehicles (AGVs)—also known as self-guided vehicles that retrieve. The recent trend is for robotic AGVs that either follow the picker, or that can be tracked by the picker. The more advanced models know where the next pick is located before the picker does. In the goods-to-person model, the AGV retrieves the goods and delivers them to the picker.

DRONES

Recently, the concept of using drones inside a hub for goods-to-person applications was proposed. Drones can be used in yard management to verify trailer location and update yard management systems in real time.

WEARABLE TECHNOLOGIES

Wearable technologies involve devices worn by the hub operators such as glasses, helmets or gloves, equipped with sensing and transmission capabilities. Together with mobile applications this is a growing materials handling innovation area designed to improve processes and safety. Augmented Virtual Reality (AVR) technologies today use heads-up displays (HuDs) that utilise [illegible]

5.2 Digital Interconnectivity

This section analyzes the search results regarding Digital Interconnectivity problems, according to projects, standards and emerging research areas. Each subsection details the research done and conclusions and statements are exposed in the final subsection.

5.2.1 Projects

The following Table summarizes the main contributions to take into account regarding digital interconnectivity:

Figure 5-26 EU Projects Contributions to Digital Interconnectivity

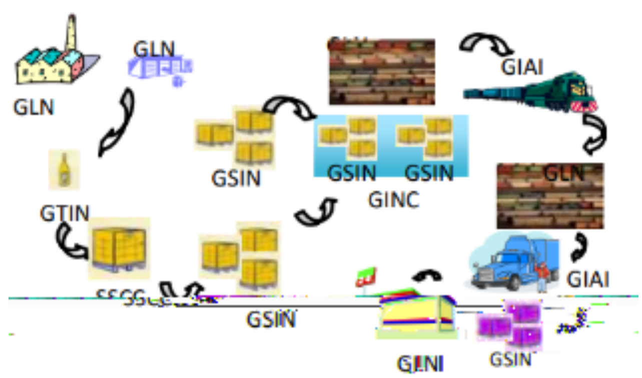
<table>
<tr><th>Acronym</th><th>Contributions to Digital Interconnectivity</th></tr>
<tr><td>COMCIS</td><td>COMCIS uses the so-called Common Framework (Pedersen2014), which supports interoperability between ICT systems in logistics and provides a basis for semantic (i.e. content-related) standards in the transport and logistics sector.
COMCIS is based on UBL version 2.1 standard and the GS1 Logistics Interoperability Model. COMCIS tools are not open source, they are not available on any repository but UBL and GS1 LIM standards usage should be considered during ICONET development stage, taking updated versions of both (GS1LIM), (UBL).</td></tr>
<tr><td>iCargo</td><td>iCargo proposed a Service Oriented Architecture for modular logistics concepts. Deliverables are not accessible. Tools are not open source, the only repository found at https://github.com/cornelisse/iCargo-API has no updates and iCargo ecosystem is not available. The usage of REST APIs is the main contribution to ICONET.</td></tr>
<tr><td>MODULUSHCA</td><td>It was based on the following standards:
GS1 Global Standards for unique identification of boxes, containers, products, location, etc. SSCC (Single Shipment Container Code) as well as GLN, GIAI, GRAI, GTIN, SGTIN and GSIN.


Figure 5-27 GS1 Standards used in the MODULUSHCA project (Barbarino 2015)
EPCGlobal initiative for allowing interoperability and information exchange.
UPU Standards (a postal standard) is interesting as an example of handling information interchange and forwarding between “abroad” partners, tracking and borders crossing.
Tracking of M-Boxes dynamic aggregation in order to simplify the tracking and tracing approach.
It proposed a common data model based on four subsets of information:
MBox info (Green): data directly available on the modular unit (stored in the RFID or QR Code).
Network flow (Yellow): boxes are identified with UUID that allows retrieving of selective information from the IT Systems.</td></tr>
</table>

<table>
<tr>
<td>MODULUSHCA</td>
<td>

Shipment flow (Orange): boxes are aggregated/unified in the IT system(s), where “restricted” information may be retrieved by authorized interests (eg. customs, police, agencies, etc.) in using a defined set of user-specific rules.
Business flow (Red): commercial and reserved data are private and held by the main actors (customer and manufacturer).

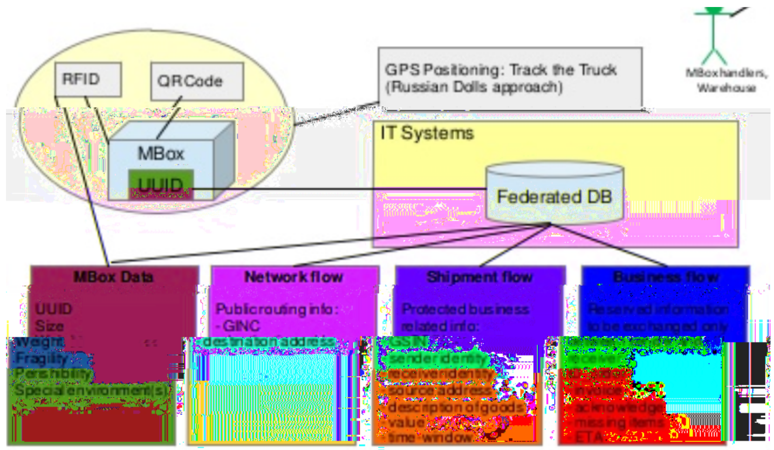


Figure 5-28 MODULUSHCA Common Data Model (Barbarino2015)

It proposed a four-layer different than OLI:

Business Layer: business goals to be achieved is the delivery of goods to the retail point and/or to the final customer, encapsulating them in modular units.
Logistics Layer: Who, where, what and when: driving the movement of goods, from original sender to intended receiver, using an end2end approach for planning and routing the modular units flow.
Transport Layer: Deals with movement of goods considering the available means to be used, the modality, in order to move the modular units from one hub to another, following a point-to-point approach.
Physical Layer: Regards the physical “objects” in the systems, the modular boxes, the transport means, the location, the links, T&T, loading and unloading, cross-docking and storage, supporting the handling operations.

Unfortunately, the MODULUSHCA common data model proposal is not public on any repository.
</td>
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<tr>
<td>SELIS</td>
<td>Supply Chain actors across Europe and globally, need a secure and trusted vehicle to share data and information for better horizontal and vertical supply chain collaboration, management, insights and optimisation. SELIS’s vision is to deliver a “Pan-European Logistics Intelligence-Sharing Platform”, that unifies business, technology and capacity across the broader EU Transport & Logistics sector in support of green, efficient and profitable T&L.
SELIS addresses the T&L sector needs by providing a trusted platform that offers easy plug-and-play ways to share and analyse supply chain industry data in a neutral and privacy preserving manner, enabling the fulfilment of intelligent collaboration across the broader T&L sector. The platform is developed as a network of Supply Chain Community Nodes (SCNs) [patent pending], designed for superior business-relevant configurability and customizability. Out of the box, each SCN combines, collaboration, connectivity, communication, privacy & data protection, analytics and visualisation tools , enabling end-to-end visibility across value chains. Further, SELIS deploys a centralized Data Hub, configured for the needs of a specific community’s Collaboration Model, aggregating</td>
</tr>
</table>

information flows in various formats. Such information is generated by the operational systems of the logistics participants, including IoT devices and event-based data flows.

In the heart of SELIS, a communication mechanism has been established to facilitate information sharing among the SCNs linking the participants' existing backend systems (ERP, CRM) through a secure cloud-based infrastructure, mobilising B2B collaboration in a broad range of logistics-related services.

Hence, the SELIS publish/subscribe system is an integral part of the SCN enabling efficient communication across the whole software stack connecting several inhomogeneous data processing platforms either serving as data producers or data consumers. Besides ensuring roducers linr)Xs Niffru8)wfiffst)4shffshsshiohtawasau)'whrDiat8)wfifrdconn8)wfiffs

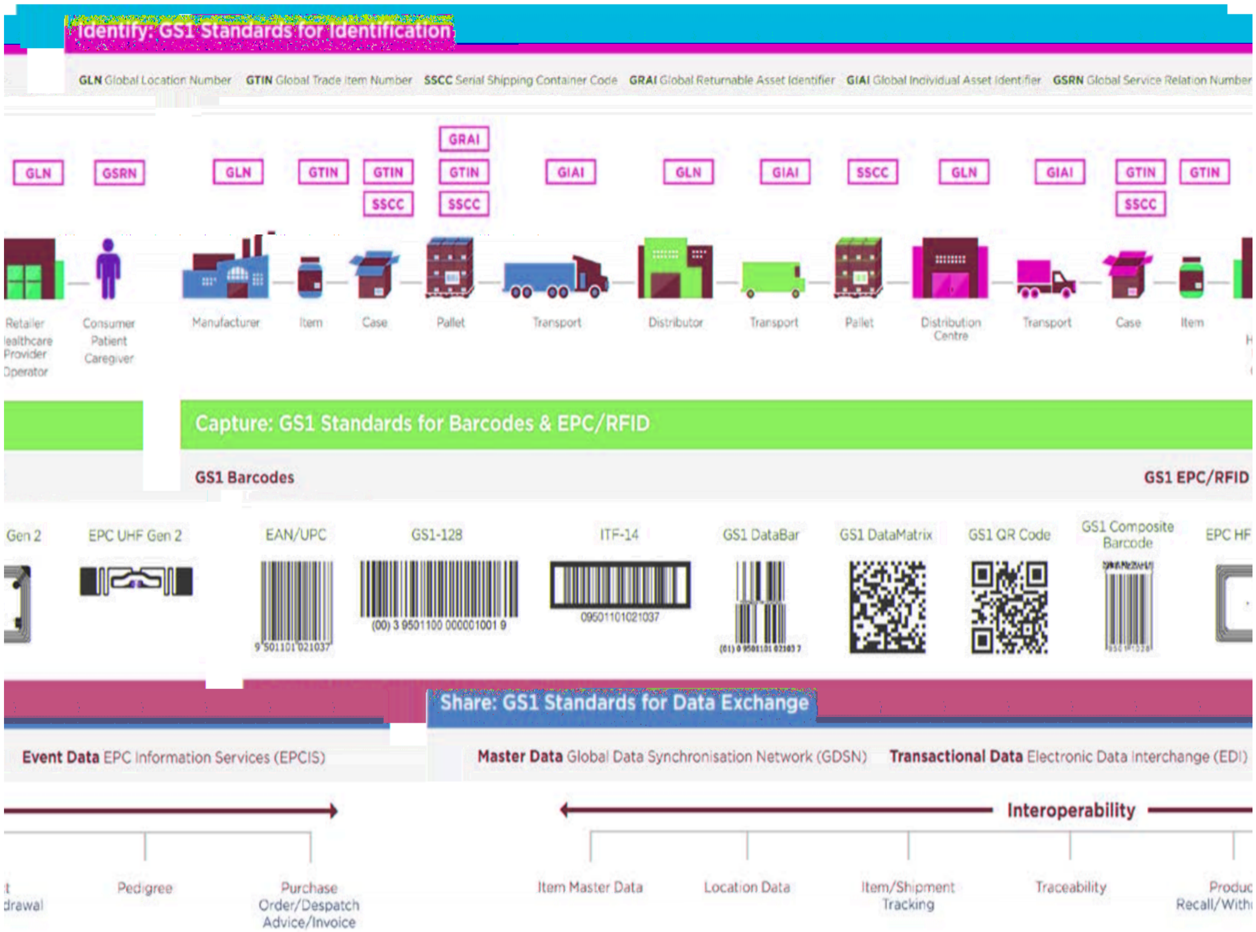

Figure 5-29 The GS1 system of standards (GS1LIM)

The scope of GS1 Logistics Interoperability Model Application Standard (GS1LIM) covers Transport and Warehouse management and includes activities associated with the movement of goods from the material supplier to the manufacturer to the retailer using logistics service providers, incorporating the return of goods (reverse logistics). An overview of GS1 LIM is shown in the following Figure:

