IPIC 2017

TU Graz

4th INTERNATIONAL PHYSICAL INTERNET CONFERENCE

Logistik Werkstatt Graz

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Editor:
Institut für Technische Logistik, Technische Universität Graz
Christian Landschützer
Florian Ehrentraut

Layout:
Christine Fraueneder
Katja Lindenthal

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Christian Landschützer

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Dear Physical Internet community,
Dear friends of Logistikwerkstatt Graz,
Dear ladies and gentlemen,

It is an honour and privilege to welcome you all to Graz. The members of staff of the Institute of Logistics Engineering (ITL) at Graz University of Technology (TU Graz) proudly present the proceedings of the 4th International Physical Internet Conference 2017 (IPIC). Within the lastyears, the Physical Internet has developed more and more into a global research initiative thus completely changing the idea of logistics. But not only research is involved. More and more leading companies ranging from logistics, as well as logistic equipment producers and retailers, are focussing on this visionary approach. Dealing with actual challenges out of sustainability, efficiency, growing logistics volumes, shorter delivery times and new disruptive business models the main vision of the Physical Internet for 2050 is a truly integrated high-performative transport system. Our conference tries to power this vision.

This is where the IPIC merges with the Logistikwerkstatt Graz, where "science meets industry" is not only a mere slogan but has been living practicefor four successful editions from 2012 on. Also Logistikwerkstatt Graz tries to integrate ideas and approaches from the areas of research and industry to power the technical and operational side of intralogistics out of ITL's engineering competence. Prof. Jodin established this unique type of conference here in Graz. It is our sad duty to inform you all of his passing away at the end of March 2017. To honour and remember him and his work for TU Graz and the PI in particular, we would like to dedicate this book to him posthumously.

There are many good reasons why to host IPIC 2017 in Graz, but as always it depends on the people behind the scenes to make such an event happen. Our thanks go to Prof. Montreuil and Sergio Barbarino, who developed together with us the idea of a Graz IPIC edition, prolonging a successful cooperation out of the MODULUSHCA projectlong ago. Despite all the efforts to organize such a conference,Prof. Montreuil, Fernando Liesa and Maximo Martinez Avila have always been much more than mere supporters. Remembering the fruitful discussions and valuable insight into the PI community, it was mainly the European Technology Platform ALICE with Fernando Liesa, who largely contributed to designing an interesting and diversified program.

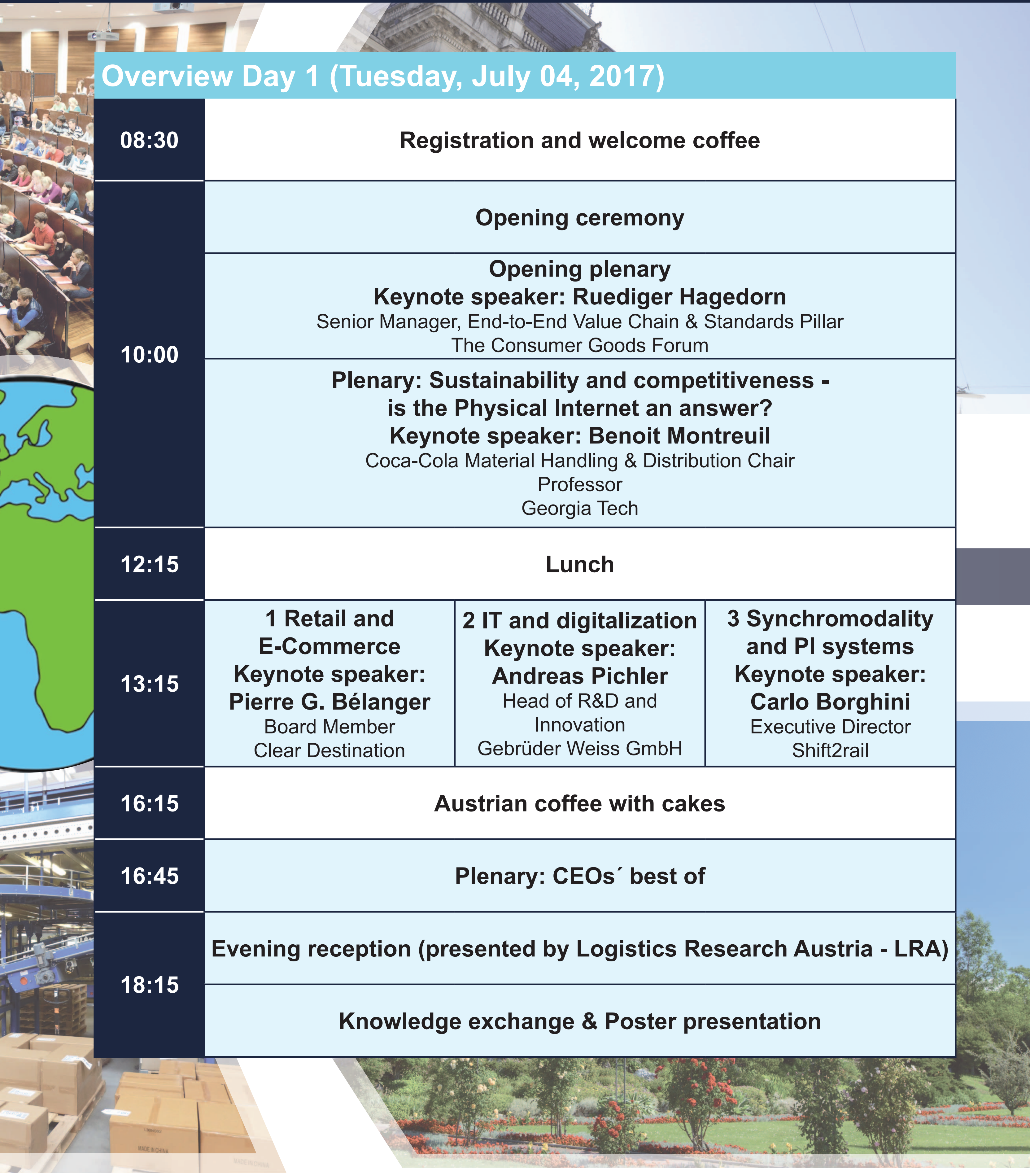
Within 19 workshops, all to be opened with a special keynote, attendees have the possibility to choose from three parallel sessions. This reflects the great interest of the community to have a more extensive conference and fuller program than ever before. The plenary lectures are general PI visions and try to level all attendees on the state-of-the-art. At least nine different topics - and mainly research directions - could be generated in advance and match the contributions by our authors. Complemented by activities for start-ups, research and funding as well as showing main impacts from ongoing PI projects, the conference tries to address a great variety of topics but even more so the specific interests of its attendees. With more than 50 scientific contributions submitted, the conference proceedings spearhead PI research and application around the globe. Around 200 attendees from more than 15 nations together with 90 speakers and workshop leaders will discuss the nine different topics in great detail.

All this is can only be possible because of the researchers and their ground-breaking work and last but not least because of our generous sponsors and supporters who we would like tohighly acknowledge on the following pages. We are deeply grateful to all our sponsors and supporters for this great conference.

Last but not least I want to thank you all once more for coming to Graz and wish you fruitful discussions, valuable insight into topics different from your own and empowering ideas for your daily business to take home with.

Yours sincerely,

Christian Landschützer,
Assoc.Prof. DI Dr.techn. - deputy head of the ITL.



Overview Day 1 (Tuesday, July 04, 2017)

08:30	**Registration and welcome coffee**		
10:00	**Opening ceremony**		
	Opening plenary **Keynote speaker: Ruediger Hagedorn** Senior Manager, End-to-End Value Chain & Standards Pillar The Consumer Goods Forum		
	Plenary: Sustainability and competitiveness - is the Physical Internet an answer? **Keynote speaker: Benoit Montreuil** Coca-Cola Material Handling & Distribution Chair Professor Georgia Tech		
12:15	**Lunch**		
13:15	**1 Retail and E-Commerce** **Keynote speaker: Pierre G. Bélanger** Board Member Clear Destination	**2 IT and digitalization** **Keynote speaker: Andreas Pichler** Head of R&D and Innovation Gebrüder Weiss GmbH	**3 Synchromodality and PI systems** **Keynote speaker: Carlo Borghini** Executive Director Shift2rail
16:15	**Austrian coffee with cakes**		
16:45	**Plenary: CEOs´ best of**		
18:15	**Evening reception (presented by Logistics Research Austria - LRA)**		
	Knowledge exchange & Poster presentation		

Overview Day 2 (Wednesday, July 05, 2017)

08:30	**Morning coffee**
09:00	**Opening and greeting address**
	Plenary: Role of Intralogistics in the Physical Internet **Keynote speaker: Rod Franklin** Adjunct Professor of Logistics Academic Director of Executive Education Kühne Logistics University - KLU
	Second breakfast
10:15	**4 Intralogistics and hub design** **Keynote speaker:** **René de Koster** Professor of Logistics and Operations Management Erasmus University Rotterdam - Rotterdam School of Management - RSM
13:15	**Lunch**
14:30	**4 Intralogistics and hub design** **6 PI activities** **7 PI fundamentals**
16:00	**8 Start-ups & Ventures elevator pitch**
17:30	**Refreshments**
17:45	**Guided walk through Graz - UNESCO World Heritage**
19:00	**GALA event** **@ Alte Universität Graz** 1 Reception City of Graz 2 Reception State of Styria 3 PI-Visions - Prof. Eric Ballot 4 PI Awards Ceremony - powered by KNAPP AG

Overview Day 3 (Thursday, July 06, 2017)

08:30	**Morning coffee**		
09:00	**Plenary: Physical Internet - Challenges and opportunities for a 3PL** **Keynote speaker: Pablo Gomez** Innovation Director and Iberia General Manager FM Logistic		
09:45	**9 Supply chain and Industry 4.0** **Keynote speaker: Michael Henke** Director of the section Enterprise Logistics Fraunhofer Institute for Material Flow and Logistics	**10 Distribution network** **Keynote speaker: Kurt Leidinger** CEO and Chairman of the Board Schenker Deutschland AG	**11 Horizontal collaboration & modularization** **Keynote speaker: Bart Vannieuwenhuyse** Partner TRI-VIZOR NV, Belgium
12:45	**Lunch**		
13:45	**12 Project contribution - Cluster 2.0**	**13 Blockchain in logistics**	
15:15	**Passion 8000 - dream of a lifetime** **Keynote speaker: Gerlinde Kaltenbrunner**		
16:00	**Closing ceremony**		
16:30	**Refreshments**		

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RESEARCH PAPER

Inducing a new paradigm shift: A different take on synchromodal transport modelling

Tomas Ambra[1,2,3], Dries Meers[1], Cathy Macharis[1]
1. Research Group MOBI, Free University of Brussels, Brussels, Belgium
2. Research Foundation Flanders (FWO), Brussels, Belgium
3. Hasselt University, Diepenbeek, Belgium
Corresponding author: tomas.ambra@vub.be