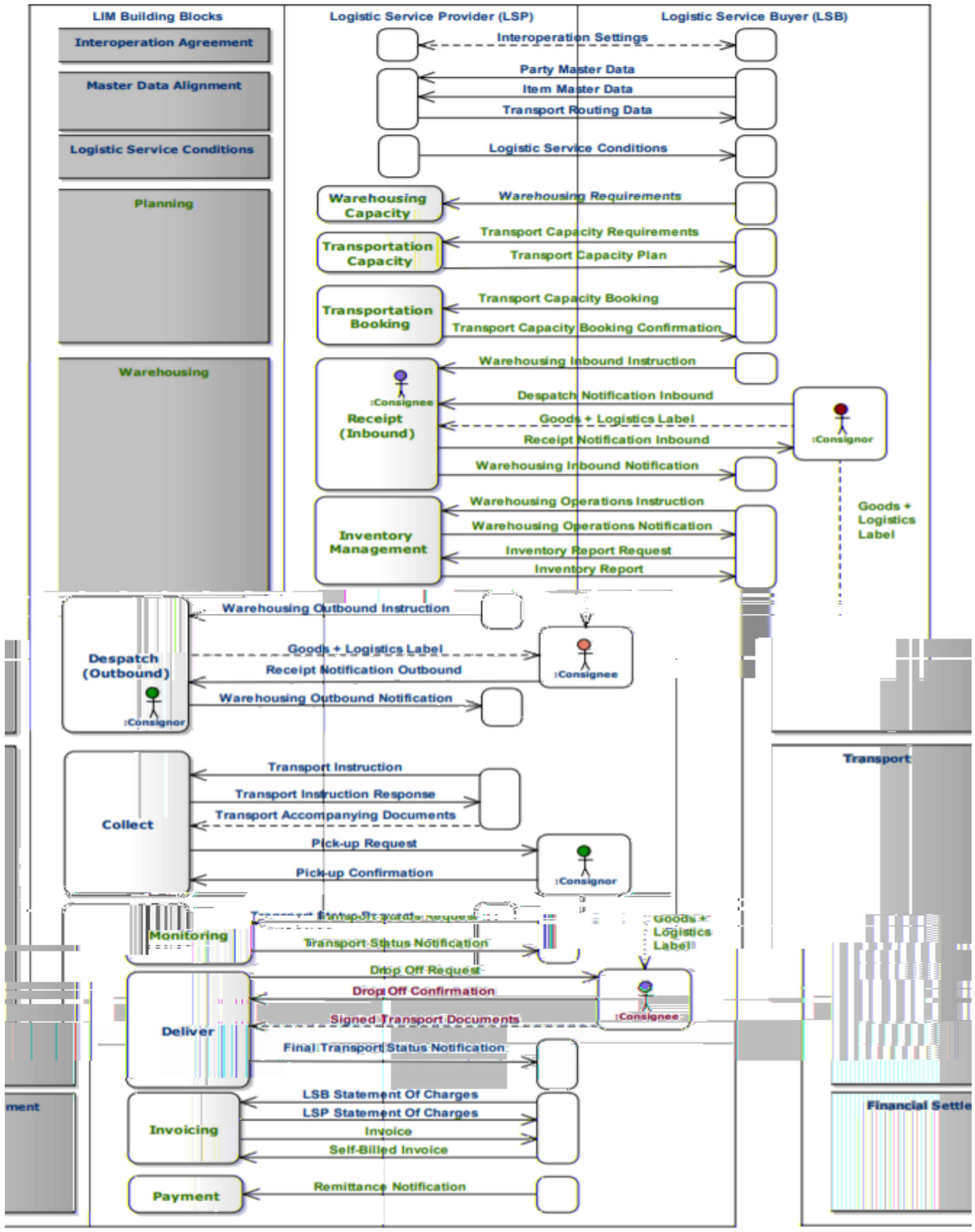

Figure 5-30 GS1 LIM Overview (GS1LIM)

The LIM describes common business processes and data interchanges to support interoperability with Logistics Service Providers. According to the specification, the following statements will further clarify the scope of the LIM:

- Focus is on continental transport modes (road, rail, inland water, short sea). For road transport, this includes Full Truck Load (FTL) transport, Less Than Truck Load (LTL) transport and Parcel distribution.
- Value added services like dry filling, repacking for promotions, re-stacking or re-labelling are also included. As long as the GTIN of serviced item stays the same it is considered a value-added logistics service (in scope), if the GTIN changes it is considered contract manufacturing (out of scope).
- Load tendering within the frame of a contract is also included. Strategic tendering (to negotiate new contracts) and load tendering on spot market are out of scope.

The LIM covers the following business functions and business processes:

Table 5-2 Business Functions and Processes included in GS1 LIM (GS1LIM)

Business Functions	Business Processes
• Procurement • Planning • Warehousing • Transport • Financial settlement	• Interoperation agreement • Master data alignment • Logistics service conditions • Planning • Warehousing • Transport • Financial settlement

UBL

UBL, the Universal Business Language, defines a royalty-free library of standard XML business documents supporting digitization of the commercial and logistical processes for domestic and international supply chains such as procurement, purchasing, transport, logistics, intermodal freight management, and other supply chain management functions (UBL). UBL is designed to provide a universally understood and recognized syntax for legally binding business documents and to operate within a standard business framework such as ISO/IEC 15000 (ebXML) to provide a complete, standards-based infrastructure that can extend the benefits of existing EDI systems to businesses of all sizes. UBL is freely available to everyone without legal encumbrance or licensing fees. The following Figure represents the main UBL use cases:

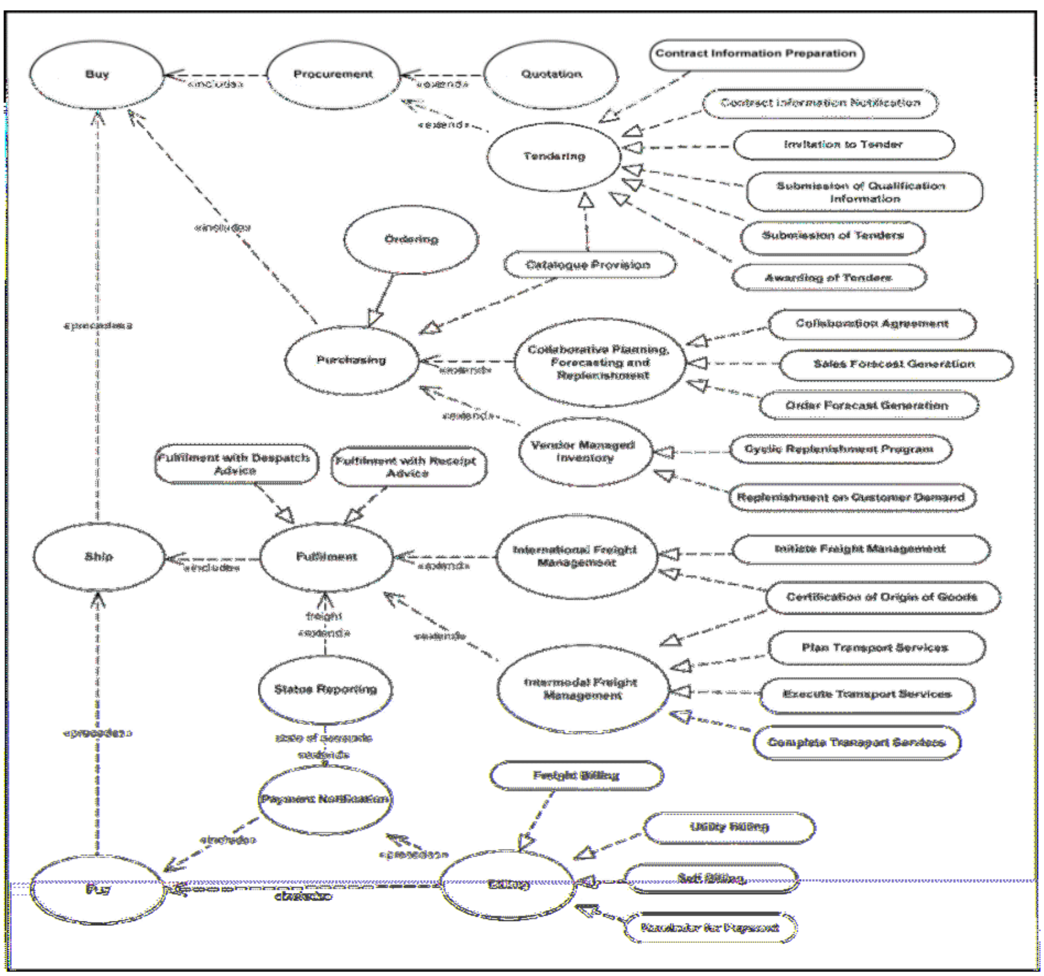

Figure 5-31 UBL Use Cases (v2.1) (UBL)

UBL v2.2 is structured according to a SCOR-based Supply Chain Business Process classification:

- *Plan* – Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production, and delivery requirements.
- *Source* – Processes that procure goods and services to meet planned or actual demand.
- *Make* – Processes that transform product to a finished state to meet planned or actual demand.
- *Deliver* – Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.
- *Return* – Processes associated with returning or receiving returned products for any reason. These processes extend into post-delivery customer support.
- *Pay* – Processes related to billing, Payment Notification and report state of accounts.

Table 5.3 describes the main UBL processes included in the specification according to the Plan, Source, Deliver and Pay Supply Chain Business Processes:

Table 5-3 Supply Chain Business Process included in UBL (UBL)

Supply Chain Business Process	UBL Process
Plan	Collaborative Planning, Forecasting, and Replenishment
Source (procurement)	Tendering (pre-award) Catalogue Quotation Ordering (post-award) Vendor Managed Inventory
Make	No specific UBL process detailed
Deliver	Logistics Transport Freight Status Reporting Certification of Origin of Goods Cross Border Regulatory Reporting Intermodal Freight Management
Return	No specific UBL process detailed
Pay	Billing Freight Billing Utility Billing Payment Notification Report State of Accounts

An example of a UBL process, namely the Intermodal Freight Management Process, is detailed in the following Figure:

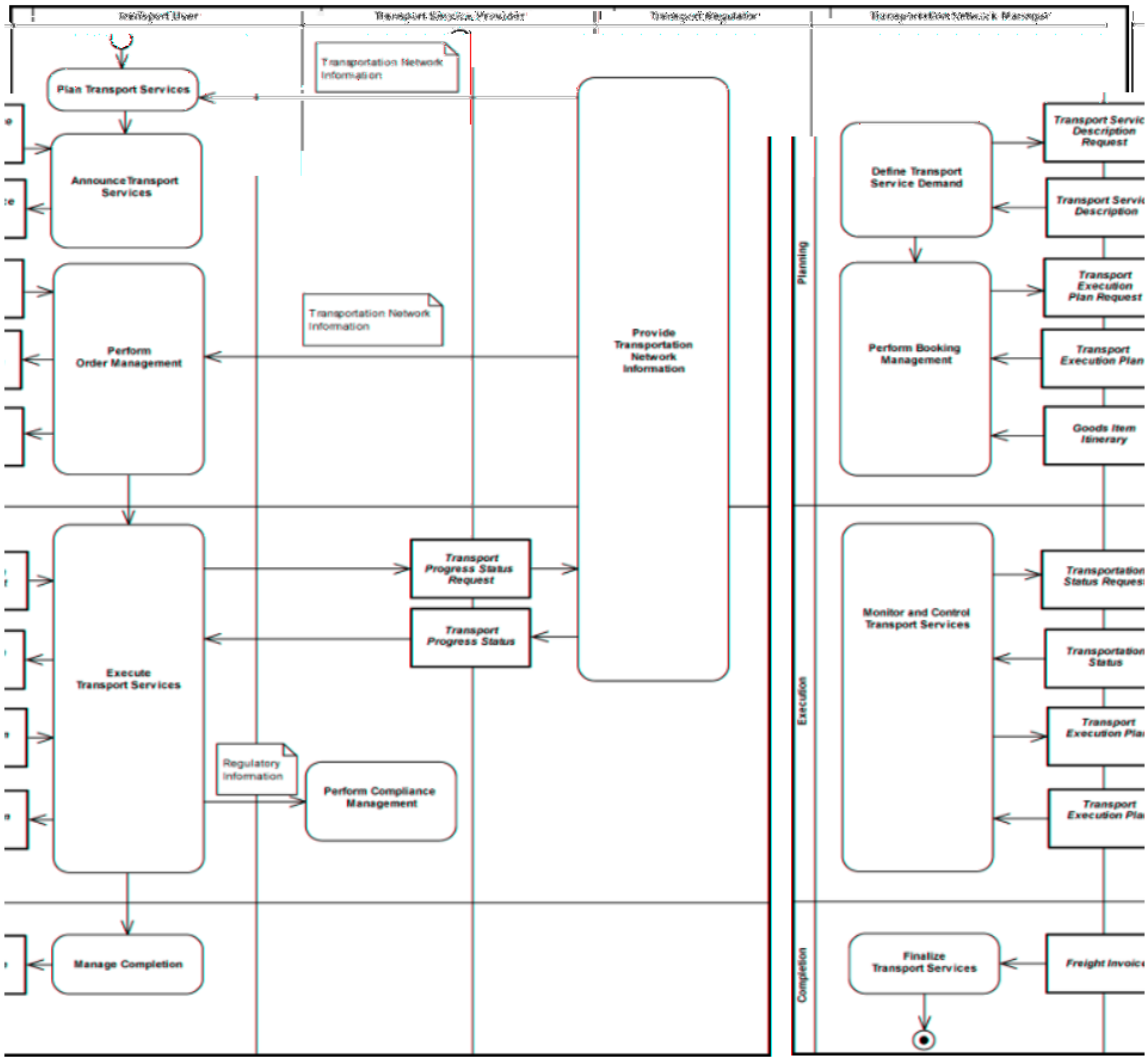

Figure 5-32 – The Intermodal Freight Management Process in UBL (UBL)

In the UBL supply chain processes, two main actors, Customer and Supplier, represent the key organizations or people involved in the processes. Each of these actors may play various roles. Some processes may also involve supplementary roles that may be provided by different parties. In UBL, the following are roles that extend the Party structure: Customer Party, Supplier Party, Contracting Party, Endorser Party, and Qualifying Party.

5.2.3 Emerging research

From the primary studies founded during the research process there is no clear contribution directly coupled to Digital Interconnectivity different than previous sections. Some of the papers are related to EU projects or standards, so that their influence has been already reported.

According to primary studies, we have created a new taxonomy for PI Digital Interconnectivity that extends the Modulushca (ModulushcaURL) layers as follows:

Table 5-4 Digital Interconnectivity Layers proposed for ICONET project

Modulushca PI-Layer	Digital Interconnectivity Layer	Description
Business	**Collaborative Business Process**	Case management & Decision BPMN vs CMMN vs DMN Smart contracts & Blockchain
	Business Process Interconnection	Usage of technological standards to automate execution of business process BP orchestration
Logistics	**Service Choreography**	Choreography based service integration Standards like WS-Choreography Peer-to-peer architectures
	Service Orchestration	Orchestration-based service integration BPEL-based engines Platforms like Enterprise Service Bus platforms, message oriented middlewares, enterprise integration patters
	B2B Interoperability	Integration to ERP and corporate systems by using Standard open protocols (XML, Web-Services, RESTful services) Approaches to integrate backend services Software Integration architectures: client-server, event process chains
Transport	**Data Integration & Standard Smart Interfaces**	Encapsulation of source and destination fields Usage of technological standards to automate data exchange IoT services Definition of software integration interfaces and protocols
Physical	**Data Capture & Encapsulation**	Identification of assets & participants Usage of technological standards to automate data capture (barcodes, RFID)

The Digital Interconnectivity Layers taxonomy proposed is detailed in the following subsection.

C B P L

This layer is responsible to handle the top-level achievements among different organizations, according to a collaborative choreographed schema. This way, each participant is responsible for a part of the global process and is aware of all collaborations, at business process level.

This way, collaborative business process should be defined, and should be aligned with the individual process performed per each stakeholder.

The most common approach is the creation of a global process by using choreography in **BPMN** (BPMN). BPMN is a precise, complete and graphical notation for documenting well-defined business processes. It resolves many ambiguities found in textual process specifications by assigning activities to specific actors. Analyzing the resulting models can be used to drive process improvement initiatives, regardless of whether processes are automated or manual. Because the graphical model is readily understandable by non-technical people, it serves as a bridge that allows collaboration between business stakeholders and IT personnel. OMG's BPMN 2.0.1 specification has been published as International Standard ISO/IEC 19510:2013.

The OMG specification BPMN version 2.0 includes diagrams to model service choreographies. In BPMN, collaboration only shows Pools and the message flow between them. To be more specific, collaboration is any BPMN diagram that contains two or more participants as shown by Pools which have message flow between them. A new model type in BPMN 2.0 is the Choreography Diagram as follows:

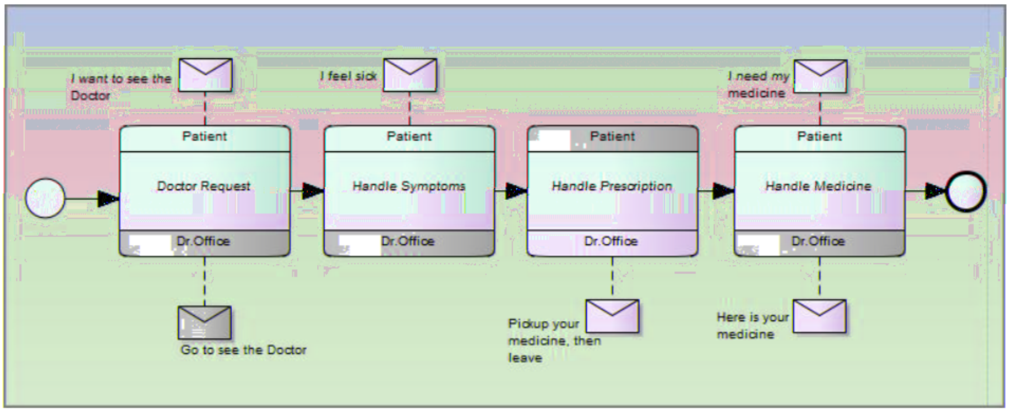

Figure 5-33 An example of Choreography in BPMN (BPMN)

When the collaboration can be completely predefined the BPMN approach is good enough. When there are uncertain elements in the process, then a more dynamic environment is required. This way a most recent standard has emerged, known as **CMMN** (CMMN). CMMN is a graphical notation used for capturing work methods that are based on the handling of "cases" requiring various activities that may be performed in an unpredictable order in response to evolving situations. Using an event-centered approach and the concept of a case file, CMMN expands the boundaries of what can be modeled with BPMN, including less structured work efforts and those driven by knowledge workers. Using a combination of BPMN and CMMN allows users to cover a much broader spectrum of work methods.

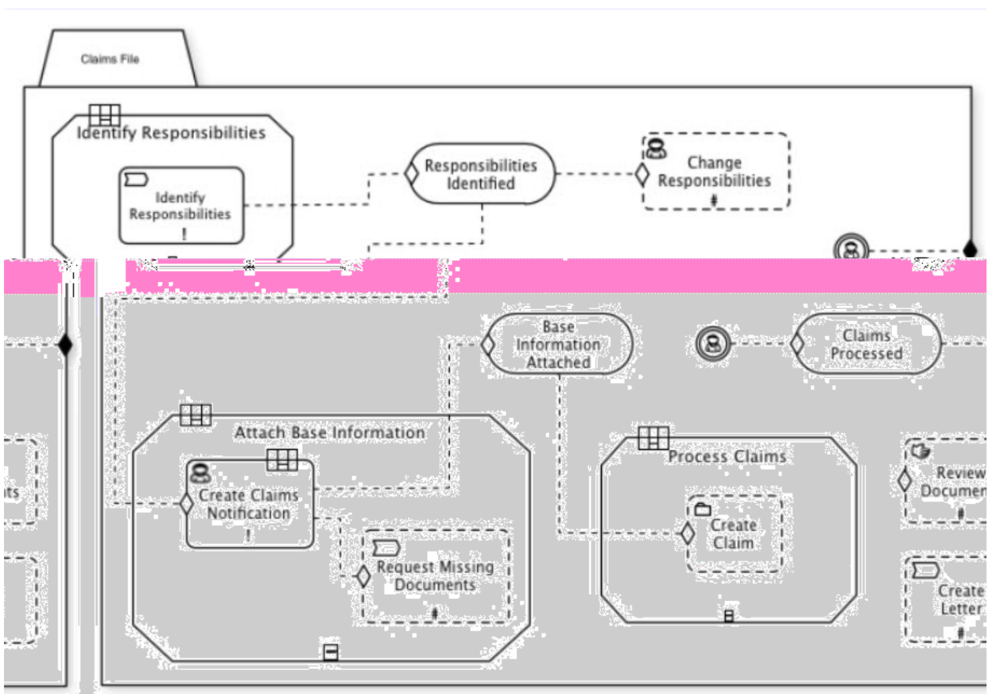

Figure 5-34 An example of a CMMN case (CMMN)

Decision models & Notation **(DMN)** is a notation for the precise specification of business decisions and rules. DMN is readily readable by the different types of people involved in decision management. These include business people who specify the rules but also monitor their application; business analysts who transform user input into detailed decision models; and software developers who implement them in enterprise systems. DMN is designed to work alongside BPMN or CMMN providing a mechanism to model decision making within both process models and case models (DMN). DMN allows models to be constructed on three levels:

- Decision requirements: a notation for Decision Requirements Diagrams (DRDs) which graphically shows the decisions to be made in a business domain, together with their dependencies on each other, on input data, and on business knowledge.
- Boxed expressions: a flexible notation allowing components of decision logic to be drawn graphically. One important contribution of DMN is an unambiguous notation for decision tables, which are a clear, convenient and commonly understood way to express business rules as boxed expressions.
- Decision logic: an expression language (FEEL) for defining decision logic, usually to be associated with the components of a DRD or the cells of a decision table. FEEL defines structured logic, calculations, simple data structures, and externally defined logic (from Java and PMML) as executable expressions with formally defined semantics. All of these three levels are executable when fully specified, and interchangeable as XML.

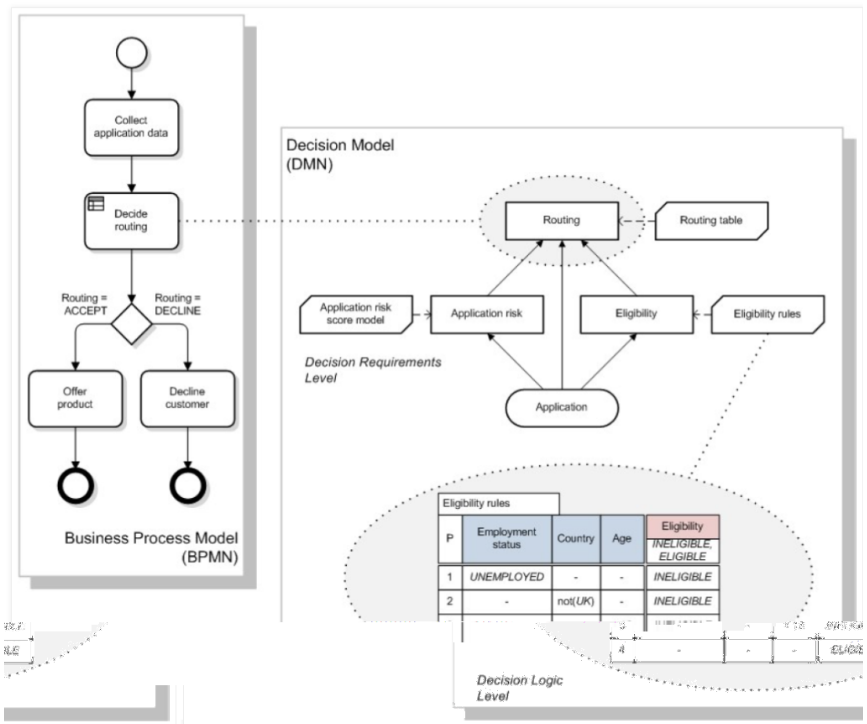

Figure 5-35 An example of a DMN diagram (DMN)

These are the main differences among the three OMG standards:

Figure 5-36 BPMN, CMMN and DMN, by OMG (CMMN)

Another most recent approach to drive automated execution of business process in a collaborative way is the creation of **smart contracts** and their deployment on peer-to-peer **blockchain** networks. A smart contract is a self-executing contract whose terms of the agreement between the contract's counterparties are embedded into lines of code. Essentially, a smart contract is a digital version of the standard paper contract that automatically verifies fulfillment and enforces and performs the terms of the contract. The concept of smart contracts was proposed by Nick Szabo, an American computer scientist and researcher of digital currencies in 1994 (CFI).

The collaboration agreements are transferred from paper to code. Then it is stored in the blockchain network and is replicated among the participants in the blockchain. Then, the code is run and executed by all computers in the network. If a term of the contract is satisfied and it is verified by all participants of the blockchain network, then the relevant transaction is executed.

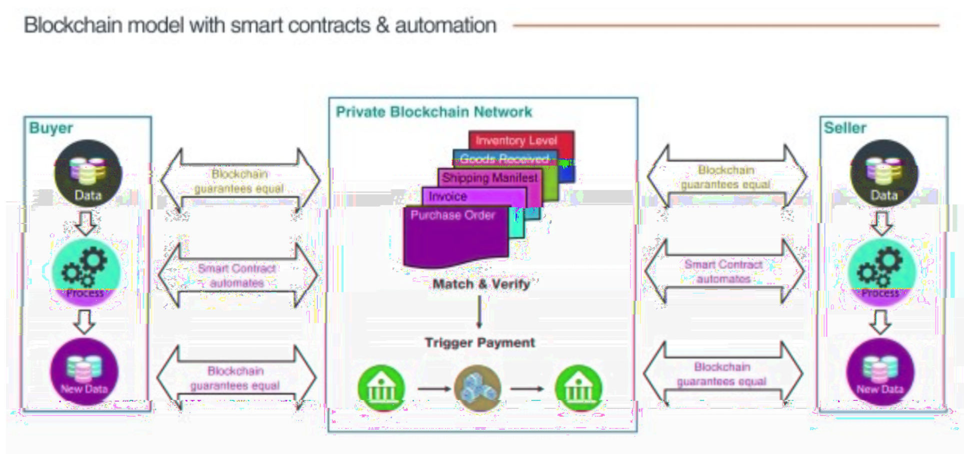

Figure 5-37 Collaboration by Smart Contracts in a blockchain (CFI)

Currently there are several blockchain implementations that support the execution of smart contracts:

- Bitcoin: it provides a Turing-incomplete Script language that allows the creation of custom smart contracts.
- Ethereum: implements a nearly Turing-complete language on its blockchain.
- Hyperledger: the Fabric, Sawtooth, Burrow and Iroha supports different smart contracts execution levels.

B P I L

This layer manages the interconnection at business process level, by the automated execution of pre-defined process-steps that may be orchestrated by a BPEL-based platform. It is similar to the service orchestration but it differs in the sense that at this level not only IT-systems are orchestrated but also business process. This way, a concrete process (i.e. a delivery) is managed among several organizations that have a common view of the execution of the process and can take corrective actions when needed.

To this aim, a standard Business Process Model and Notation (BPMN) was created by OMG. BPMN provides businesses with the capability of understanding their internal business procedures in a graphical notation and gives organizations the ability to communicate these procedures in a standard manner. Furthermore, the graphical notation facilitates the understanding of the performance collaborations and business transactions between the organizations. This ensures that businesses understand themselves and participants in their business and enable organizations to adjust to new internal and B2B business circumstances quickly.

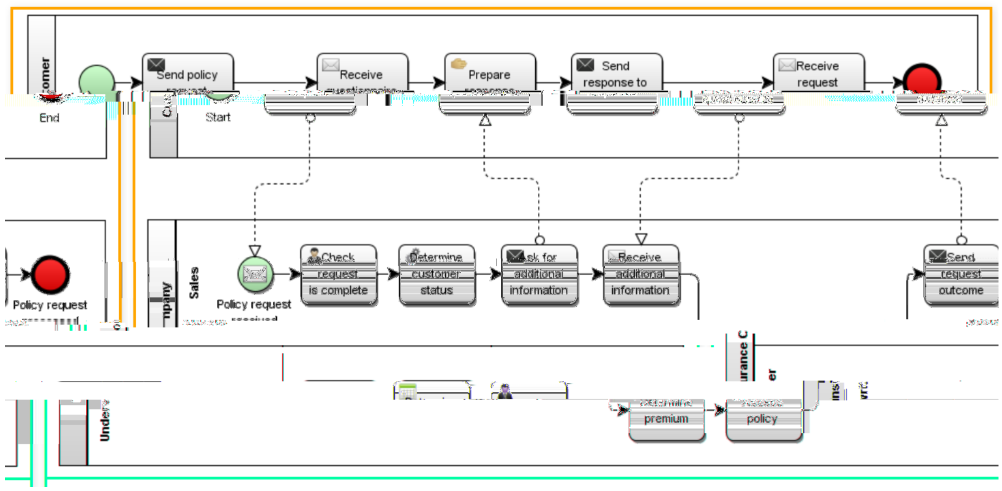

Figure 5-38 An example of a Collaborative Process in BPMN (BPMN)

S C L

This layer is responsible for the integration of services, as a collaboration of stakeholders and their respective IT-based systems, according to a choreography mechanism where there is no central controller or authority.