Abstract: *To achieve socio-economic and environmental sustainability, utilization of existing capacities and assets has become a key challenge for the transportation sector. New concepts such as the Physical Internet and synchromodality offer an alternative to the current "business as usual" setting of freight transport services. In this paper, we thus start by conceptualizing the Physical Internet (PI) and synchromodal transport where we examine the state-of-the-art models together with their designs and methodologies proposed in the scientific literature. This is to assess and explore possible correlations between these two concepts to understand how they can reinforce each other. The assessment results in a more unified vision of the freight transport research. The focus of our second objective is on synchromodality, where we translate the PI methodological approaches into a new conceptual framework for synchromodal transport modelling. Given the analytical nature of all synchromodal transport models, the authors intend to induce a paradigm shift; a different way of thinking about the modelling philosophy related to synchromodality. The underlying elements of our approach are multi-agent technology and GIS.*

Keywords: *physical internet, synchromodal transport, intermodal transport, agent-based modelling, geographic information systems.*

1 Introduction

With projected growth of international trade and cargo demand, the current infrastructural capacities are put under pressure resulting in congestion problems, safety issues, environmental concerns and decreasing reliability of services. Instruments used in the 'business as usual' approach are not sufficient to cope sustainably with the expanding market (EC, 2011). Therefore, it is necessary to introduce innovative solutions that would support optimal integration of different transportation modes and their cost-effective use. To achieve socio-economic and environmental sustainability, utilization of existing capacities and assets has become a key challenge for the transportation sector. This challenge has been recognized by many scholars, policy makers and practitioners leading to a substantial body of new concepts, models and initiatives. One of these concepts is synchromodal transport which is built on the same chain composition like intermodal transport – combining two or more modes in a single run (Reis, 2015) – but the main differentiator is the ability to detect and respond to unexpected infrastructural developments (congestion, accidents, low water levels, blockages, maintenance etc.) that lead to delays and time/money losses. Besides these external aspects affecting the smooth flow of freight transport processes, the purpose of synchromodality is also to synchronize containers/orders with other modes so that a more resilient transport system is achieved. Thus, incorporation of real-time information in a dynamic manner should facilitate the most suitable selection of modes, routes and handling points. These selection decisions are not predefined long in advance, but are taken as late as possible (Verweij, 2011). In this type of dynamic environment, new technologies and modelling approaches are necessary. However, all current modelling approaches that focus on the dynamic context of synchromodal transport are based on mathematical formulations using analytical models. Synchromodality is contingent due to the wide range of external inputs that affect internal resource states, and current practices are not always convenient to simulate the changing world as they are based on static principles and heavily simplified environments. To reflect on real-world developments more accurately, new thinking and modelling approaches are necessary to bridge academic models with physical transport processes. To facilitate the synchromodal complexity, we address another emerging trend; the parallel evolution of the Physical Internet (PI) presents an opportunity to consider its physical, digital and operational interconnectivity with the synchromodal vision. We thus start by exploring the correlations between these two concepts to understand how they can reinforce each other (section 3). Section 4 addresses agent-based modelling (ABM) and Geographic Information Systems (GIS), and section 5 introduces our conceptual approach. Conclusions and future research are described in section 6.

2 Methodology

This scientific literature review applies a computerized search strategy to detect and gather papers from different channels. As an initial step, SSRN (Social science research network) database was searched in order to acquire publications which contain the following words: the Physical Internet/PI, synchromodality, synchromodal transport or dynamic/flexible freight transport. These words of interest had to appear in the title, abstract or keyword section of journal publications. Next, an additional search was performed covering electronic databases such as research gate and google scholar. Only freight related research was considered whereas other fields, such as education and “synchromodal learning classes”, were filtered out. Papers and conference proceedings related to flexible and real-time modelling of freight transport were included as well to account for the synchromodal nature. Relevant research retrieved from authors we knew about based on informal connections is also included in this review together with studies tracked through previous citations of earlier work (ancestry approach). The body of literature related to the Internet of Things (IoT) is beyond the scope of this review. Figure 1 depicts the division of the reviewed papers discussed in the following sections.

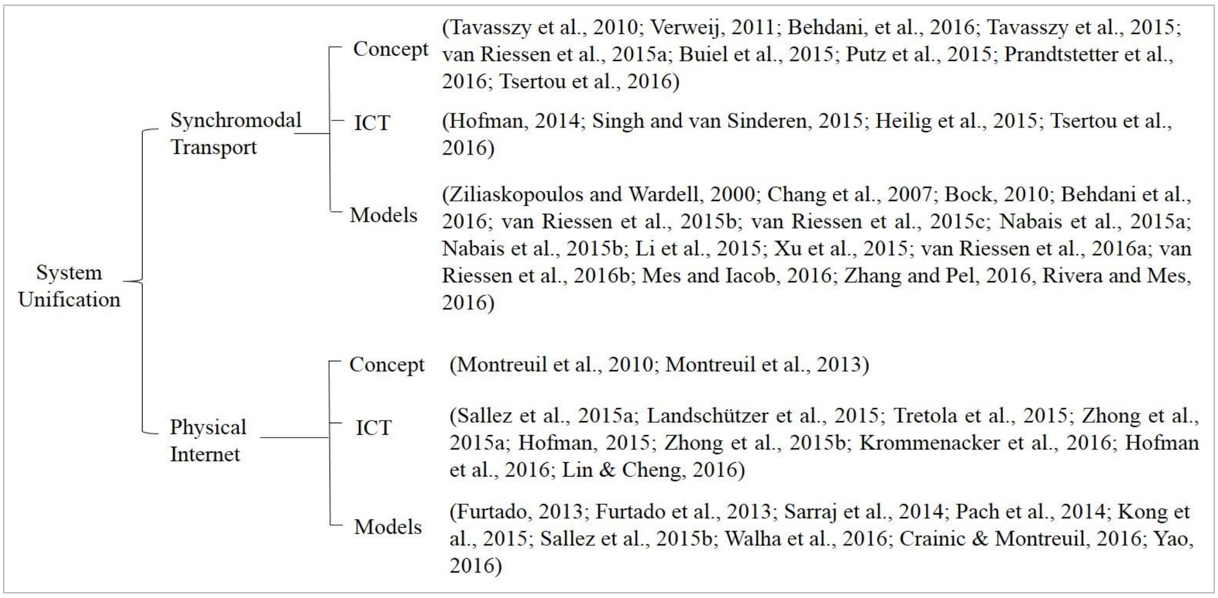

Figure 1: Overview of recent developments in freight transport.

3 Unifying synchromodality and physical internet

The general observed pattern, observed in the literature review, indicates two integrative flows. The PI research tends to address manufacturers, retailers and distributors whereas synchromodality aims at LSPs, terminals and network operators. The PI can thus be perceived as a major supply chain project covering the strategic level by designing means and operations to improve and optimize the vertical integration. In this regard, the warehouses and manufacturing sites are to be decentralized and moved closer to the point of consumption. On the other hand, synchromodality approaches the supply chain from a different angle where the focus is given on horizontal integration, accounting for operations at the tactical and operational levels. In this setting the modular π-containers can be pooled in a collaborative way while improving the chain resilience with disturbance management, event handling and dynamic response modelling to support better asset and network utilization. Given these two integrative flows, the unified transport system has the potential to become an intertwined set of flows resulting in a holistic supply chain resilience and efficiency. The commonalities of the studied concepts are very noticeable since both constitute of 3 main entities with similar characteristics. Figure 2 depicts these characteristics by overlaying the integrated views of the synchromodal service design and PI elements. Despite these similarities, each element addresses problems at different levels with unequal dimensions. Nevertheless, these gaps present opportunities where the concepts can complement each other to create a more resilient and efficient transport system. The following sub-sections elaborate further on these opportunities by assessing the relations between the customer and π-containers (Order/Demand), moving resources and π-movers (LSP Assets), closing with stationary resources and π-nodes (Freight Grid).

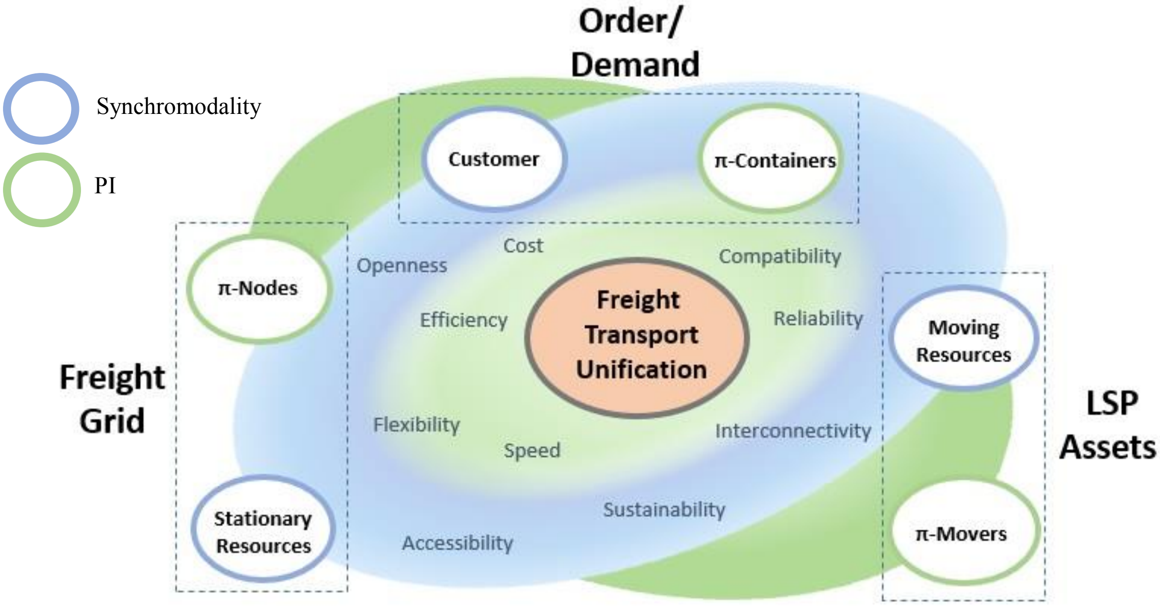

Figure 2: An overlaid unified vision of the synchromodal and PI concepts (Source: own setup, based on Montreuil et al. (2010) and Behdani et al. (2016))

3.1 Order/Demand

The Order/Demand group consists of the customer, who ships products, and the π-containers, which are boxes containing the products in this unified setting. The PI encapsulation is the core differentiator from the contemporary packing and handling of goods. In the current (synchromodal) freight transport state, the networks are highly proprietary and the opportunities among competitors, who could engage in collaboration, are hindered by trust.

The PI offers a solution to this problem through encapsulation. The π-containers are to serve as envelopes where the sender's content inside it cannot be open by the transporting party but only by the final addressee. In this context, the π-containers are handled by service providers who do not know the content of each π-container, resulting in a more secured and trustworthy order combinations without exposing any sensitive details of the shippers. This way, the π-containers would be treated as black boxes. Smart tags and sensors described in the reviewed papers, also contribute to better visibility of orders based on tracking and location intelligence of the goods encapsulated in the π-containers. The visibility is a crucial factor for establishing a unified system which can then identify dedicated overlapping flows. The unified system should therefore be a system that assesses these inefficient flows and translates them into a transparent web where orders and freight volumes can be efficiently bundled. The π-container research, such as the MODOLUSHKA project in Landschützer et al. (2015), prototypes mostly packing containers (p-containers) and pallet-level containers (h-containers) at a single enterprise level whereas limited research is done on transport containers (t-containers) being carried by trucks, trains and barges. This gap can be filled by synchromodality by addressing the flexible revenue management and order resilience in terms of cancellation and delay handling of t-containers which are the biggest transportation unit carrying the p- and h-containers. The combination offers a more holistic approach where the PI deals with fill rates and space utilization at pallet levels and synchromodality with external container management that occurs outside warehouses and manufacturing facilities.

3.2 LSP Assets

The orders, being the shippers' goods, are transported and handled by LSPs who possess the means compatible with π-containers. Since the logistics web enabler consists of inter-connected physical, digital, human, organizational and social agents, the PI allows any goods to be handled by any kind of LSP as long as they are PI certified (Montreuil et al., 2013). In this setting, the shipper determines pick-up location, drop-off location, arrival time windows, assigned transport budget and the LSP decides on the mode combination, the routes they will follow and which containers will travel together. Hence, the uniformity of the PI designs can help solve interoperability and proprietary issues since the PI is based on the principle of totally open and connected networks. The reactiveness and automation of π-containers, π-conveyors and π-handlers should also be applied in the synchromodal context in which the response of planning operators to delays and unexpected events is done manually. Not only does this slow the procedures but also allows for inaccuracies due to the lack of insights concerning other affected services that could be potentially bundled or handled more efficiently. On the other hand, synchromodal related research addresses the problem of uncoordinated and separately planned services by integrating service schedules of different transport means such as barge, rail and truck. Furthermore, the dynamic response modelling, event handling (vehicle breakdowns, accidents) and general disturbance management fortifies the role of synchromodal transport in creating a more resilient chain in which a better utilization of assets is achieved. However, shared and cooperative consumption of assets is of high importance and certain standard coordination protocols should be first established to facilitate bundling or transition between constituents without imposing special closed collaboration contracts inaccessible by other service providers.

3.3 Freight Grid

The freight grid represents a network connecting different elements. In general, networks form a basis of various structures such as the internet, which is made of a network of servers. Similarly, a network of hubs (terminals, ports, warehouses…) connected by arcs (inland waterways, roads, rails) forms the PI. However, the metaphor of the digital internet should be considered with caution since digital internet movements incur negligible costs (Sarraj et al., 2014) whereas the PI constitutes of fixed, transshipment, handling and variable costs. The synchromodal but also intermodal research can improve the PI performance with studies related to the cost-impact of intermediate transfers in combination with break-even distances and routing over the network to reach a more realistic flow within the PI network, compared to the digital network. The freight grid herein embodies the network of stationary resources - addressed in the synchromodality studies and π-nodes - denoted by the PI concept. As for the latter, the reviewed literature suggests the predominant transport will take place between π-nodes/hubs and thus the π-loading process studies are of high importance. Hubs, and more specifically terminals, infer an integrative role where the feeds from LSPs, terminal operations and road-rail-iww (inland waterway) networks are combined. In this setting, storage and management of 'big data' will become more pronounced. The PI is designed to reshape the supply chain as to bring the deployment and manufacturing of products closer to the end-users by redesigning the distribution and realization web. In this regard, synchromodality has the potential to improve the chain resilience with disturbance management, event handling (traffic congestion and accidents) and dynamic response modelling to achieve better network flow. In the academic sphere, synchromodality offers model predictive control approaches to account for cargo evolution at critical points so that delays and unexpected developments are handled more efficiently and preferably in real-time to avoid bottlenecks. These external perturbations, occurring outside of the hub, should complement the internal operations within it. In this respect, predictive analytics that estimate turnaround times within terminals can be linked to the external developments so that smart objects can react in an active manner and group accordingly to reduce loading and delivery times. In terms of methodology, all synchromodality-related models are based only on analytical approaches whereas physical internet models make mostly use of agent-based models. In the following sections, we conceptually apply the ABM notion to the synchromodal paradigm. GIS features are further applied to account for a more realistic modelling environment.

4 Combining ABM with GIS

Having defined the unified vision, the focus is shifted to synchromodality where the PI methodological approaches are translated into a new conceptual framework for modelling synchromodal transport. The framework presents an incipient step to a proof-of-concept model for assessing synchromodal benefits by a means of simulation, rather than focusing on analytic solutions of operational planning alone. By doing this, the authors intend to induce a paradigm shift; a different way of thinking about the modelling philosophy related to synchromodality. The underlying elements of our approach are multi-agent technology and GIS. The former represents physical objects of the transport chain (transport means, containers, terminals…) as active software processes, and the latter accounts for location intelligence so that the objects can be queried in space and time.

4.1 GIS as a modelling environment

Geographic Information Systems model the real world in real sense by capturing, storing, coding, checking, displaying and analyzing data about different aspects linked to the earth's surface (Burrough, 1992; Murphy, 1995). The evolution of GIS has undergone substantial technological developments since 1995 when the GIS was not considered as a sufficient decision support tool (Murphy, 1995). GIS is mostly known for its "traditional" approaches such as multiple regression, location allocation and spatial interaction models (Batty, 2012) with a focus on strategic planning horizons. However, technological developments have induced a move from ESRI's ArcMacro, ArcView and AML to industry-standard programming and scripting languages like Java, C++, visual basic, Jscript and Python which have the ability to incorporate GIS software libraries such as ArcGIS, OpenStreetMap, Landsat, GeoTools etc. (Crooks & Castle, 2012). It is not just the technological developments that allow us to compose more realistic models, but also the interdisciplinary nature embodied in geography, incorporating economics, mathematics, physics and computer science. Interdisciplinarity as such has a tremendous potential to model freight transport processes, compared to stand-alone operations research (OR) applications. In this sense, GIS serves as a medium for communicating results and assessing patterns which are generated by simulation runs. As will be discussed in the next sections, agents can roam a certain artificial environment and there is no other environment representing reality better than GIS. This particular ABM-GIS link has been also addressed by Patel and Hudson-Smith (2012) who highlight the importance of ABM visualization via GIS. Most obvious elements reinforcing agents in geographical space are navigation, route finding (Batty et al., 2012) and most importantly, situational and environmental awareness of surroundings represented by spatial, temporal and topological relationships. GIS is thus an essential milestone allowing for a shift from generative models, where designed agents represent simplified conditions, to fitted models, where agents mimic real-world entities based on values that are realistic substitutes of observed processes (Couclelis, 2001). In general, GIS present a modelling canvas full of geocoded information and location intelligence which facilitate the movement of agents and contribute to better and more informed decisions.

4.2 Agents as synchromodal entities

Planning in synchromodality is done as late as possible, bringing the planning and execution horizons closer together. Responding to system changes will not be carried out with deterministic algorithms since reaching an optimum could take too long and by the time it is reached, the system state can change again in the meantime. In this sense, near optimum scheduling algorithms offer a solutions (Bongaerts, 1998) accounting for the stochasticity in the synchromodal system. In case schedules become altered or invalid because of internal or external perturbations, alternatives must be determined as soon as possible. In this regard, ABM exploit the power of parallel computing where the problems are decomposed into sub-problems and solved by agents in order to avoid stand still (Karageorgos et al., 2003). Agents possess various properties capable of mimicking the dynamic behavioral aspects that should be represented in the synchromodal system. Actions of agents are prescribed by the modeler at individual level in a series of rules that are activated under different conditions (Batty et al., 2012; Borshchev & Filippov, 2004). Agents can process and exchange information with other agents as well as perceive other entities, obstacles or sense their surroundings (Crooks & Heppenstall, 2012). These features are highly relevant as synchromodality is to create a more resilient system that reacts to unexpected data changes such as disruptions, incidents, breakdowns, newly incoming orders but also infrastructural developments like congestion, lower water levels etc. The awareness of these events but also awareness of asset locations can be simulated in a transparent manner allowing for more bundling opportunities once the agents know about each other. These simulation capabilities enable modelers to truly assess the synchromodal rigors.

The synchromodal paradigm involves many entities that have timing, directions, objectives, event order, various behaviors and many other aspects affecting the transport system once exposed to perturbations. In our synchromodal setting, there are three agent classes; 1) decision making/coordinating agents (LSP, Terminal Operator, Network Operator), 2) stationary agents (terminals) and 3) moving agents (barge, train, truck). Agents are able to perceive their environment through sensors and act upon the input via actuators (Russell et al., 2003). Table 1 points out the varying goals and characteristics of agents which may affect the synchromodal chain as the agents rely on each other and subsequently affect one another, resulting in emerging behavioral patterns. In other words, the movement of LSP agents is restricted or facilitated by their environment which is managed by network operators through control centers. This relationship also works vice versa as the developments within the network control center environment ((big) data feeds), is determined by the movement of LSP agents. Lastly, terminal operations also influence the timeliness of barges, trucks and trains that are in return affecting the overall network flow.

Table 1: Examples of synchromodal agent characteristics. Italics present decision making agents and underlined text presents physical agents (Source: adapted from Russell et al. (2003))

Agent type	Percepts / Sensor	Action	Goal	Environment
LSP (Barge/Train/Truck)	Orders, asset location, containers / GPS, 'mediator', radar, RFID	find/take route, shift, bundle, assign orders	destination, arrival time, fill rate, max. profit	IWW/Rail/Road networks, locks, terminals, containers, other modes
Terminal Operator Terminals	Incoming LSP agents / camera, scanner, 'mediator'	scan, report, assign/organize flow	detect bottlenecks, optimize flow, high queue performance and cargo items per day	Gate, terminal personnel, cranes, tugs, yards
Network Operator Network (Waterways/Rail/ Road)	Infrastructural developments / GPS, cameras, land stations (antennas), 'mediator', infrared or sonar sensors	Open/close lock, assign flow, navigate, variable message signs	Safety, lock throughput, smooth network flow	Big data feeds

The LSP acts as a broker who receives orders from shippers and assigns transport means to them. Table 1 provides a simplified conceptual example of the main agents. In reality, shippers may book services via forwarders (4PL non-asset based), or 3PL (asset-based) companies to deliver their goods. On the demand side, forwarders and 3PLs serve the shippers' needs and order transportation services. On the supply side, these service orders are served by intermodal and terminal companies who provide actual locomotives, barges, trucks, terminal equipment etc. For simplification purposes, we define the LSP as an intermediary who stands between the shipper and intermodal/terminal companies.