The choreography describes the interactions between multiple services, whereas orchestration represents control from one party's perspective. This means that choreography differs from an orchestration with respect to where the logic that controls the interactions between the services involved should reside.

Regarding web services area, there is a set of standards to model choreographies:

Table 5-5 Service Choreography Specification Standards

Specification	Description
WS-CDL	The Web Services Choreography Description Language (WS-CDL) is an XML-based language that describes peer-to-peer collaborations of participants by defining, from a global viewpoint, their common and complementary observable behavior; where ordered message exchanges result in accomplishing a common business goal. The Web Services specifications offer a communication bridge between the heterogeneous computational environments used to develop and host applications. The future of e-Business applications requires the ability to perform long-lived, peer-to-peer collaborations between the participating services, within or across the trusted domains of an organization. The Web Services Choreography specification is targeted for composing interoperable, peer-to-peer collaborations between any type of participant regardless of the supporting platform or programming model used by the implementation of the hosting environment.

WSCI	The Web Service Choreography Interface (WSCI) is an XML-based interface description language that describes the flow of messages exchanged by a Web Service participating in choreographed interactions with other services. WSCI describes the dynamic interface of the Web Service participating in a given message exchange by means of reusing the operations defined for a static interface. WSCI works in conjunction with the Web Service Description Language (WSDL), the basis for the W3C Web Services Description Working Group; it can, also, work with another service definition language that exhibits the same characteristics as WSDL. WSCI describes the observable behavior of a Web Service. This is expressed in terms of temporal and logical dependencies among the exchanged messages, featuring sequencing rules, correlation, exception handling, and transactions. WSCI also describes the collective message exchange among interacting Web Services, thus providing a global, message-oriented view of the interactions. WSCI does not address the definition and the implementation of the internal processes that actually drive the message exchange. Rather, the goal of WSCI is to describe the observable behavior of a Web Service by means of a message-flow oriented interface. This description enables developers, architects and tools to describe and compose a global view of the dynamic of the message exchange by understanding the interactions with the web service.
ebXML	ebXML (Electronic Business using eXtensible Markup Language), is a modular suite of specifications that enables enterprises of any size and in any geographical location to conduct business over the Internet. Using ebXML, companies now have a standard method to exchange business messages, conduct trading relationships, communicate data in common terms and define and register business processes.

In this kind of integration, the most common architectures are peer-to-peer networks, where each service infrastructure is in charge of the logic to handle the direct connections to each other systems. This situation avoids the single point of failure problem, but adds more complexity to the individual solutions which have to be aware of each integration or service choreography.

S O L

This layer handles the performance of a service (i.e. a delivery), where several organizations may collaborate according to a predefined set of steps that may be automate by using process orchestrators.

The low level of an orchestration is based on Enterprise Integration Patterns (EIP) (Hohpe2014) that defined 65 messaging patterns that provide technology-independent design guidance for developers and architects to describe and develop robust integration solutions. The purpose of the authors was to establish a technology-independent vocabulary and a visual notation to design and document integration solutions. Each pattern not only presents a proven solution to a recurring problem, but also documents common "gotchas" and design considerations.

According to Hohpe (Hohpe2014), these patterns are classified as follows:

- Integration Styles document different ways applications can be integrated, providing a historical account of integration technologies. All subsequent patterns follow the Messaging style.
- Channel Patterns describe how messages are transported across a Message Channel. These patterns are implemented by most commercial and open source messaging systems.
- Message Construction Patterns describe the intent, form and content of the messages that travel across the messaging system. The base pattern for this section is the Message pattern.

- Routing Patterns discuss how messages are routed from a sender to the correct receiver. Message routing patterns consume a message from one channel and republish it message, usually without modification, to another channel based on a set of conditions. The patterns presented in this section are specializations of the Message Router pattern.
- Transformation Patterns change the content of a message, for example to accommodate different data formats used by the sending and the receiving system. Data may have to be added, taken away or existing data may have to be rearranged. The base pattern for this section is the Message Translator.
- Endpoint Patterns describe how messaging system clients produce or consume messages.
- System Management Patterns describe the tools to keep a complex message-based system running, including dealing with error conditions, performance bottlenecks and changes in the participating systems.

These conceptual patterns can be implemented in:

- Messaging technologies, such as JMS, SOAP, MSMQ, .NET, and other EAI Tools.
- Integration tools and platforms, such as IBM WebSphere MQ, TIBCO, Vitria, WebMethods (Software AG), or Microsoft BizTalk.
- Enterprise Service Bus or messaging systems, such as JMS, WCF, Rabbit MQ, or MSMQ, ESB's such as Apache Camel, Mule, WSO2, Oracle Service Bus, Open ESB, SonicMQ, Fiorano or Fuse ServiceMix.

The following Figure represents the global picture of EIPs:

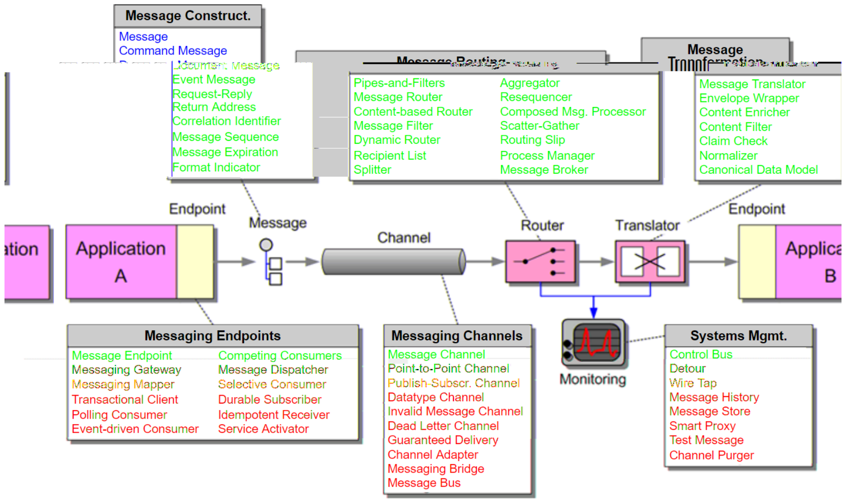

Figure 5-39 Enterprise Integration Patterns (Hohpe2014)

These solutions are commonly based on process models to define the service orchestration. One of the most relevant standards in this field is the Web Services Business Process Execution Language (WS-BPEL), commonly known as BPEL (Business Process Execution Language). It is an OASIS standard executable language for specifying actions within business processes with web services. Processes in BPEL export and import information by using web service interfaces exclusively.

B B I L

This layer is responsible for the basic integration of IT-systems, more commonly described as business to business interoperability. In this level the process is not completely automated and should be performed by manual intervention.

The key aspect in this layer is the successful integration with legacy systems. Generally, the IT-systems have been created before B2B integration is required, so that it is important to adapt them to cover different new features to achieve this kind of integrations with new systems. To handle the evolutionary software development, the architectures have been evolved to a N-tiers layered, so that new changes to cover new requirements may be included in a specific layer, but changes should not affect the whole system.

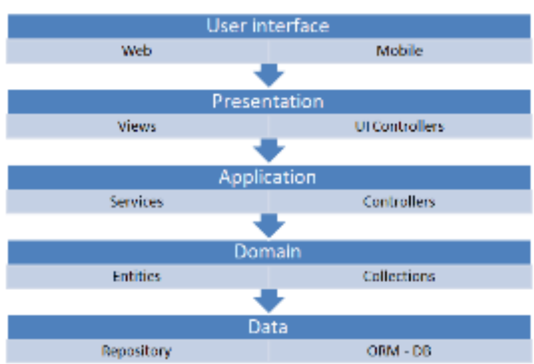

Figure 5-40 Layered Architecture N-tiers

Then existing approaches to integrate backend services are focused on the generation of an application or service layer that acts as a wrapper of a legacy system, and offers a set of interfaces to handle with internal data or behavior. To serve these interfaces, there are several standard and protocols:

Table 5-6 Standard Interface Protocols

Standard Interface	Description
Web Services	W3C (W3CURL) standards define an Open Web Platform for application development that has the unprecedented potential to enable developers to build rich interactive experiences, powered by vast data stores that are available on any device. W3C define a set of standards, but the most common to cover the minimum functionality for ICONET project should be: • Universal Description, Discovery, and Integration (**UDDI**), for Service Discovery, is an XML-based registry for business internet services. • Simple Object Access Protocol (**SOAP**) is a messaging protocol specification for exchanging structured information in the implementation of web services in computer networks. • Web Services Description Language (**WSDL**) is an XML-based interface description language that is used for describing the functionality offered by a web service.
RESTful Services	Representational State Transfer (**REST**) is a software architectural style that defines a set of constraints to be used for creating Web services. Web services that conform to the REST architectural style, termed RESTful Web services (**RWS**), provide interoperability between computer systems on the Internet. RESTful Web services allow the requesting systems to access and manipulate textual representations of Web resources by using a uniform and predefined set of **stateless operations**.
Remote Procedure Call (RPC)	Remote Procedure Call (RPC) is a protocol that one program can use to request a service from a program located in another computer on a network without having to understand the network's details. A procedure call is also sometimes known as a function call or a subroutine call. There are some proprietary technology specific proprietary solutions, like .NET Remoting or Java RMI, but there is a couple of technological independent proposals: • XML-RPC is a remote procedure call (RPC) protocol which uses XML to encode its calls and HTTP as a transport mechanism.[1] • JSON-RPC is a remote procedure call protocol encoded in JSON. It is a very simple protocol (and very similar to XML-RPC), defining only a few data types and commands. JSON-RPC allows for notifications (data sent to the server that does not require a response) and for multiple calls to be sent to the server which may be answered out of order.

D I S S I L

This layer manages the data integration of IT-based systems of each organization by the usage of shared data. This information should be transmitted among participants by using standard interfaces. In general, there are five approaches to handle this data integration (MuleURL):

Table 5-7 Data Integration Patterns (MuleURL)

Data Integration Pattern	Description
Migration	This approach refers to the act of moving a specific set of data at a point in time from one system to the other. A migration contains a source system where the data resides at prior to execution, a criterion which determines the scope of the data to be migrated, a transformation that the data set will go through, a destination system where the data will be inserted and an ability to capture the results of the migration to know the final state vs the desired state.

Broadcast	Broadcast can also be called "one-way sync from one to many", and it is the act of moving data from a single source system to many destination systems in an ongoing and real-time (or near real-time), basis. The broadcast pattern, unlike the migration pattern, is transactional. This means it does not execute the logic of the message processors for all items which are in scope; rather, it executes the logic only for those items that have recently changed.
Bi-Directional Sync	The bi-directional sync data integration pattern is the act of combining two datasets in two different systems so that they behave as one, while respecting their need to exist as different datasets. This type of integration need comes from having different tools or different systems for accomplishing different functions on the same dataset. Using bi-directional sync to share the dataset will enable you to use both systems while maintaining a consistent real-time view of the data in both systems.
Correlation	The correlation data integration pattern is a design that identifies the intersection of two data sets and does a bi-directional synchronization of that scoped dataset only if that item occurs in both systems naturally. This is similar to how the bi-directional pattern synchronizes the union of the scoped dataset, correlation synchronizes the intersection. In the case of the correlation pattern, those items that reside in both systems may have been manually created in each of those systems. The correlation pattern will not care where those objects came from; it will agnostically synchronize them as long as they are found in both systems.
Aggregation	Aggregation is the act of taking or receiving data from multiple systems and inserting into one.The aggregation pattern derives its value from allowing you to extract and process data from multiple systems in one united application. This means that the data is up to date at the time that you need it, does not get replicated, and can be processed or merged to produce the dataset you want.

A new trend to solve Data integration issues come from Adobe, Microsoft and SAP as an initiative launched in 2018, known as the **Common Data Model (CDM)** (CDMURL). The CDM metadata system enables consistency of data and its meaning across applications and business processes, which store data in conformance with the CDM. In addition to the metadata system, the CDM includes a set of standardized, extensible data schemas published. This collection of predefined schemas includes entities, attributes, semantic metadata, and relationships.