5 Our approach - Synchromodality in the light of ABM and GIS

In synchromodality, communication among the 3 agent types in table 1 is a key factor to create a more resilient and responsive system. Given the existing network monitoring platforms, there is enough evidence that real-time infrastructural data is available and should be further improved by integration of IWW, road and rail data. Historical data from these links offers added value for models that can capture real physical flows by deploying dynamic agents and simulate various logical combinations of orders, routes and response handling based on perturbations. Since pilot projects are very costly to carry out, computer simulation offers a more affordable alternative for introduction of new concepts. Main advantage of ABM, compared to current synchromodal models, is the ability to simulate and assess communication structures based on a certain level of transparency determined by the modeler. This is possible due to the ability of agents to send messages that are assumed to be transmitted via sensors. The sensors in table 1 are mere examples of currently used technologies and may change over time, but the agent communication structure remains the same as conditional statements determine when and how agents detect and respond to different phenomena in the program. The sensors thus serve as an information input feature for the agents.

5.1 Process overview

The orders are a-modal, a precondition for synchromodality, giving the LSP freedom to choose a mode based on the availability and network developments. The barges, trains and trucks are then queried by the LSP to learn their location via various sensors. The LSP then takes actions to meet its goals. The terminal agents also use sensors to detect barges, trains and trucks at their gates to proactively optimize flows and utilize their assets. In case of network operators, the infrastructural developments are monitored from a more centralized perspective using land-based sensors deployed alongside roads, inland waterways (IWW) and rails or satellite-based receivers. Information from different sensors can be combined in Automated Identification System (AIS) used for vessel tracking, road traffic control centers and rail managements systems. All three network segments are becoming more digitalized resulting in new data platforms. Road and IWW segments offer real-time GIS based traffic flows, whereas the railway network seems to be lacking behind.

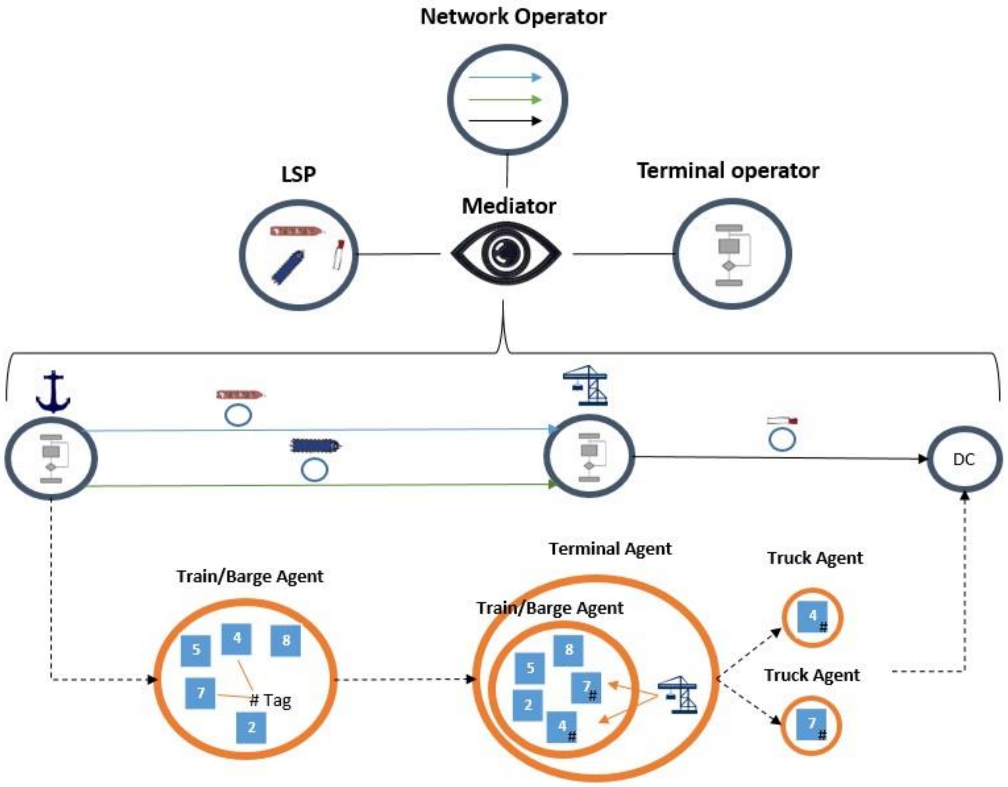

Figure 3: A conceptual perspective of the agent-based synchromodal hinterland chain. (Source: own setup)

Figure 3 illustrates a synchromodal journey that originates at the port and ends at a distribution center (DC) with an inland terminal as a handling/switching point. Moving agents coordinated by the LSP (barge, train, truck) roam the environment between these stationary agents by following one of the three infrastructural links. The links are managed by the network operators and handling points by terminal operators. Note, that moving agents may enter a terminal agent that becomes the head agent of the agent society. The role of the head agent is then to communicate with the rest of the agent society that it contains, and manage terminal resources accordingly. This type of structure is known as a holarchy (Cossentino et al., 2008; Koestler, 1967) where acceptable solutions are reached through negotiation about resources and elaborate cooperative solutions (Becker et al., 2006; Gambardella et al., 2002).

In this respect, the LSP agent is also perceived as a head agent that contains sub-agents, being the means of transport. The decision power thus lies on the level of synchromodal agents who search for local optimal solutions via negotiation with higher structures; transport means talk to LSPs and terminals, and LSPs/terminals talk to network operators to make better informed decisions and adapt proactively.

The action of agents is determined by commands in statecharts (figure 4). Each agent has a specified action code with an objective to fulfill its goals (table 1). The action code may contain transitions that are induced by network messages in case of disruptions. In this setting, the LSP has the possibility to react to network developments and chose an appropriate agent which fits his needs based on conditional statements. This consequently leads to mode assignments and switching at handling points, such as the port or inland terminal, before transport execution takes place. The LSP thus runs a simulation facilitated by the mediator, taking into account the network developments, terminal locations and their handling processes as well as nearby available agents. Agent transitions are triggered by external or internal events captured by conditional statements and/or timeouts.

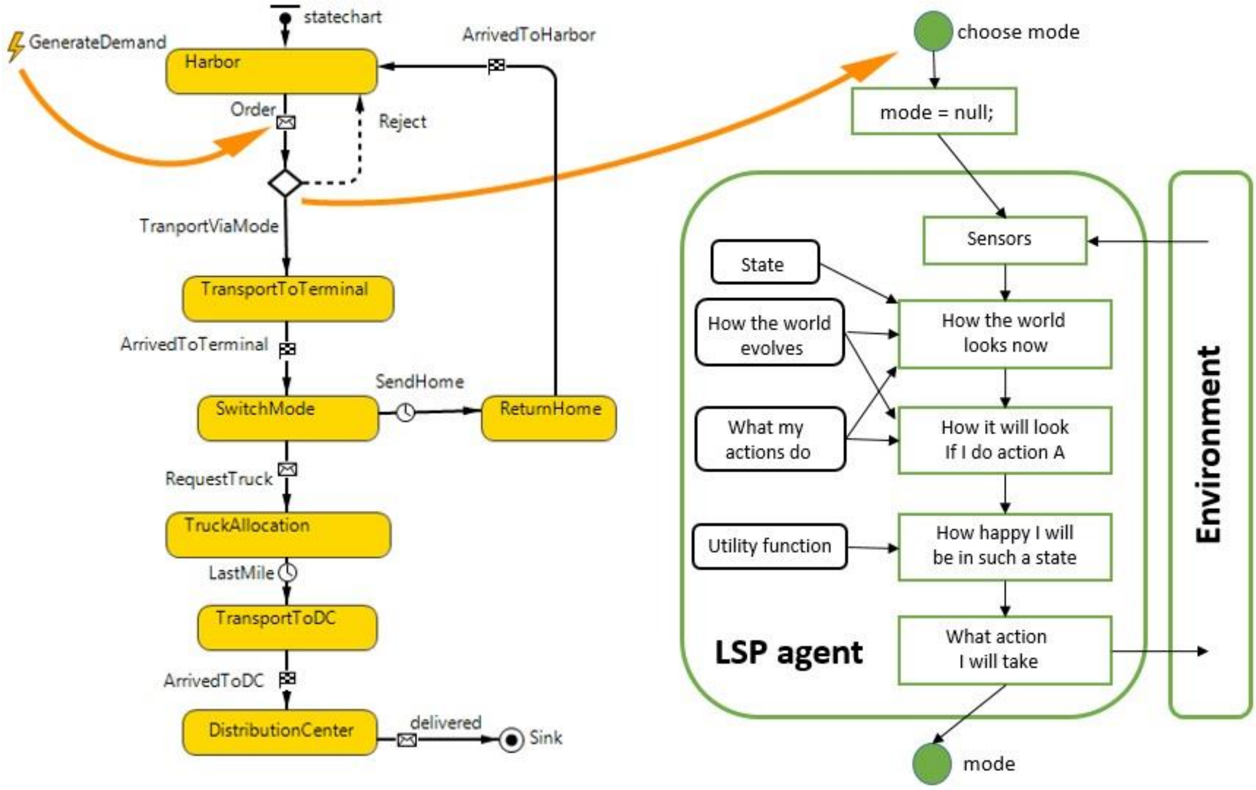

Figure 4: Mediator perspective using statechart assessment of LSP's action chain. (Source: own setup based on Russell et al. (2003))

As indicated in figure 4, the decision process linked to mode selection takes place when the LSP receives an order to transport a certain quantity of goods. The first step is to assess the current system state of the agents' environment through the sensors (figure 4, right). Next step is to project, via Monte Carlo for instance, the transport evolution (see "How the world evolves") based on historical data and examine how the selected LSP's action, related to the modal choice, will affect the transport system and whether the actions meet the LSP's restrictions. The restrictions are usually imposed by shippers who specify the origin/destination and time windows. The "utility function" is to determine the fulfillment of the LSP's objectives considering its budget. The action taken is then recorded and sent back to the "environment" for future system state estimations. The geographical location for the return trip is known and contained in the environment. This may be very useful for identification of transport means that are returning home empty so that another LSP can again query the current state of "the world" and its evolution. In this regard, the simulation is not confined only to decisions at ports; it can run in parallel with the execution of transport, and once the agent is approaching a terminal, the LSP may query near-future options and available actions that can be taken upon the agents' arrival at the terminal.

5.2 The Environment

The artificial environment from figure 4 is represented in a GIS form (see figure 5). The most upper layer (a) contains agents in continuous space. To mimic their movement and location that would be close to reality, vector files are used for determination of the agents' possible routing in geographic space. The GIS network provides paths (b) for agents (trucks, barges, trains) to execute movements from an origin to a destination determined by the LSP. The network links lead to terminals which are geocoded as points in the map (c), and at each point a terminal agent is created. This third layer contains 3 types of terminals, namely rail-road, IWW-road and trimodal terminals. Finally, an Open-Street-Map tile layer (d) is used to assess the visual fit of the IWW/rail/road paths taken by the moving agents. Since synchromodality is a real-time system, Anylogic environment proves to be suitable as it provides real-time tracking of movements and events which are consequently recorded in logfiles.