Figure 5-40 represents the main elements of the standard entities:

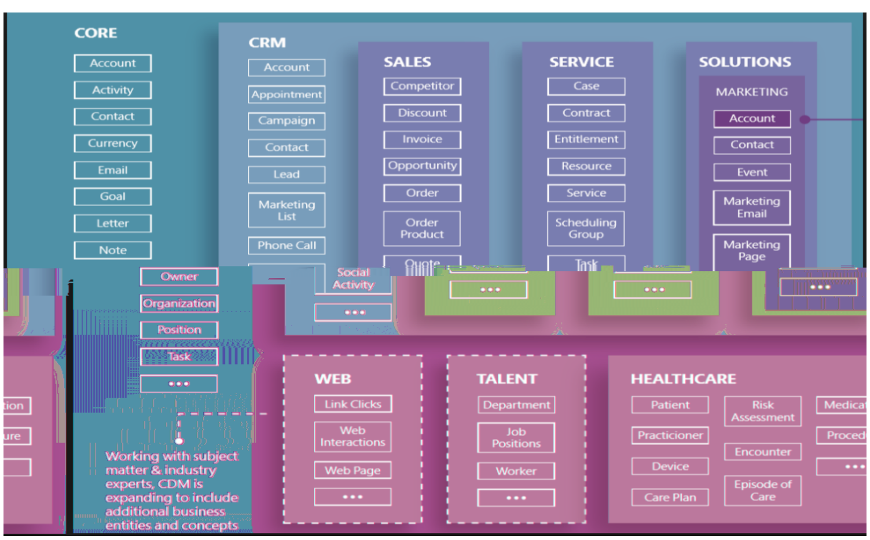

Figure 5-41 The Common Data Model (CDM) Poster (CDMURL)

The Internet of Things (**IoT**) is a novel paradigm that can also affect logistics and supply chain management based on the idea of connecting inanimate objects. By providing objects with embedded communication capabilities and a common addressing scheme, a highly distributed and ubiquitous network of seamlessly connected heterogeneous devices is formed, which can be fully integrated into the current Internet and mobile networks, thus allowing for the development of new intelligent services available anytime, anywhere, by anyone and anything (Ballot2014). AIOTI, the Alliance for Internet of Things Innovation, has created a High-level architecture (AIOTIHLA) (**AIOTI HLA**), that is based on the **ISO/IEC/IEEE 42010** standard which specifies minimal requirements for architecture descriptions, architecture frameworks, architecture description languages and architecture viewpoints.

The functional model of AIOTI is composed of three layers:

- The Application layer: contains the communications and interface methods used in process-to-process communications.
- The IoT layer: groups IoT specific functions, such as data storage and sharing, and exposes those to the application layer via interfaces commonly referred to as Application. Programming Interfaces (APIs). The IoT layer makes use of the Network layer's services.
- The Network layer: the services of this layer can be grouped into data plane services, providing short- and long-range connectivity and data forwarding between entities, and control plane services such as location, device triggering, QoS or determinism.

AIOTI HLA includes a functional model which describes functions and interfaces between functions of the IoT system, as follows:

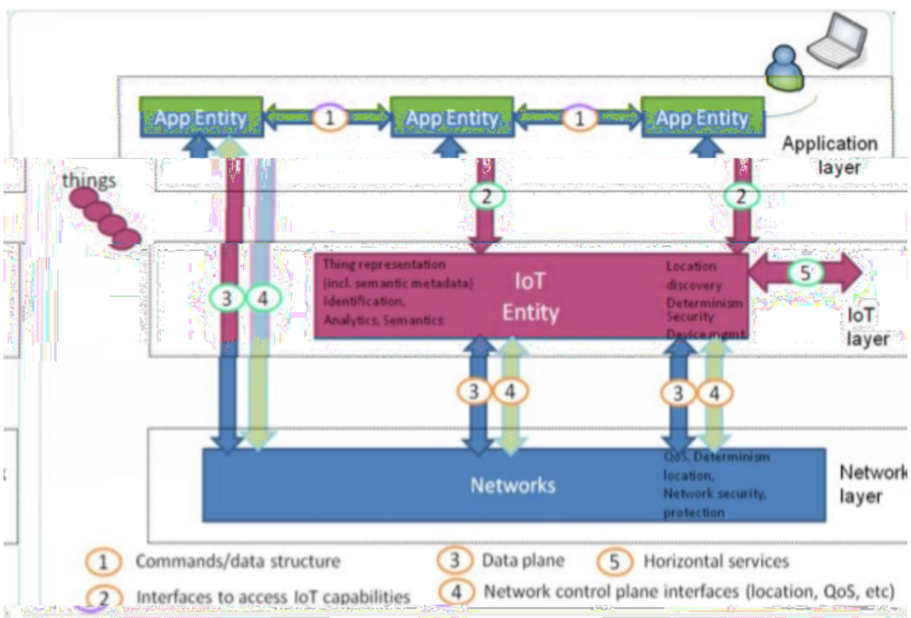

Figure 5-42 AIOTI HLA functional model (AIOTIHLA)

IoT is a clear enabler of PI and should be considered, but there is an enormous number of technologies, providers and solutions, as it is described in the IoT Landscape 2018.

D C E L

This layer is responsible for the encapsulation of data in a standardized way to ensure the identification of participants and assets. GS1 standards seem to be the best approach to cover:

Data Identification:

- Global Trade Item Number (GTIN): for products and services (i.e. can of soup, chocolate bar, music album).
- Global Location Number (GLN): for parties and locations (i.e. companies, warehouses, factories, stores).
- Serial Shipping Container Code (SSCC): for logistics units (i.e. unit loads on pallets, roll cages, parcels).
- Global Returnable Asset Identifier (GRAI): : for returnable assets (i.e. pallet cases, crates, totes).
- Global Individual Asset Identifier (GIAI): for assets (i.e. medical, manufacturing, transport and IT equipment).
- Global Service Relation Number (GSRN): for service provider and recipient relationships (i.e. loyalty scheme members, doctors at a hospital, library members).
- Global Document Type Identifier (GDTI) : for documents (i.e. tax demands, shipment forms, driving licenses).
- Global Identification Number for Consignment (GINC): for consignments (i.e. logistics units transported together in an ocean container).
- Global Shipment Identification Number (GSIN): for shipments (i.e. logistics units delivered to a customer together).
- Global Coupon Number (GCN): for coupons (i.e. digital coupons).
- Component/Part Identifier (CPID): for components and parts (i.e. automobile parts).
- Global Model Number (GMN): for product model (i.e. medical devices).

Data capture:

- GS1 Data Capture EAN/UPC barcodes: used to encode information such as product numbers, serial numbers and batch numbers.
- Tag Data Standard (TDS): defines the Electronic Product Code (EPC), including its correspondence to GS1 keys and other existing codes. TDS also specifies data that is carried on Gen 2 RFID tags, including the EPC, User Memory data, control information, and tag manufacture information.
- Tag Data Translation (TDT): is concerned with a machine-readable version of the EPC Tag Data Standards specification.

Data exchange:

- EDI (Transaction Data): GS1 XML, EANCOM, GS1 UN/CEFACT XML.
- Product Data Sharing (Master Data)
    - Global Data Synchronisation Network (GDSN)
    - Global Product Classification (GPC)
    - GS1 SmartSearch
- Product Data Sharing (Master Data)
    - Global Data Synchronisation Network (GDSN)
    - Global Product Classification (GPC)
    - GS1 SmartSearch
    - GS1 Digital Link
    - GS1 Mobile Ready Hero Images

S D L

This transversal layer should be considered in order to handle who is allowed to see or to modify what data, as well as who organization or participant may perform what kind of activities (tasks, messages, services or business process executions).

This layer aims to cover the identification of participants, their potential roles, their granted privileges as well as the management of the asset's information lifecycle.

Table 5-8 Security issues on Digital Interconnectivity Layers

Digital Interconnectivity Layer	Security & Data privacy aspects to be considered
Collaborative Business Process	• Identification and verification of participant authorities. • Management of peer-to-peer consensus algorithms. • Cryptography-based information saving on a distributed ledger.
Business Process Interconnection	• Identification and verification of participant authorities. • Role-base granted permissions on orchestrators.
Service Choreography	• Identification and verification of participant authorities. • WS-Security for transactions.
Service Orchestration	• Identification and verification of participant authorities. • WS-Security for transactions. • Role-base granted permissions on orchestrators.
B2B Interoperability	• Identification and verification of participant authorities. • Role-base granted access to service interfaces. • Role-base granted access to data.
Data Integration & Standard Smart Interfaces	• Identification and verification of participant authorities. • Role-base granted access to service interfaces. • Role-base granted for IoT services.
Data Capture & Encapsulation	• Data privacy.

WS-Security standard, created by OASIS, is a framework designed to work with SOAP 1.1 and SOAP 1.24 by defining the security tokens and encryption mechanisms that go in the SOAP headers. WS-Security provides a general-purpose mechanism for associating security tokens with messages. No specific type of security token is required by WS- Security. The protocol specifies how integrity and confidentiality can be enforced on messages, and allows the communication of various security token formats, such as Security Assertion Markup Language (SAML), Kerberos, and X.509. Its main focus is the use of XML Signature and XML Encryption to provide end-to-end security.

5.3 Universal Interconnectivity

According to the various encyclopedias and online dictionaries, 'Universal', used as adjective, can be defined as '*existing everywhere or involving everyone*' (e.g. universal interest such as security, justice…) whereas 'Interconnectivity' could be defined as '*the state or quality of being interconnected; how well parts are connected and work together*'. Universal Interconnectivity would mean in generic term '*the overall quality of the (inter)connections for all involved partner permitting a high degree of collaboration*'. In this context, the need for defining a set of collaborative messages and protocols is absolutely a key driver.

A fundamental aim when conceptualizing and implementing the Physical Internet is universal interconnectivity. It has been fully integrated in the PI Manifesto from 2012 with the following main components:

- High-performance logistics centers, movers and systems, making it seamless, easy, fast, reliable and cheap to interconnect physical objects through modes and routes, with an overarching aim toward universal interconnectivity.
- Multimodal logistics centers designed for the PI enabling seamless, fast, cheap, safe, reliable, distributed & multimodal transport and deployment of PI containers across the Physical Internet.
- Interfaces optimized for universal interconnectivity: physical and digital interfaces exploiting the characteristics of PI containers and standardized worldwide.

Therefore, universal interconnectivity transposes in a quest for high-performance logistics centers, systems and movers exploiting world standard protocols to interconnect PI containers through modes and routes. The nodes of the Physical Internet are concurrently routing and accumulation sites and facilities within the networks, as well as gateways interfacing with the entities out of the Physical Internet.

As currently conceived, the activities of sorting, storage and handling physical objects are most often brakes to interconnection. This occurs in train sorting yards, as well as in crossdocking platforms. There are exceptions, however, such as some of the recently implemented and reengineered container ports.

The Physical Internet generalizes and functionally standardizes unloading, orientation, storage and loading operations, widely applying them to PI containers in a smart automated and/or human assisted way. As the Physical Internet has to operate as well in Chicago as in Dakar, between the Netherlands and Italy as well as between Helsinki and Beijing, or yet as well from Singapore to Los Angeles, as from Québec to Iqualuit, this universal interconnectivity between automatic, automated, mechanically assisted and manual operations is of upmost necessity.

In the context of ICONET, two fundamental aspects will therefore be further analysed: (1) The requirements and high-level specifications for IoT-based components of the PI such as containers, wagons, trucks,and (2) the automation needs and overall trends in particular in warehousing and nodes.

5.3.1 IoT requirements

IoT (Internet of Things) is a key innovation enabling a massive number of devices to connect to the Internet. The concept of IoT leads to an explosive growth of IoT practical applications that can be found in many fields including smart home, smart health, smart metering, asset tracking, and agriculture (see also Figure 1). It is believed that IoT is revolutionizing human life to be smarter in every life aspect.

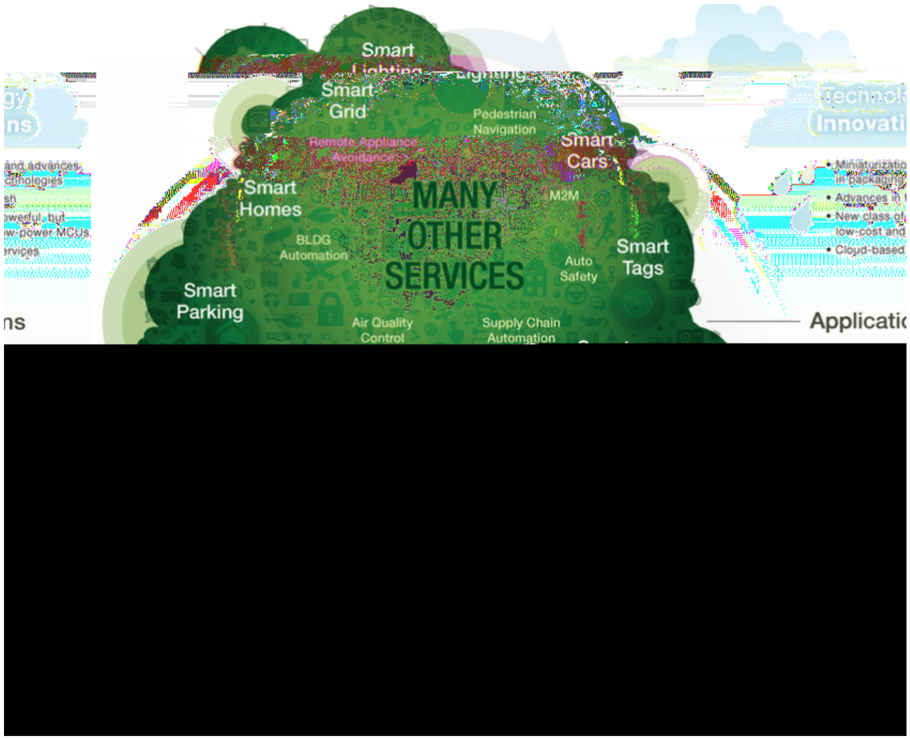

Figure 5-43 IoT systems in a snap-shot

However, the world of IoT is fragmented. The fragmentation of IoT firstly comes from a diverse option of connectivity for end devices provided by different manufacturers. We have seen a dramatic growth of communication technology for IoT in the market. Each technology certainly aims at different application domains. Secondly, there exists a variety of application protocols to connect to the Internet with many data formats that could be exploited. Besides, vendors tend to create their own IoT platform exploited a proprietary protocol that leads to the creation of vertical IoT silos. An IoT silo is similar as a nation using a language that other silos are unable to understand. Those problems are known to be the interoperability issue in IoT.