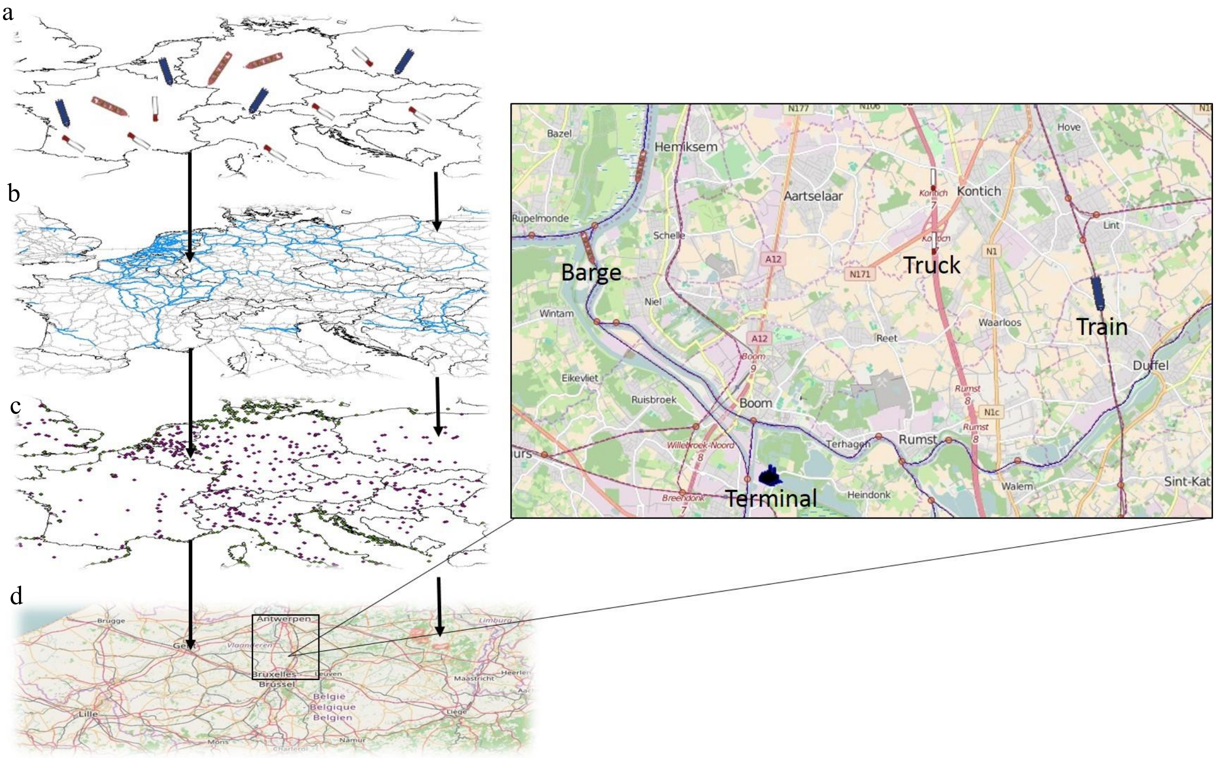

Figure 5: Illustration of an agent-based GIS environment. (Source: own setup)

The real-time switching and resource/asset allocation is carried out at terminals via discrete events. The terminals thus serve as central points containing bundling logic based on the availability and occupancy of other nearby agents. Therefore, the distinction between the above 3 terminal types is crucial since they determine the switching possibility as a result of mode accessibility. In other words, the possibility to switch to train which follows the rail network can be done only at road-rail and trimodal terminals, but not at road-IWW terminals.

5.3 PI elements in our approach

To simulate the system's transparency and consequent advantages in reality, a tag is added (the # in figure 3 on each container and moving agents) that serves as an extended hand of the mediating agent. The tag enables asset visibility so that the mediator has an overview of the current system state. In case of perturbations, the LSP decision making agent may query the mediator for solutions. Since not all assets are monitored and shared in reality, the tagging solution is to account for what-if scenarios that might occur in a certified group or community of users. In such sense, the tag may present equipment and transport means that are PI certified and comply with uniform handling and communication standards. The main element of our approach is the ability to assess communication structures and information exchange by passing messages between agents. These messages represent signals sent and intercepted by sensors from different sources (section 4.2) to account for the reactive behavior of agents in case of perturbations. Unlike analytical models that focus mainly on schedule synchronizations, the proposed framework enables simulating communication structures and potential cooperation concepts to gain more confidence in future investments towards more transparent (PI) networks. Given these capabilities provided by ABM, various cases may be assessed in terms of comparative analysis (PI vs status quo) of freight flows while having and not having communication capabilities and visibility within the system. For this reason, simulation is chosen to test transparent flows of goods and network developments in real-time to evaluate responsiveness of the system prior to its implementation and practical use.

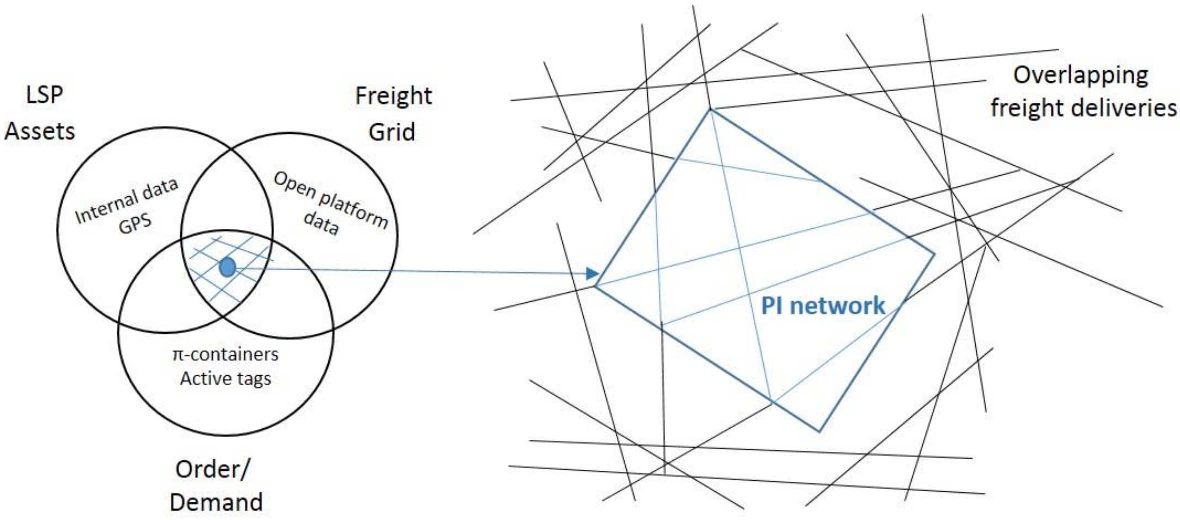

Figure 6: Conceptual illustration of a transparent and resilient freight network

The unified transport system (figure 6) has the potential to become an intertwined set of flows resulting in a holistic supply chain resilience and efficiency. The transparency and identification of flows acquired via agents' contextual awareness and communication, has a potential to fill backward empty flows as they can detect cargo and its attributes such as O/D, expected delivery time, weight, fill rate, cargo type etc. This may be achieved by creating a cooperative community of providers who are PI-certified so that containers (Orders) and available transport means (LSP assets) can be queried in space and time, facilitated by open infrastructural data (Freight grid) for better ETAs for timely bundling opportunities.

6 Conclusion

The underlying elements of our vision on synchromodal modelling are multi-agent technology and GIS. The former represents physical objects of the transport chain (transport means, containers, terminals…) as active software processes, and the latter accounts for location intelligence so that the objects can be queried in space and time. The proposed conceptual framework has a potential to contribute to more empirical assessments, once actual real-world data is obtained to simulate physical transport phenomena. To account for the real-time nature of the artificial agents moving in space and time, the trajectories and transitions need to be further validated. The main contribution of our approach is the capability to simulate information availability/exchange that is linked to consequent reactive agent behavior induced by it. This will lead to emergence, the typical characteristic for ABM, since it is unknown how the system will evolve once agents start taking actions based on their different goals. The emerging patterns will arise from the environment as the final LSP action will be fed back to it (as indicated in figure 4) which will consequently affect the behavior of other agents given the updated state of the system. As far as the mediating platform is concerned, the authors are developing a SYnchronization Model for Belgian Inland Transport (SYMBIT) for testing new business trends and synchromodal logic in a near-to-reality simulation environment to assess the implications of different management policies and technologies. In conclusion, the work presented herein invites researchers to think differently about modelling such complex phenomena as synchromodality. A wide range of proprietary service networks and different information and communication structures may also be assessed from a PI perspective; given the agent’s ability to interact, the modelers can compare various transparency levels and a degree of sensitive data exposure/visibility. Our approach still poses a computational challenge when it comes to including thousands of agents operating and interacting with raster or vector features of the map display. However, with the huge progress made in information technologies in the last decade and the manifestation of cloud-based parallel computation, the utilization of such an approach should not hold us back in solving highly complex synchromodal problems. Future research should focus on incorporating system dynamics in the decision making process of the agents since, in most cases, decisions are made by human operators which calls for multi-actor multi-criteria analyses to be involved.

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Physical Internet
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GLN standard as a facilitator of physical location identification within hyperconnected logistics

Martyna Zdziarska
Institute of Logistics and Warehousing (ILiM), Poznan, Poland
martyna.zdziarska@ilim.poznan.pl

Abstract: *Distribution, from the business point of view, is a set of decisions and actions that will provide the right products at the right time and place, in line with customer expectations. It is a process that generates significant cost, but also effectively implemented, significantly affects the positive perception of the company. ILiM, based on the research results related to the optimization of the distribution network and consulting projects for companies, indicates the high importance of the correct description of the physical location within the supply chains in order to make transport processes more effective. Individual companies work on their own geocoding of warehouse locations and location of their business partners (suppliers, customers) but lack of standardization in this area causes delays related to delivery problems with reaching the right destination. Furthermore, cooperating companies do not have a precise indication of the operating conditions of each location, eg. Time windows, logistic units accepted, unloading supporting equipment etc. Lack of this information generates additional costs associated with re-operation and the costs of lost benefits for the lack of goods on time. The solution to this problem seems to be a wide-scale implementation of GS1 standard, which is the Global Location Number (GLN) that, thanks to a broad base of information, will improve the distribution processes within hyperconnected logistics.*

Keywords: *GS1 standards, GLN, distribution process, physical location identification, hyperconnected logistics*

1 Introduction

Physical Internet concept requires new standards in terms of distribution within hyperconnected logistics. One of them is an unified physical location identification that would support and ease word wide deliveries. Global Location Numbers that is a key concept in EDI seems to be the best solution for PI. It provides the globally unique identification needed to securely exchange business information on the Internet as well as unambiguously identifying all legal entities, physical/operational locations described in business documents. GLNs ensure lean and efficient communication and processing since names, addresses and other information about particular locations do not need to be communicated with every transaction. The necessary information is communicated only once, stored in the relevant system (e.g.Enterprise Resource Planning system) and subsequently retrieved by referring to a globally unique GLN. It allows computers to route information to the correct destination with no manual involvement. GLNs must be used when identifying locations and trading partners within Electronic Data Interchange (EDI) business messages and data pools, and they can also be used in barcodes to identify a physical location or to provide relevant information for delivery or invoicing purposes (http://www.gs1.org).