In the context of the Physical Internet, the modular PI containers will be continuously monitored and routed, exploiting their digital interconnection through the IoT. The objective of the ICONET's D1.16 on "*Requirements and High-Level Specifications for IoT-based Smart PI Containers*" is about the definition of an IoT-enabled PI environment. In this context, a generic, innovative and interoperable IoT architecture will be defined to track and monitor the goods throughout the logistics chain (from the sender to the receiver). Furthermore, the deliverable highlights the contribution of innovative IoT components to the PI configuration, that will be formalised and developed within the project lifetime.

Besides the π-containers fitted with IoT devices, all other components of the PI hubs and networks would need to be equipped with telematic solutions not only for monitoring or rerouting purposes but also for predictive maintenance, automation and autonomous driving, safety, security and data analytics. Those components are (non-exhaustive list): infrastructure (road, rail, barge), traction units (trucks, locomotives, ships), rolling stock (wagons, semi-trailers), lifting devices (fork lifts, cranes) and goods. The use of telematics and IoT technologies serves the main following objectives: (1) enhancing productivity, (2) reducing costs, (3) providing additional services, and, (4) making business models more flexible.

In the following section, recommendations and best practises extracted from various communities (wagon and road) are briefly summarised.

Wagon community

The Technical Innovation Circle for Rail Freight Transport (known as *Tis*) pursues the objectives to identify relevant basic innovations to meet or support the following 5L functionalities: i) Low-noise, ii) Lightweight, iii) Long-running, iv) Logistics-enabled, v) Life-cycle-cost-oriented.

TIS has set out technical, operational and economical requirements on Telematics and sensor technology in a report[7]. TIS identified altogether 24 practical application opportunities for telematics solutions (see figure 5-43 for an overview of the possible services). Seven (7) of these were defined as basic applications that should be implemented in every freight car.

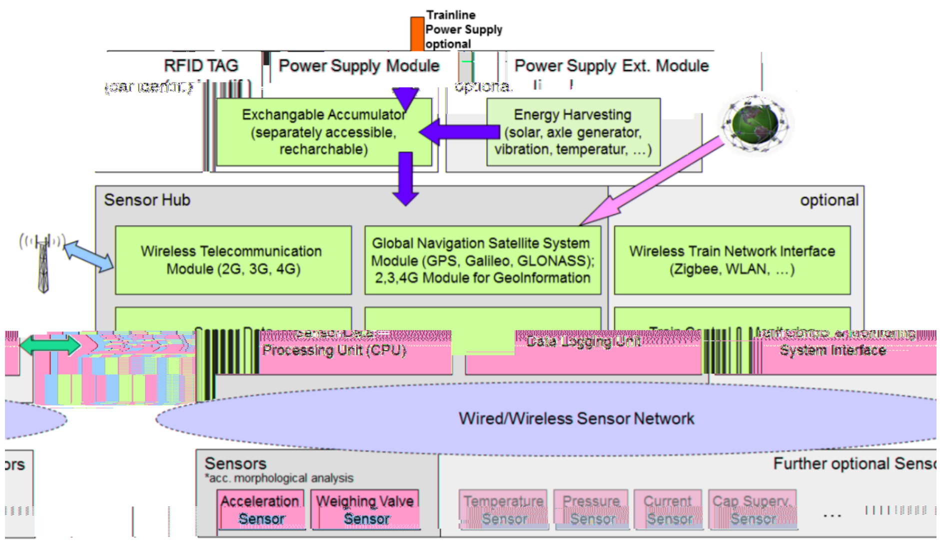

Figure 5-44 - TIS - IoT for freight wagons

Compatibility of telematic units and sensors of different suppliers was not guaranteed as there has been no standardisation of data exchange. Only with a common standard for the different interfaces of telematics and sensor technology devices of different suppliers can communicate with each other and a widely spread migration into the European wagon fleet seems possible. Initiated by dialogue between the TIS-group and various suppliers of telematics and sensor technology, an industry platform for telematics and sensor technology (ITSS) has been founded. The objectives of the ITSS practice group are:

- Development of a common, open and free-of-charge standard for exchange of telematics date in rail freight traffic.
- Provider neutral, sustainable, modular, flexibly expendable.
- Applicable in Europe / worldwide.
- Low efforts for implementation for providers and user.
- No regulation on overlapping processes.

[7] See http://www.innovative-freight-wagon.de/wp-content/uploads/TIS-requirements-telematics-and-sensor-technology-EN.pdf

- Non-restrictive.

Currently sixteen (16) companies participate in this ITSS-platform.

Road community

In order to facilitate the uptake of automated and connected driving in the near future, the European automotive and telecom sectors have identified three priority areas for further cooperation: (1) Connectivity: firstly, automated driving will require upgraded communication systems that provide higher performance levels in terms of latency, throughput and reliability of the network. (2) Standardisation: crucial for a timely and cost-efficient market development of connected and automated driving and (3) Security: to obtain customer trust in connected and automated driving, it is critical to ensure that all data transmission to and from vehicles, as well as all data processing that is required, occurs in a secure manner.

IRU, the official representative of the road community in the world, has highlighted the importance and the huge potential of road telematics in its 2018 report on the future of road transport. It is clearly reported that:

- 80% of respondents from transport companies across the three regions believe that new fleet management solutions, new digital platforms for vehicles and telematics on board will boost productivity
- 21% of the transport companies globally, automation and telematics are the biggest innovation opportunities for world transport.

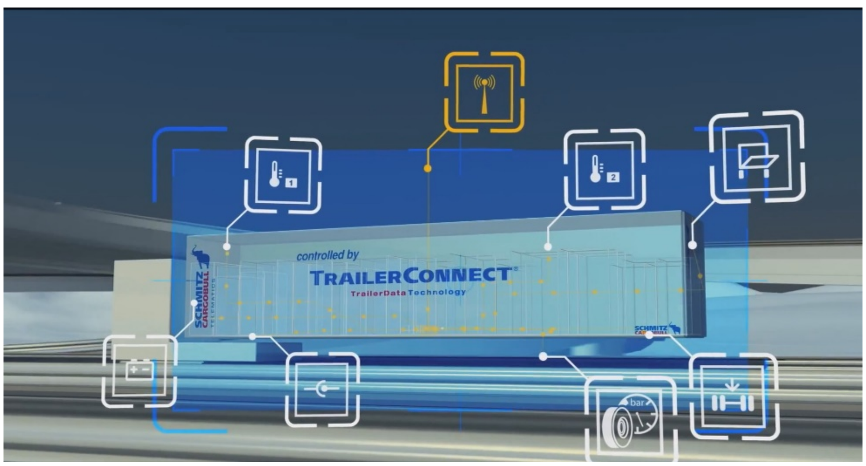

Figure 5-45 IoT on road vehicles

The European-leading producers of semi-trailers, Krone and Schmitz Cargobull, have now integrated in their portfolio telematic devices and services for the following main purposes: (1) positioning of the vehicle, (2) safety/security (doors), (3) reefer specific functions (temperature) and (4) monitoring of the basic features of the vehicles (tyres, brake pressures, etc. All data are transferred via standard protocols and available in cloud solutions. The key challenge, as for the wagon community, is to create a standardised environment for all players and actors. Solutions developed by commercial entities like Transics (a Wabco company) pushed forward standardisation in communication and data sharing. The development of the Transics platform has been made possible thanks to the strong support and collaboration of other industry players such as Krone, Schmitz-CargoBull, ThermoKin

5.3.2 Automation

A machine works – to put it simply – like a person. Just as humans perceive their surroundings using their sensory organs, a machine detects its environment using sensors, devices and distance measurement systems. The machine continually picks up signals and sends them over the network to the controller. The controller interprets them as input signals and sends them as output signals to the actuators.

A machine is the technical counterpart to the human body:

- **Sense of sight, taste, smell, touch** – Vision, pressure, photoelectric, inductive, capacitive sensor, position/distance measurement system.
- **Sense of hearing** – RFID read head, ultrasonic sensor.
- **Nerves** – Network, cable, connector.
- **Brain** – Controller, PLC.
- **Language** – RFID read head, horn, SmartLight.
- **Muscles** – Valve, drive, motor, stack light, horn.

Figure 5-46 Man versus machine

Automation in logistics and transport is taking place in the context of a broader transformation of the industry and the world of work. Ongoing discussions about the future of work, the impact of the digital transformation on labour markets, and challenges and opportunities of the 'fourth industrial revolution'1 attest the need of analysing and anticipating the upcoming changes.

In the context of ICONET, the following automation trends and best practices have been approached:

- Automation in the logistics industry (focus on automated storage and warehouses).
- Automation in the hubs/nodes (focus on automated handlings of maritime containers).
- Automation in the transport modes (focus on road and rail).

L I

The main categories of warehouse/materials handling automation reviewed in this section are:

- Goods-to-Person Automation.
- Automated Palletizing/Case Packing.
- Pick-to-Light/Put-to-Light/Pick-to-voice Technology.
- Robotic Picking/Retrieving Systems.

<u>ROBOTICS FOR MATERIALS HANDLING</u>

Robotics is a technology long established in materials handling, which is however continuously evolving and advancing.

Although initially robots were deployed in manufacturing operations, in today's distribution centers, robots are also used for loading/unloading, retrieval/put-away functions, pallet stack solutions, goods-to-picker applications and other purpose. Larger distributors and retailers like Amazon and Walmart plan to extend their existing robotics installations in the next five years.

Latest robotic applications include the outbound inventory flows from the warehouse rack to the pick station. This category includes auto-guided vehicles that typically follow electronic navigation grids in the warehouse floor. However more flexible autonomous vehicles are also been under development. These, for example, learn the warehouse landscape without the aid of a floor-guided track system. Such vehicles carry a payload of 3000 pounds or more and travel at a speed of 4-5km/hr.

Robotics have started to be used for unloading, bin retrieval, and pallet stacking. Stationary robots with flexible arms can perform a multitude of tasks such as unloading trailers, stacking pallets, and picking orders. Some robots have built-in 3D vision sensors to enable them to identify the carton size to retrieve in the stacking order of a pallet configuration and create optimal stacking. New generation robots in this category can identify a product on a shelf or rack via a two- or three-dimensional camera, grab it and transport it to the staging area for final distribution, without human assistance.

Flexible robots can be quickly reconfigured for different tasks such as unloading cartons from an inbound trailer stacking boxes on a pallet etc. Autonomous robot can operate on an open path navigation system without the aid of magnetic tape, wires, or reflective targets and can learn the layout of the hub.

AUTOMATIC IDENTIFICATION OF INCOMING P-CONTAINERS

PI container automatic identification can be achieved using several different technologies. Barcodes is one of the oldest technologies that is still widely used, while RFID is also gaining traction. Other in-motion weighing labelling and manifesting systems can also be deployed in a manner to minimise touching points.

SORTING

Sorting may occur immediately after picking, so that items can be assembled into the appropriate orders ready for dispatch. If there is a separate packing operation, sortation may also occur after packing so that the packed goods can be assembled into vehicle loads (or into postcode areas ready for postal deliveries). Mechanized sortation can be undertaken by using conveyor systems. For high-speed sortation, conveyors normally feed into specialist sorters [6]. Products to be sorted are normally identified by means of an automatic recognition system (e.g. bar code). Next-generation sortation systems provide order accuracy and speed, particularly in high-throughput facilities.

FORK LIFT AUTOMATION

Narrow aisle configurations and towering ceiling heights in today's hubs can create several access, safety, and productivity issues. While tighter aisles and maximized stacking capabilities result in better space utilization, it becomes more challenging to retrieve pallets and boxes stored above a certain height. Many high-bay lifts are equipped with a high visibility mast to expand the operator's visibility.

GOODS-TO-PICKER

In general, picking today is largely a manual operation. Up to 75 percent (75%) of an employee's day is linked to order picking. Increasingly, however, technological aids are employed to provide high levels of productivity and accuracy. For instance, picking operations tend to be manually operated with technological assistance. It is inefficient for a picker to travel the whole length of a pick face if a relatively small proportion of the total product range is to be picked during that pick run. Various types of equipment have therefore been devised to bring goods to the picker rather than the other way around. These goods-to-picker systems are normally computer controlled so that the precise SKUs are presented to the picker in the required sequence.

Various hub designs are used to facilitate picking, such as zone picking. In zone picking, the hub/warehouse is split into different zones with specific order pickers dedicated to each zone. On receipt of a customer order, the warehouse management system (WMS) examines each order line on the order and identify in which zone the picking should be carried out. WMS then issue separate picking instructions to each zone.

To improve picking efficiency, most distribution facilities have adopted the "goods-to-picker" concept. Goods-to-picker strategies reduce the distances a picker has to cover to retrieve orders. Instead, inventory in a goods-to-person platform is delivered to the picker/packer workstation via conveyor systems or robotic delivery modules. This improves order accuracy and processing speed. Advanced materials management systems—such as conveyors, robotic pickers and packers, and auto-guided vehicles—all collectively yield more efficient fulfilment processes and order accuracy. Advanced conveyor systems with voice-directed order fulfilment and pick-to-light systems, increase order efficiency to up to 5,000 pickings a day.

AUTOMATED PICKING SYSTEMS

Automated storage and retrieval systems (AS/RS) are used for computer-controlled inventory management.