2 Physical Internet - hyperconnected logistics

Logistic networks intensely use means of transportation and storage facilities to deliver goods. However, these logistic networks are still poorly interconnected and this fragmentation is responsible for a lack of consolidation and thus efficiency. To cope with the seeming contradiction of just-in-time deliveries and challenging emissions targets, a major improvement in supply networks is needed. This new organisation is based on the universal interconnection of logistics services, namely a Physical Internet where goods travel in modular containers for the sake of interconnection in open networks (Sarraj et al., 2014).

The Physical Internet has the potential of revolutionizing the fields of material handling, logistics, transportation and facilities design. It exploits the enabling concept of standardized, modular and smart containers as well as the universal interconnectivity of logistics networks and services. Its underlying paradigm shift creates a tremendous breakthrough innovation opportunity for the material handling and facility logistics community in terms of equipment, systems and facility design and operation (Montreuil et. al., 2010).

The definition of Physical Internet, proposed by Montreuil et. al. (2014) is as follows: “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” (Ballot et al., 2014).

The concept of Physical Internet aims to create a logistics system in which there is unwavering flow of information and cooperation goes far beyond the standard schemas. Physical Internet is based on the full sharing of the supply network, resources and infrastructure, while leveraging standard, modular packaging. It is planned to replace the existing models. Its foundation is the cooperation of all entities involved in the distribution of goods and the full flow of information between them. Physical Internet aims at transforming handling, storage, distribution and implementation of the supply of goods, aimed at increasing the efficiency of global logistics and sustainable development (Zdziarska, 2015).

To prove efficiency of postulated concept many test, research and projects were conducted. Sarraj et. al. (2014) modelled the asynchronous shipment and creation of containers within an interconnected network of services in order to find the best path routing for each container and to minimise the use of transportations means. To carry out the demonstration and assess the associated stakes they used a set of actual flows from the fast-moving consumer goods sector in France. Various transportation protocols and scenarios were tested, revealing encouraging results for efficiency indicators such as CO2 emissions, cost, lead-time, delivery travel time, and so forth.

This innovative concept is based on three main pillars. The combined infrastructure means that companies start to take action aimed at optimizing the operation of such resources like storage space, vehicles capacities and production systems through sharing. The current situation shows that most companies are not in a position to fully exploit its potential, thereby freezing their capital. The market of logistics services will strive to create a common infrastructure. Logistics centres, hubs and transit points located all over the world will be widely available to all operators, thus creating one global network. The ability to use a large amount of docs will increase the efficiency of transport. P&G and Tupperware conducted the first tests of such activities. Thanks to the collaboration and joint programming of supplies, they were able to reduce logistics costs by 15%, reduce CO2 emissions by 2 million tonnes per year and increase the vehicle utilization from 55% to 85%. But these are not the only such initiative in the market. Companies such as Walmart, HP, Volvo and Boeing are also heavily involved in the implementation of this concept among its business partners.

The second area is the introduction of modular cargo units. Trying to be achieved with analogy of the Digital Internet data distribution in physical processes in the real world. Digital Internet does not provide the information but only transmits packets with embedded data. These packages are designed in such a way as to be easily recognizable by internet networks. Information in the package is closed and is not directly decoded by the network. The packet header contains all the information necessary for the identification and designation of transit routes to the destination. Digital Internet is based on protocols that structure the data packets regardless of the mode of transmission. In this way, they can be processed in different systems and networks such as modems, fibre optic cables, routers, local area networks, Intranet, Extranet and virtual private networks. Similarly to the Physical Internet (open logistics network) will not handle the goods directly (whether they are raw materials, components or finished products), but only manipulated specially designed modular containers that allow an encapsulation of these goods. Target solution involves a complete change of pallet system into modular loading units. This involves, of course, the adaptation of vehicles, handling equipment and warehouse space that will allow handling this type of packaging. However, simulations conducted for research projects clearly demonstrate that the investments made in the long term will help to significantly reduce logistics costs and losses related to the movement of goods. Containers thanks to the folding panels can create boxes of various sizes tailored to the individual needs of the sender. M-Boxes are easy for handling, storage, transport, loading and composition. They have a standard phrases recognizable throughout the system and are equipped with sensors and transmitters to maintaining full control during the transportation process. As a result, shipping safety is maintained throughout the journey, and all actors involved in the distribution have full overview of the status of the order. Moreover, the package is reusable and easy to recycle.

The last pillar is the exchange of data. This is the most crucial element of the whole concept. Physical flow of information in the Physical Internet will operate through an integration of infrastructure. In the PI you would be able to report and organize the individual orders from your own ERP system in a standardized format, which will be processed into 'the cloud' and decrypted by the other participants in the process. An important aspect in this data exchange is the access level. The architecture concept, developed so far, has designated four areas. Information on the container (its designation, dimensions, special conditions of carriage) will be available to all, then the data associated with the transport process (detailed route and delivery address), reserved only for the carrier. Another area is an information covering the delivery data such as sender and recipient, description of goods, value of the contract and the terms and time of delivery. For this type of data only logistics operators and customs will get an access. Most sensitive information will be used only by the sender and recipient, and will be associated with contracts, number of orders, invoicing or discrepancies in the delivery.

Logistics service providers, carriers and owners of the storage infrastructure will also share their detailed information. They will provide information on the availability of their resources, capacity and the status of implementation of orders. By combining all these data, the system will optimize the process and suggest the best possible solution for minimizing the cost of each of the participants in the process. Physical Internet is called the concept of win-win-win, because it allows the balanced growth of all actors in the supply chain. (Zdziarska, 2015)

Although a lot of work has already been done, concept of the Physical Internet will not be able to emerge globally without international unified standards. One of the most significant problem in terms of deliveries in hyperconnected supply networks is lack of detailed information about destination points (both physical location and their characteristics). Basic address and postal code is no longer sufficient. Physical Internet to work smoothly needs a wide range of logistic information that will be easy to send, transform and decode by any IT tool within the PI system in order to organize deliveries in dynamic environment. Physical Internet needs one unified number of the client (destination point) that will be understandable for everyone and identified with ease within the whole network.

The answer to these needs seems to be the GLN (Global Location Number) standard developed by GS1.

3 Characteristics of GLN standard

All organizations exchange information in business processes, both internally and externally. Global Location Number (GLN) uniquely identifies these entities and their positions (Nakatani, Chuang, Zhou, 2006). GLN is a globally unique number that can be used to gain access to basic data about the physical location of the objects (example on Fig. 2).

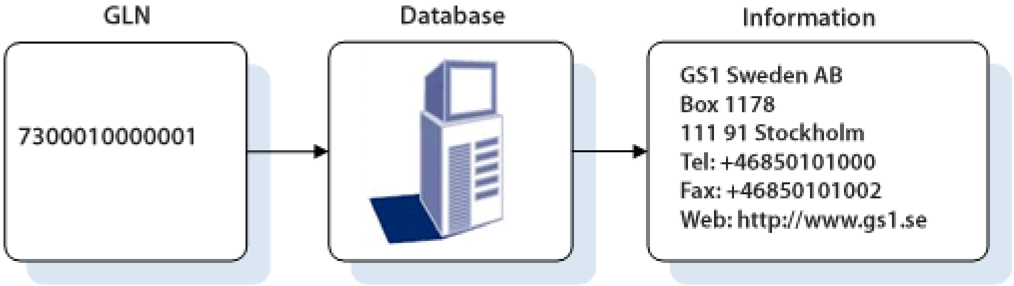

Figure 1: Example of information that can now be retrieved from the database using the GLN identifier
Source: http://www.gs1.se/en/our-standards/Identify/gln/

GLN is a key identification tool (according to GS1 standards) used to identify any location (physical, digital, functional or legal), which must be defined for the needs of processes in the supply chain.

3.1 GLN standard and its value for the customer

The primary use of GLN is to identify the company in business transactions, such as sending orders and invoices. If the company has buildings in different locations, it may need to assign the GLN to each object. This is especially important in the loading and delivery process to factories, warehouses, distribution centers and stores.

GLN enables companies to efficiently perform various operations and implementation processes without the need to repeatedly transmit the address or other location data (Śliwczyński, Hajdul, Golińska, 2012). Supply chain can efficiently perform transactions, knowing that the information associated with each of the sites is accurate, so you will direct the flow of goods and services in the right place. GLN identifies not only particular area, but also information about the locations and its additional attributes that may be used in the process of distribution. Usage of GLN positively affects the precision and accuracy in communicating and sharing information about the location of the transaction. In addition, all the data is stored in a central database, which reduces the effort needed to maintain and transfer of information between the stakeholders both nationally and globally.

Global Location Number can be used to identify the various organizational units. Under the principle of allocation GLN is distinguished by its 4 main types:

- physical location: the place (area, object or group of objects)
- legal entity, every company, government body, department, charitable organization, person or institution having the ability to enter into agreements or contracts,
- function: the organizational department of the company in separate structures on the basis of specific tasks / functions
- digital location: the location represents the digital electronic address (not physical) used for communication between computer systems of individuals

GLN assigned to the company tells us "who?". GLN assigned to the physical location tells us "where?" The ability to determine "who" and "where" in business processes makes the GLN an essential key to tracking the flow of products and information in the supply chain, and to increase the visibility and location authentication.

Structure of GLN

GLN is a 13-digit code consisting of the Company Prefix by GS1, a reference to a specific location and a check digit (structure is shown on Fig. 3).

Figure 2: GLN Structure
Source: http://www.gs1.se/en/our-standards/Identify/gln/

- GS1 Company Prefix - awarded by the state organization GS1 user / subscriber
- Localization Number - assigned by the company to a specific object
- Check digit - calculated according to a standard algorithm helps ensure the integrity of the system.

GLNs are recognized by the Center for the United Nations as a tool for the implementation of improvements in trade and electronic commerce (UN / CEFACT). The extension component is optional - it is the attribute data of 20 characters used to identify physical internal locations in the object specified in the GLN (for example: shops, factories, buildings). Companies can assign unique GLNs to accurately identify the internal locations of a specific area, eg. rooms in buildings or slots in warehouses.

Using the GLN bar codes and RFID applications

Like all GS1 identifiers, GLNs can be presented in the form of a barcode or EPC / RFID for efficient data collection (Ramos, Lazaro, Girbau, Villarino, 2016; Nam, Yeom, 2011). The three most popular use:

- Marking a physical location - GLN encoded in the carrier data, such as a bar code to identify the physical location, a ramp or shelf storage,
- Logistic label by GS1 standard - GLN specifying the place of delivery of encoded carrier data on the label,
- Label with a trade - GLN encoded in the carrier data in order to determine the trading party on the label.

Regardless on its presentation form, GLN could be used in different situation of data exchange process – some are shown on Figure 3.

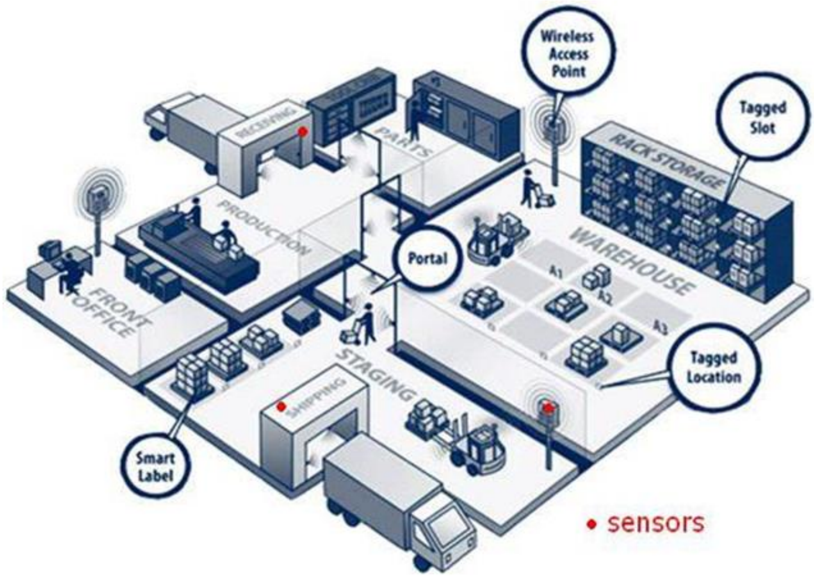

Figure 3: Use of GLN in the process of data exchange
Source: Own elaboration by ILiM

Electronic Data Interchange (EDI) ideally uses Global Location Numbers (GLN) to identify trading partners and their physical locations. EDI mailbox and network addresses can also be identified with GLN. EDI standards promoted by the GS1 System (EANCOM GS1 XML) use GLN to simplify the message in the course of trade.

GLNs are a key concept in EDI. They represent a unique global identification standard needed to secure exchange of business information in the Internet, as well as uniquely identify all legal, physical and functional entities described in the working documents.
GLNs provide efficient communication and processing of data as names, addresses and other information about the individual locations / entities that do not have to be transferred in each transaction. The necessary data is transmitted only once, stored in the system (eg. ERP) and then recovered by reference to the globally unique GLN (Fig. 4).

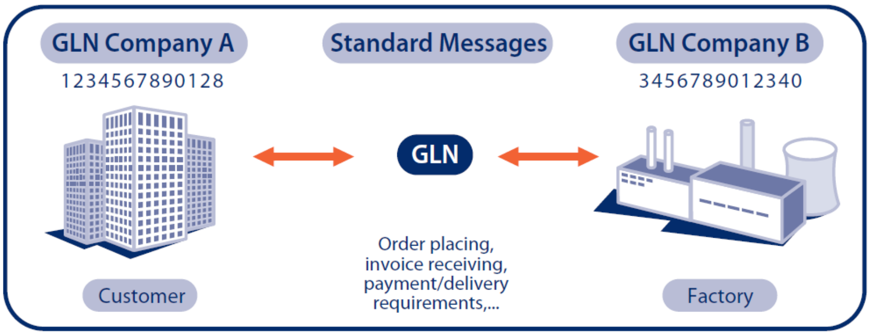

Figure 4: Use of GLN standard
Source: Own elaboration by ILiM

Other common identifiers

Physical Internet is a hyperconnected logistics system so smooth data exchange between involved parties at the level of transactions is crucial. European Union and United Nations have been working on unified identifiers that may support business transactions at the wide scale. Two of the most common (EORI and DUNS) are presented below.

EORI (Economic Operators' Registration and Identification) - one of the constituent parts of the e-customs e-customs environment created within the European Union (EU) - ie a "paperless" environment For customs and trade within the EU. Entrepreneurs are subject to a one-time registration in EORI and are assigned a unique EORI identification number. Entrepreneurs are required to use this number in all transactions and customs operations within the EU. In Poland, the general rule of creating an entrepreneur's EORI number was adopted based on the NIP number.

The main purpose of the EORI system is to accelerate the processing of formalities and customs operations by traders and private persons engaged in business activities. The creation of a European system for the identification of traders, involving trade participants across the EU and provides the customs administrations of the Member States with current information on the entities involved in customs operations. On the other hand, entrepreneurs allow access to specific data on other economic entities (with the prior consent of these entities). Undertakings established in the EU are registered in the EORI system by the customs authority or the designated authority of the Member State in which they are established (ie the Polish system does not register entrepreneurs from other Member States).

The **Data Universal Numbering System**, abbreviated as DUNS is a proprietary system developed and regulated by Dun & Bradstreet (D&B) that assigns a unique numeric identifier, referred to as a "DUNS number" to a single business entity. It was introduced in 1963 to support D&B's credit reporting practice. It is standard worldwide. DUNS users include the European Commission, the United Nations, and the United States government. More than 50 global industry and trade associations recognize, recommend, or require DUNS. The DUNS database contains over 250 million entries for businesses throughout the world. A DUNS number is a unique nine-character identification numer. The information required to obtain a DUNS number includes the business/organization name, type, location, number of employees, and contact information. The federal government uses the DUNS number to maintain consistent name and address data about organizations/businesses. This helps maintain and organize applications and contracts across federal agencies.

Economic Operators' Registration and Identification and Data Universal Numbering System may seem like an alternative to the GLN standard. However taking physical location of the entity and their logistics aspects into consideration none of these solutions respond fully to the needs of the PI actors. That particular facet will be elaborated later on in this article.

4 Research methodologies exploring the GLN standard implementation

Research into the use of the GLN standard is based on the methodology outlined in Figure 5.

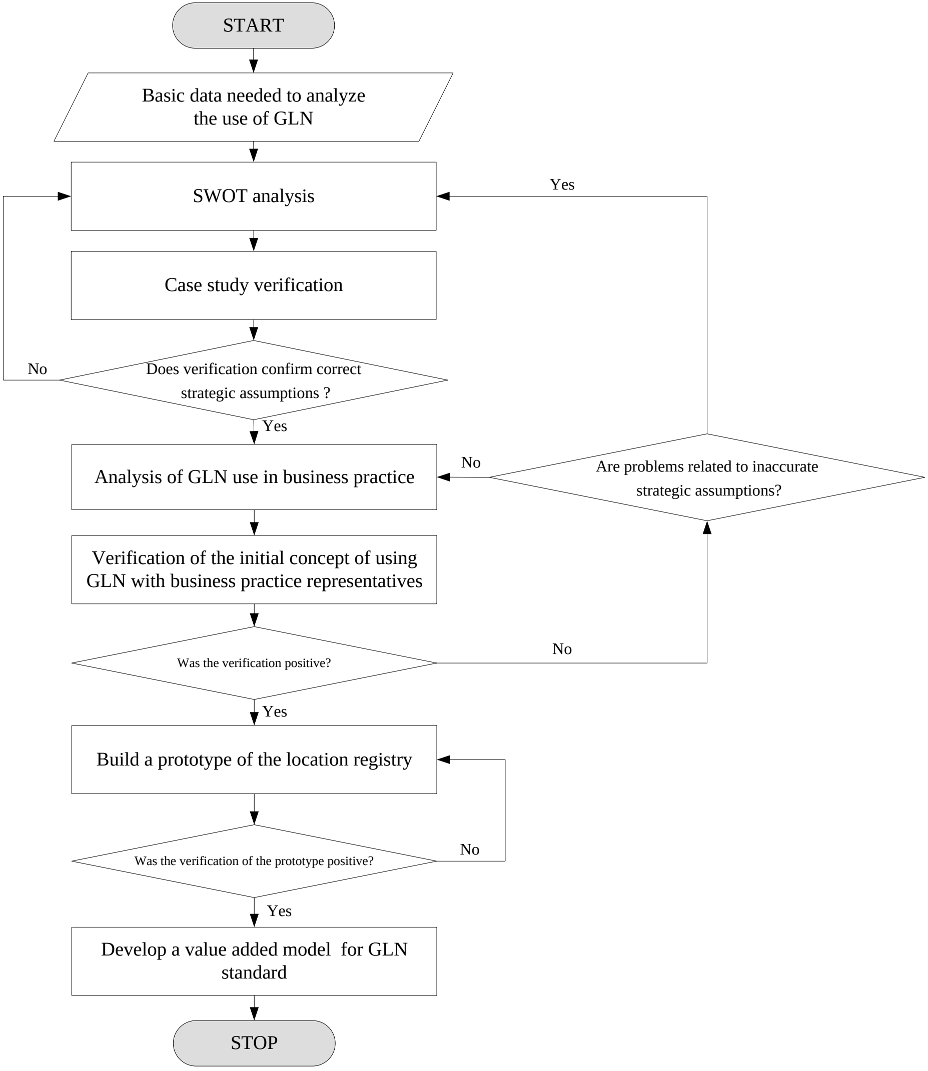

Figure 5: Methodology of GLN application analysis in information flow efficiency
Source: own elaboration

Developed methodology enables the case study method to be repeatedly applied as an effective research method, allowing multi-criterion analysis of the problem. The case study is designed to show the relationship between phenomena occurring in the described processes. Quantitative methods based on a statistically representative sample do not allow such analyzes. Taking into account the specifics of the GLN standard usage, the author have studied a multiple cases in order to compare variant features in a larger case. Case-by-case review is considered to be more reliable than a single case study (Eisenhardt, Grabner, 2007, p. 27), as it enables a description of the differences and similarities between the analyzed variants to identify general trends. In the literature on the subject of the ability to verify models through case studies, you can find different views on the number of variants to be analyzed so that the conclusions of the study are scientific in nature. The dominant view suggests to conduct four to ten case studies (Eisenhardt, Grabner, 2007; Yin, 2009). The verification of the use of GLN in practice was based on 8 case studies that allow author to create the general trends.

Presented methodology also uses observations and consultations on the degree and conditions of using GLN in the leading logistics companies, which increases the reliability of conducted research in this field. The next part of the paper presents the steps of the research carried out in accordance with the presented methodology.

4.1 GLN standard SWOT analysis

In order to explore scientifically the possibility of GLN standard author conducted SWOT analysis based on secondary research: literature, materials available on the enterprises and existing case studies described in research and optimization projects.