The picking systems described so far all require a person to pick the individual items that make up an order. However, there are automated picking systems available that are suitable for certain applications. These include the following:

- Dispensers. Items are dispensed automatically from the magazines into a bin as it passes on the conveyor below the magazines. This bin may represent a customer order that is conveyed directly to packing.
- Pick-to-light and put-to-light. Normally, in these systems, every picking location is fitted with an LED light controlled by computer. A common application is for a plastic tote bin, representing a customer order, to be taken by conveyor to a specific zone of the warehouse. The bar code on the tote bin is read, and the appropriate LED panels illuminate, showing the quantities of items to be picked for all SKUs required for that order.
- Pick-to-light and put-to-light technologies offer order accuracy and visibility, short learning curve for personnel and potential for optimisation.
- Pick-to-voice. Pick-to-voice technology requires low capital investment and provides quick integration. Voice-directed picking offers increased efficiency, accuracy, and safety. Voice technology can be integrated with existing WMS software, leading to order accuracy of 99.9 percent (99,9%).

BEST PRACTICES

1. Online supermarket OCADO

OCADO, a British online-only supermarket designs highly automated warehouses and sells the technology to other grocery chains. They operate from a warehouse in Erith, UK. When fully ramped up, it represents 0.75 million storage locations, managed by over 3,500 robots that ship over 296,000 orders per week. The paradigm is all about ‘efficient use of space’. Crates are stored in huge stacks, the positions of which are algorithmically decided. A typical 50-item order in a traditional warehouse can take hours, at Ocado, the robots come together in a huddle or split up and reduce the picking time to 5 minutes. Where humans do the unpacking and packing, robots sort and rearrange the inventory 24/7. The robot’s actions are coordinated by a central computer.

Website: https://www.ocadotechnology.com/

The robot is developed under the H2020 SecondHands project and uses artificial intelligence, machine learning and advanced vision systems to understand and support human workers. Key areas of focus, include:

- Proactive assistance: the robot developed will have cognitive and perceptive ability to understand when the operator is in need of help, understand how this help can be given and provide relevant assistance.
- Artificial intelligence: The team will enable the robot to progressively acquire skills and knowledge needed to provide assistance. In fact, it will even anticipate the needs of the maintenance technician and execute the appropriate tasks without prompting.

- 3D perception: Advanced 3D vision systems will allow the robot to estimate the 3D articulated pose of humans and offer support when it is needed without being asked.
- Humanoid form and flexibility: A humanoid shape and human-like flexibility will enable natural collaboration between humans and the robot. It will feature an active sensor head, two redundant torque-controlled arms, two anthropomorphic hands, bendable and extendable torso and a wheeled mobile platform.

The main objective is to increase safety, efficiency and productivity.

Website for more information: https://secondhands.eu/

From the Erith experience, OCADO strategically decided to technologically innovate on the issue of handling of 'sensitive' product. In May 2015, they kicked of the H2020 funded 'Soft Manipulation' (SOMA) project. The developed Soft Manipulation technology will be applied to an open manipulation problem in the food and agriculture industry, that is the handling of irregularly-shaped, flexible, and easily damageable goods, such as fruit and vegetables, and to a security problem in a field, such as that of entertainment, when human and robots have to physically interact. SOMA will design capable soft hands for the versatile and competent exploitation of the environmental constraints, and develop versatile, robust, cost-effective, and safe robotic grasping and manipulation capabilities.

Website for more information: http://soma-project.eu

2. Wehkamp

In 2015, Dutch e-commerce specialist wehkamp.nl opened the world's largest automated distribution center in Zwolle, Netherlands. Knapp supplied the automated handling systems. 468 automated shuttles retrieve items from 525,000 pick locations. The maximum pick capacity is 196,000 items per day, or 61 million items per year. The system handles approximately 12,350 picks/hour, leading to 30-minute turn-arounds between the time a customer places an order and when the package is ready to be shipped. Dispatch tasks – such as dispatch sorting and finishing, including document insertion and closing of dispatch cartons or bags – are carried out automatically, using KiSoft warehouse logistics software.

Website for more information: https://www.wehkamp.nl

3. Albert Heijn

Albert Heijn is the first Dutch supermarket that has an automated distribution center for sustainable products. The automated process is handled by 28 robots, 2 in each of the 14 robot cells. There are 57 automated guided vehicles (AGV) in the distribution center that prepare the roll containers for shipment. Drivers drive a pallet in 8 infeed stations, after which the pallets are stored by 7 cranes. After a pallet has been stacked, the products are placed in special trays via a conveyor. From there a system of conveyor belts runs to the warehouse, where there are 137,000 places for package storage with 122 600 trays that are equipped with movable floors.

Stacking is done via two robots. One positions a package, the other places it on a roll container. The systems can calculate per order how the products should be stacked on a roll container, so that there is no need to split. Each product receives sixteen parameters. Is it in a box, does the packaging contain glass, how large is the product, how fragile is it, etc. The system then calculates in which order the products must be delivered from the storage and how stacking is required. Finally, the 57 AGVs ensure that all orders are placed in the right place in the expedition, after which the driver loads his truck manually. The number of packages to be processed per day increases by 50 percent to 400,000 per day. AH achieves that productivity with one third of the people.

Website for more information: https://www.ah.nl

4. BASF

With an integrated warehouse and transport concept, BASF, leader in chemical products, implements a new logistics concept for the chemical logistics. The most important components of this concept are fully automated transport vehicles, the new rail-optimized tank containers instead of railway tank wagons as well as a tank container storage.

Together with the VDL Group, BASF has developed a prototype of an autonomous driving vehicle that is 16.5 meters long and can carry 78 tonnes. Today, the delivery of a tank wagon from the BASF station to one of the over 150 loading points at the location takes about 22 hours, with such a vehicle it will only take an hour in the future.

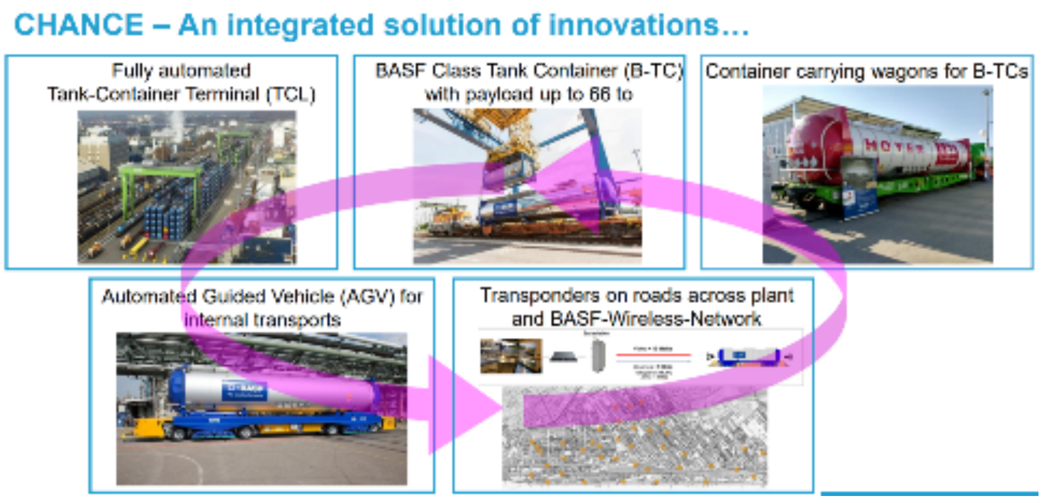

Figure 5-47 The new BASF logistics concept

The company has developed the new 45- and 52-foot tank containers together with the Belgian tank container manufacturer van Hool based on the 20- and 30-foot tank containers. These are already used today in combined transport. The so-called B-TC (BASF Class tank container), combined with railway carriages, can be used more flexibly as classic railway wagons. The containers can be transported independently of the rails and can be stored in a space-saving manner (six pieces one above the other).

The logistics concept also includes the fully automatic tank container warehouse at the Ludwigshafen site. It is a fully automatic outdoor storage facility for tank containers for the storage of liquid substances and liquid waste. It is designed for a capacity of 2,000 standard containers and has two cranes with a loading capacity of 75 metric tons each. Goods can be handled by AGV, truck and rail.

C

According to B2B research group Marketsandmarkets, the semi and fully automated container terminal market is currently worth $9.09 billion. This is expected to jump 20% to $10.89 billion by 2023. This report credits the growth to increasing demand for larger container vessels, high labour costs in developed nations and rising competition among container terminals. As it stands, Asia Pacific holds the largest share in the automated container terminal market, followed by Europe and North America.

Despite the clearly identified advantages towards automation, of all the terminals in the world, only 3% are either semi or fully automated. In Europe, the most important ones are based in Rotterdam (known as EUROMAX) and in HAMBURG (known as CTA). Figure 53 provides a map of all existing and planned automated container terminals in the world.

Figure 5-48 Existing and planned automated container terminals

In the next section, some of the leading fully automated terminals around the world and how they've managed to adopt automation to take their port efficiency to the next level are presented.

(1) Rotterdam EUROMAX

The Euromax Terminal is situated at the north-westerly corner of the Maasvlakte, just around the corner from the entrance to the Rotterdam port. With its depth of 16.65 meters, it can easily accommodate even the largest fully laden container vessels. The quay walls of the Euromax Terminal, which go 34 meters into the ground and are 1.20 meters wide, have been designed with a further deepening of the port to 19.65 meters in case of even move the containers to and from the stack. In comparison to previous generations, the speed of the new AGVs has doubled: from three meters to six meters per second.

(2) Hamburg Container Terminal Altenwerder (CTA)

Apart from the compact layout with its clear structure and short distances, Altenwerder's hallmark is its highly sophisticated automation. A complex, continually upgraded IT system controls all the different elements, from the container gantry crane to storage management. The basis of CTA's efficiency is optimized interplay.

Container handling is split into two stages: on the waterside, double trolley gantry cranes load and discharge from/to the vessel. The gantry crane's main trolley is operated by a driver, instinctively offsetting a ship's inevitable movement. Computers are unable to do this and moreover do not attain the productivity of experienced crane drivers. Nor can the responsibility for the safety of cargo handling at this ship-terminal interface be assigned to a computer.

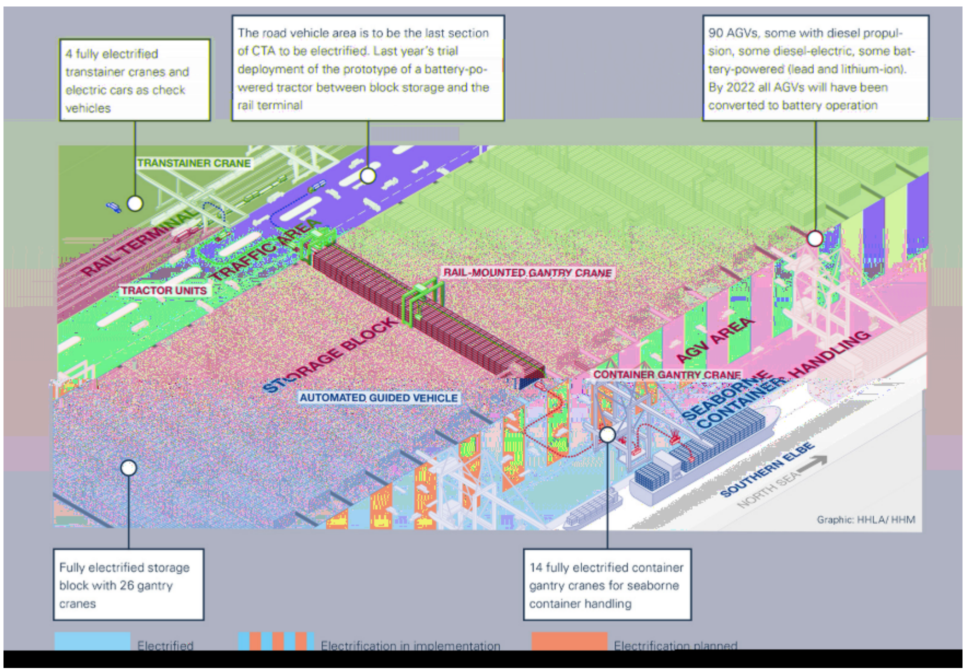

Figure 5-50 HHLA CTA Container Terminal

The container yard consists of 26 storage blocks, each serviced by two rail-mounted gantry cranes (RMGs). The cranes are of different heights and can, therefore, work in parallel. This also enables containers to be fed to the RMGs during essential maintenance work. Boxes are stored to instructions from the software, and slots optimized during quiet phases to facilitate the fastest possible release. Landside release is carried out by staff in the control center, using a joystick and a camera to lower a box on to a truck or chassis. Transport between the storage block and the rail terminal is by tractor plus the terminal's own chassis.

Figure 5-51 The QQCTN Container Terminal

(3) Qingdao New Qianwan Container Terminal, Port of Qingdao

The Qingdao New Qianwan Container Terminal (QQCTN) at the Port of Qingdao is Asia's first fully automated terminal. It is known to locals as 'ghost ship'. With two fully automated berths stretching across some 660 meters of its quay, the port of Qingdao can handle 5.2 million TEUs. It's also equipped with seven ship-to-shore cranes, 38 automated stacking cranes, and 38 automated guided vehicles (AGV). With machines having taken over from berth to container yard, the humans can retreat to their control rooms and monitor them from there.

The terminal began operations in May 2017. In its first year, it handled close to 800,000 TEUs and serviced over 660 vessels. When operations started, it had an average loading efficiency of 26.1 containers per crane per hour. That figure has since increased to 33.1, which is reportedly 50% more than the average worldwide.

(4) Yangshan Deep Water Port, Port of Shanghai

The world's largest fully automated port is at the world's busiest port - the Port of Shanghai. It's located on Yangshan Island, just across Donghai Bridge, which was specially built to service the terminal. Phase 4 of the Yangshan Deep Water Port, covering 2.23 million square meters and 2,350 meters along the shoreline, began trial operations in December 2017.

Upon completion, the Yangshan container port will be fully handled by 130 automated guided vehicles AGVs, the most in any single container terminal the world. Alongside them will be 26 bridge cranes, 120 rail-mounted gantry cranes, and just a handful of workers tucked away comfortably in a control room.

T

Road Transport – first/last-mile freight delivery solutions

First developments are under way for deploying small automated vehicles (sometimes called road drones) for urban freight distribution. Although currently a smaller niche application compared to the examples above, in the longer term, this might develop into a viable addition to the wider freight and logistics sector.

Due to the sharp timing demands valid in this sector, in many vehicles some sort of communication system is integrated. The further use of this for safe, clean and fast (urban) freight delivery need to be implemented. A challenging part here is the scattered market and varying local (governmental) demands.

Furthermore, for a successful implementation of first/ last mile freight delivery in a cooperative and/or automated mode, a solid connection to other transport modes like rail and waterborne are essential. An important likely future trend will be the combination of this type of transport also with short distance transport of people. Another need is the need for further standardization of modular load units (boxes, pallets, containers), transference processes between vehicles and for goods delivering, which will largely affect effective automation of cargo transfer and cross-modality, both for first/last-mile freight delivery and long-distance transport.

Road Transport - Heavy Goods Vehicles (HGVs) on highways

Truck platooning is an example of both connected and automated transport. Clear benefits in terms of road safety, emissions, and road capacity have been proven through the automation and operation at minimum headways. Several EU projects (i.e. SARTRE, COMPANION, CONVOI, AutoNET2030, iGAME, ENSEMBLE) have tackled the technical challenges of road trains in order to leverage its benefits. These projects have implemented different levels of automation for the vehicle control and all of them heavily rely in the use of cooperative systems and connectivity to improve the platooning performance and facilitate its integration to the logistics chain in an efficient, safe way.

Also driven and (partially) performed by industry in conjunction with government funded efforts, is the testing of automated HGVs on motorways in many countries including the USA, Japan, and many EU countries. A highly visible example of this is the recent Truck Platooning Challenge42, organised by the Dutch Government as part of their EU Presidency in the first half of 2016.

Potential obstacles to widespread real-world roll out include relevant regulation, cross-border legal fragmentation, fragmentation of technologies and equipment, appropriate business models and cases for sharing benefits in a platoon among transport companies and necessary infrastructure changes.

Specific tailored solutions will also have to be developed for the transfer of goods from these vehicles on specific corridors to other (automated or manually operated) road vehicles and/ or modes. Automated HGVs will also need the support of current and new ITS technologies, which together with logistics-related ICT, should be able to provide cost-benefit of platooning and thus enable European competitive logistics. The most likely future trend is that governments will allow for some larger scale pilots for truck platooning with a strong emphasis on the connectivity side of the technology.

This needs to be coordinated in some way to ensure seamless, efficient and safe multi-brand platooning in cross-border situations taking into account national regulation and a potential harmonization to enable European level deployment. More information on Truck Platooning: https://www.eutruckplatooning.com/default.aspx

Rail Transport

Automation technologies are already well embedded in selected market segments of rail transport, specifically in passenger systems such as metros. The highest grade of automation (GoA) 4 – a fully automated driverless rail systems exist today in metro systems, e.g. in Copenhagen or Paris. Next to automatic operation based on moving block principle (creating in real-time safe distances between moving vehicles), the GoA 4 system is responsible for door closing control, dealing with obstacles on track during the journey and emergencies. It should be noted that this highest GoA level was mainly introduced on newly constructed metro lines, in an isolated environment, not accessible for third parties. Solutions are not standardised and expensive.

Railway competitiveness against other modes of transport depends to a larger extend on economies of scale in deploying new technologies and an overall acceptation of standardization of the technical requirements and operational rules on European level. Without a wide deployment, the impact of automation on policy goals will stay limited.

The existing state of the art and ongoing R&I efforts under the flagship of European Commissions' Shift2Rail Joint Undertaking (JU), creates a promising perspective for an automated and connected rail technological roadmap. Moreover, the recently created technology & innovation roadmaps of ERRAC are used as a guideline, to establish a dedicated roadmap related to automation & connectivity in the rail domain.

The existing Strategic Rail Research Innovation Agenda (SRRIA) and related roadmaps for various parts of rail-bounded systems address directly and indirectly several aspects of automation and connectivity. Already today the on-going R&I efforts under Shift2Rail are responding to the following objectives:

- Improving rail system performance by moving to open, harmonized and interoperable technologies: automatic driving, communication, intelligent measuring, monitoring and information systems, shift to multimodal traffic management systems, financial transactions/ticketing, tracking and tracing vehicles and goods in real time.
- Sustain and further develop the railway sector robustness by increasing capacity by automation.
- Increase rail attractiveness (passenger & freight) by improving connectivity, passenger information and experience, freight data handling, achieving shorter travel times.

- Improve competitiveness by reducing operational costs e.g. by automation of asset management systems, intelligent maintenance and operational processes and tools through whole life cycle.
- Sustain and further develop the environmental friendliness to become carbon-free transport mode by 2050 and provide society with a climate neutral transport alternative, partly by improving technical characteristics like energy efficiency due to higher automation.
- Effectively leveraging new technologies such as digitalization, new materials, big data, energy storage and efficiency.

The S2R Master Plan identifies eight priority research and innovation areas in which activities should be undertaken with a view to achieving the ambition of IP5 (freight):

- Implementation Strategies and Business Analytics;
- Freight Electrification, Brake and Telematics;
- Access and Operation Wagon design;
- Novel Terminal, Hubs, Marshalling yards, Sidings;
- New Freight Propulsion Concepts;
- Sustainable rail transport of dangerous goods;
- Long-term vision for an autonomous rail freight system.

The 'Autonomous train operation' aims to actively pursue the objective of Autonomous Train Operation (ATO), realised progressively until 2030, for mainline freight operation and the underlying operations, in order to increase the railway's competitiveness and to achieve operational efficiency gains and optimised resource utilisation. The following table summarises the projects related to ATO within the S2R programme.

Table 5-9 - ATO projects in S2R programme

Acronym	Objectives
ARCC	The overall aim of this specific Automated Rail Cargo Consortium (ARCC) proposal is to carry out an initial phase of rail freight automation research activities in order to boost levels of quality, efficiency and cost effectiveness in rail freight operations of the European railway sector. The three areas of research activities are: Transporting and delivering freight via automated trains, developing automated support processes at the nodes (e.g. terminals, yards and transhipment points) and advanced timetable planning. If automation and digitalisation processes are exploited in an appropriate way, rail freight transport can generate significant positive impacts for rail freight transport. For example, increased efficiency on the main railway lines and nodes, reducing lead time and energy costs. Additionally, improved services and customer quality so that the operational timetable is met reliably. Furthermore, optimised business processes and management of complex situations, such as a 15% reduction in time when rail assets sit idle within nodes.
FR8RAIL II	FR8RAIL II addresses following challenges: (1) New Automatic Couplers, provided with electrical power supply and data transmission functionalities, need to be implemented. (2) Telematics and Electrification will enable Condition Based Maintenance (CBM) and Cargo Monitoring System (CMS). (3) Future freight wagon design for the core and extended market will contribute to increased reliability of the freight transport due to its integrated solutions for telematics and electrification. (4) Future main line electric freight locomotives must feature highly flexible freight propulsion systems with reduced operational costs. (5) The connection of Automated Train Operation (ATO) and Connected Driver Advisory Systems (C-DAS) to the Traffic Management System (TMS) in train control

	centers of the Infrastructure Manager (IM) in order to allow transferring the traffic regulation information to the driving system.
SMART	SMART (Smart Automation of Rail Transport) main goal is to increase the quality of rail freight, as well as its effectiveness and capacity, through the contribution to automation of railway cargo haul at European railways. In order to achieve the main goal, SMART will deliver the following measurable objectives: • complete, safe and reliable prototype solution for obstacle detection and initiation of long-distance forward-looking braking, • short distance wagon recognition for shunting onto buffers, • development of a real-time marshalling yard management system integrated into IT platform available at the market.

6 Conclusions

6.1 Physical Interconnectivity

The following table summarizes the analysis done the state-of-the-art of existing projects, standards and emerging trends in the field of Physical Interconnectivity for the PI.

Table 6-1 Physical Interconnectivity - Summary of results

Components	Projects	Standards	Emerging Trends
PI Containers /Boxes	CLUSTERS 2.0 AEROFLEX MODULUSCA	• Primary packaging: standards exist for specific products • Secondary packaging: industry standards have been created (FEFCO for cartons) • Tertiary packaging: ISO and EUR pallets dimensions • Quaternary packaging: ISO and CEN standards	• IoT integration • New concepts for urban logistics • New material handlings • Micro boxes
PI Nodes / Hubs	CLUSTERS 2.0	• No standard exists to design or build a hub	• New concepts for hub and bundling services • New concepts towards enhanced multimodality • Automation • New value-added services

Regarding the Physical Interconnectivity (PI), the state-of-the-art and review of emerging technologies on the PI Boxes and PI nodes reveal the necessity to define a common approach aiming at enhancing interoperability and standardization.

The main recommendations and suggestions for this PI pillar are the following:

- PI Containers/Boxes:
    - *Push for standardization in all levels of packaging*: event if promising prototypes and demonstrators are developed within the projects CLUSTERS 2.0 and AEROFLEX, the need for fully interoperable and integrated PI container do not exist, in particular for the first and second levels of packaging impacting significantly the logistics processers and may be considered as a huge barrier in full automated warehouse handlings.
    - *Connect 'Urban logistics' with 'Long-distance supply chain logistics'*: new emerging technologies and concepts on both sides will significantly influence the possible dimensions of the future PI containers but the two worlds (logistics and transport modes) are lacking integration and collaboration. A logistic concept based on the Russian puppet principle should be elaborated.
- PI Nodes / Hubs:
    - *Elaborate an inventory of all current nodes in Europe*: the future PI network will be a reality under the condition that the current network of nodes is clearly identifiable. Initiative like railfacilitiesportal.eu should be further promoted and developed for all transport modes.
    - *Develop incentives for enhanced collaboration between nodes*: the benefits of collaborative models should be clearly identified and shared with the node community. The Living Labs should integrate this aspect when designing new solutions or services.
    - *Create and design new concepts for easy stuffing/un-stuffing of goods in a multimodal/intermodal PI environment*: to benefit of the full power of the Physical Internet,

goods should be easily packaged and transferrable to the PI containers. It is therefore required to create new interfaces to handle – in a full or semi-automated way – goods in an intermodal context (such as transferability between road and rail).

6.2 Digital Interconnectivity

The following table summarizes the analysis done regarding the state-of-the-art of existing projects, standards and emerging trends in the field of Digital Interconnectivity for the PI.

Table 6-2 - Digital Interconnectivity - Summary of results

DI Layer	Projects	Standards	Emerging Trends
Collaborative Business Process		GS1 LIM, UBL OMG CMMN	Smart contracts P2P blockchain
Business Process Interconnection	COMCIS	OMG BPMN, DMN	BPMN platforms
Service Choreography		WS-Choreography WS-CDL WSCI	ebXML
Service Orchestration		WS-BPEL	Messaging Platforms (JMS, MSMQ, EAI Tools)
B2B Interoperability	iCargo, SELIS	Web Services (UDDI, SOAP, WSDL, WS-Security) RESTful Services RPC (XML-RPC, JSON-RPC)	Layered Architecture N-tiers for legacy integration
Data Integration & Standard Smart Interfaces	MODULUSHCA	GS1 Data exchange (GS1 XML, EANCOM, GS1 UN/CEFACT XML, GDSN) XML Encryption, XML Signature, X.509 IoT ISO/IEC/IEEE 42010	Common Data Model AIOTI HLA
Data Capture & Encapsulation		GS1 Data Identification (GTIN, GLN, SSCC, GRAI, GIAI, GSRN, GDTI, GINC, GSIN, GCN, CPID, GMN) GS1 Data capture (EAN/UPC Barcodes-RFID, TDS, TDT)	

Regarding Digital Interconnectivity (DI) the review done shows that there are many research projects and standardization initiatives but a full integrated approach for PI is not available. Then ICONET Project should create a full PI-compliant stack of models and should take existing standards as basis.

The main recommendations and suggestions as review conclusions for DI layers are detailed as follows:

- Data Capture & Encapsulation: the usage of GS1 Data Identification standard should be considered.
- Data Integration & Standard Smart Interfaces: a good work has been done in the MODULUSHCA Project, which may be extended by GS1 Data Exchange standard. To design an IoT-based architecture, the AIOTI HLA has to be considered as a clear emerging trend that will become an EU standard.
- B2B Interoperability: ICONET software architecture should consider distributed software systems, integrated by using loosely coupled protocols like web-services or RESTful services.
- Service Orchestration & Service Choreography: to achieve an integration of distributed systems, both approaches may be included. For a first prototype, a simplest orchestration integration based on messaging platforms like enterprise service bus is recommended, potentially extended by ebXML choreography solutions in future.

- Business Process Interconnection: BPMN is the current standard for business process definitions and must be considered. Already existing BPMN-engines may accelerate the development of a first prototype of ICONET platform.
- Collaborative Business Process: the top layer for DI interconnectivity in the PI clearly lacks a common technique or standard to be used. GS1 LIM should be considered but it is not adopted by industry yet. CMMN, as a new approach for business process definition considering dynamics and runtime decision-making, is a new standard but it lacks real usage by companies. ICONET may consider the emerging smart-contracts techniques that drives Blockchain platforms, as a way to automatically build agreements in the PI following a top-down approach, from business process to technical infrastructures.

6.3 Universal Interconnectivity

The following table summarizes the analysis done regarding the state-of-the-

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