Table 1: SWOT analysis

S – Strengths	W – Weaknesses

- All the benefits of GS1 standards: global, international, simple structure, coding in various forms (EAN, RFID / EPC) so it can be widely use within PI
- Data protection - you cannot directly identify the location of the object – that is very important from the perspective of hyperconnected systems
- Ability to use different entity angles: legal, physical, functional
- Allows reduction of returns due to incorrect address information delivery
- The ability to extend the range of information related to the GLN (ie. geolocation, driving directions, characteristic of delivery places) – that may easily solve most of the logistics problems
- Precise uniform nomenclature (the problem of many towns of the same name) – errors exclusion / duplication of company names, cities
- Numbers can be given by the independent body (eg. Public administration) – so it would be easy to introduce worldwide
- The ability to extend the GLN (GLN extension component) to address internal location – “door to door” deliveries
- The ability to easily "connect" local routes planning to the register (API)
- Benefits of the registry:
    - unified way to collect and store information
    - single point of access to data
	- To be given GLN you must be a member of GS1
	- Currently GLN in Poland applies only to businesses - no application for the couriers industry services for private customers
	- No description of good practices to use GLN in Poland
	- A large flexibility in assigning numbers within prefix, lack of mechanisms to control (except for providing unique number) of the information contained under no clear structure (everyone can construct any name, description)
	- Locations with no classification (flat floor, loading gate)
	- Descriptions are created based on the knowledge not on the needs
	- Lack of a public database / registry in Poland
	- Lack of knowledge - necessary education among current and potential users

O – Opportunities	**T – Threats**
- Ability to use in logistics industry - Existing use cases - the ability to take advantage of the experience – eg. Unilever Global - Ability to top-down / administrative updates (eg. Change zip codes, street names, etc.). - Low margin in transport business (every penny spared counts) - environmental savings through better route planning and avoiding mistakes - Trend for the digitization and standardization - digital exchange of information - The trend to globalization – GLN - very useful especially in international transport, - Physical Internet development - distribution planning, accounting, data protection - The notion of large entities (companies - eg. Retail chains (case codes requirements GTIN), offices - case number NIP, REGON) will result in avalanche expansion of the system.	- GLN topic did not came out from the potential users but from the supplier (GS1) - Lack of GS1 Global coordination (Global Location Register) on local activities - The high cost of reaching the stage when the GLN and the register will be widespread and benefits will be tangible / incentives of joining / using the system - Expected "resistance of the stakeholders" if it is not tangible

Source: Own study by ILiM

4.2 Research on use of the GLN standard in enterprises

Despite several satisfactory implementations of GLN standard in Europe, this topic is not very popular in Poland, and the content of the national database still leaves much to be desired. The results of surveys among the leading Polish enterprises in the TSL conducted in the second half of 2016 indicate an unsatisfactory degree of implementation of the transport processes, resulting from incorrect or inaccurate description of the location, and thus, a significant number of errors in deliveries.

Lack of details about location generates enormous costs on both the supplier and the customer site. Therefore, the efficient retrieval of information regarding the location and including elements such as time windows, time of unloading, conditions for unloading etc. would allow the optimization of the distribution process and delivery within the prescribed period (no need to re-supply, eliminating the cost to the operator). One of the solutions to avoid supply problems is to implement register of locations using GLN numbers. Such a register in addition to the address data identifying specific company would have information about the characteristics of the location such as unloading conditions, opening hours, time windows, ramps, etc.

Accordingly, the literature and examined case studies indicate the possibility of using GLN standard to identify the physical location and to show the perspective of its implementation in the TSL industry. In the next section, author present materials that were collected during the meeting on the current problems of enterprises in the location identification. The meetings were characterized by the Delphi study using the method of network thinking.

Conclusions from the research studies:

- Companies create their own address database with relevant logistics information and individualized information regarding the location - this is due to the lack of unified market standards of such data collection and lack of access to an open database,
- Customers of contract logistics, even though many of them are members of the GS1 organization, do not fully benefit from the opportunities offered by the GLN, that makes it difficult to work with logistics operators,
- Problem of who will be responsible for updating the database. The essence of the registry is preserved only when it is valid and reliable,
- An important player for a greater popularization of the use of GLN are **retail** chain stores – they may force their suppliers and logistic operators to participate in the GS1 System,
- The problem is the low level of awareness and knowledge among entrepreneurs about the benefits that entails the use of a GLN standard.

4.3 Verification of the location register prototype

In each meeting, the participants verified or added the data fields to the location register prototype. The most common needs for additional location information:

- Categories of materials stored (eg. Food, chemicals...),
- Accepted logistic units (eg. Pallets, containers, roles...),
- Ability to accept the goods with temperature control - frozen or fresh goods,
- Storage Temperature,
- The possibility of storing ADR materials (eg. Gas, explosive substances and articles, flammable liquids...),
- Supported transport (eg. TIR, tanker, tilt, cold ...),

- The landing surface,
- Types of ramps (eg. A simple, gear, stepped ...),
- Equipment of the ramps (eg. Crane, lift, loading bridges ...),
- Technical conditions of the ramps (eg. Turning radius, maximum load, height ...),
- Technical delivery conditions (eg. Pallets arranged by narrow side, the wide side, stackable acceptable...).

Because of the strictly defined information structure for GLN standard and its large number and requirement for a relatively quick access to the on-line data, it is proposed to use a relational database in conjunction with a Web site allowing interactive access to the base in order to view, add, edit and delete records.

4.4 Developing the proposal value model for use the gln standard

In the second half of 2016 at the headquarters of ILiM author organized a meeting, which the main aim was to develop a business model and determine the unique value proposition, which entails the use of a GLN standard in the TSL.

One of the most popular concepts in defining business models is the Business Model Canvas by Alexander Osterwalder. This model accurately describes how organizations create and deliver value to its customers. The model is presented by 9 elements that represent different aspects of the enterprise.

Description of individual parts should start from the most important of them, that is, customer segmentation (1). It is the basic model. It defines different groups of recipients, which receive the added value produced by the company. Customer segments identified for GLN are mainly companies from the TSL industry, retailers and producers with an extensive distribution network.

Another key aspect is the value proposition (2), which is to satisfy the specific needs or solving customer problems. In other words, the value proposition is a set of perks that the company offers to its customers. Author defined the following advantages within GLN standard:

- reduction of costs associated with re-handling the point and the cost of lost benefits due to the lack of goods on time,
- discount on transport companies for use GLN (win-win situation),
- easy update of data visible to everyone in the database,
- access to full location information in one place,
- reduction of delays and increase of on-time deliveries,
- reduction of errors in the delivery,
- a positive impact on Customer Service rates,
- guidance on the selection of the vehicle by the carrier,
- the appointment of load (eg. Stacking pallets in AMAZON),
- guidance for on time delivery and advising,
- directions, coordinates.

Channels (3) is an element that describes how the company communicates and gets to customers segment to provide added value and knowledge about the product. In its activities, the organization GS1 may use the database of GS1 members to promote GLN content (eg. trainings, webinars, brochures, newsletters) to disseminate knowledge about the GLN through partners (eg. The Ministry, ILiM), contact with the associations of producers / clusters / Chamber of Commerce, share information in magazines and at industry conferences (eg. ECR Forum) and publication of good practices on web sides of GS1 and partners.

The element named customer relationships (4) describes the type of interaction that the company establishes with separate customer segments. As part of the implementation of the GLN, GS1 will build a personal relationship with the customer (consultants for individual support to replenish and register GLN - the co-value) and the open access to the database - automatic assignment to the self-service platform.

Structure of revenues (5) describes the way the company generates profits of individual customer segments. In the case of GLN standard income will come from fees for granting the pool of numbers and the fee for participation in the GS1 System.
Key resources (6) are necessary to generate benefit and reaching out to segments of customers through distribution channels. The main resources identified for GLN:

- GLN hotline supports clients in completing the data,
- database of registered numbers GLN - ICT infrastructure,
- Internet platform with access for the user,
- technical consultants (human resources),
- financial resources to carry out the educational and promotional activities,
- intellectual resources related to the brand and the rights to the GS1 GLN standard,
- database errors, problems, additional costs created by the industry TSL, which allows to calculate the potential savings from the use of GLN and thus, the basis for the promotion of the standard.

Key actions (7), the most important tasks that the company needs to do to provide benefit, establish a relationship with customers and generate revenues. The creation of a fully functioning registry GLN is associated with:

- the introduction of customer support services for the creation and configuration of the base,
- filling and update the database and quality check of the information entered by the customer,
- increasing awareness of members of the GS1 and their need to use GLN - trainings, webinars,
- creation of case studies with examples and implementation of pilot actions,
- analysis of data from the database of interference - to calculate the costs of errors by logistics operators,
- joint projects with operators, retailers and manufacturers in order to complete GLN registry in cooperation with retail chains,
- consultations with the public administration (eg. Ministry of Development, Ministry of Digitization).

The concept of key partners (8) describes a network of suppliers and contractors who make the service implementable. In case of GS1 we are talking about state administration (eg. Ministry of Development, Ministry of Digitization), large logistic operators (eg. Dachser, Raben, Schenker, etc.), Institute of Logistics and Warehousing, large retail chains (eg. Jeronimo Martins) and producers who are members of the GS1 system (eg. Kompania Piwowarska, Colian, Zywiec Group, etc.).

The last element is the cost structure (9) - all the expenses, which are generated by the business model i.e. creating and delivering value, maintaining customer relationships and generating revenue. As part of the implementation of GS1 standards, we have to deal with the cost of creating the GLN register (the conception and information technology), the cost of data collection and individual customer support in rectifying the base and the cost of promotional activities and education.

5 Conclusions

In this article, author presented the case of the efficiency of the flow of information in enterprises and supply chains, using the Global Location Number (GLN). Both theoretical considerations, supported by expertise in creating SWOT analysis of the discussed issues, as well as research conducted by the Institute of Logistics and Warehousing, on the use of standard GLN to improve the identification of physical and unification descriptions of locations, indicate the potential for new opportunities for the use of GS1 standards in the integration of information flow in economic practice within supply chains.

Based on the results of work carried out in the framework of the study author can draw the following conclusions:

- there is a market need for both research and design work associated with the construction of GLN location register in the practice of economic enterprises,
- effective implementation and popularization of location register requires not only the support of major players in the market, or industry leaders, but also scientific support for the conceptual work,
- strong interest in economic practice in the construction of GLN location register is proof of the need to propose business solutions, allowing their practical application, but also the existence of the possibility of continuing further research in this area especially in terms of hyperconnected logistics.

Presented, in this article, case studies, regarding the specifics of distribution processes, were based on research and observations carried out in the leading logistics companies in Poland. The test results are only a basis for further studies in the use of GLN in the flow of information throughout the supply chain.

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RTI Capabilities of Air Cargo Transport Chains by Evaluating Processing Interfaces and Actor's Responsibilities

Dipl.-Ing. (FH) Andreas Romstorfer, MA[1]
Dipl.-Ing. Dr. rer. nat. Heinz Dörr[1]
Dipl.-Ing. Viktoria Marsch[1]
[1] arp-planning.consulting.research, Vienna, Austria
a.romstorfer@arp.co.at

Abstract: *The issues outlined as follow are based on results of the ACCIA project which have been manifold, due to its being a subject formatting study. By summarising these results, first a documentation of the field of airfreight based on introductory literature and an exploration of official statistical sources on airfreight traffic are given. Subsequently, a deeper analysis of the airports investigated will be shown, whereby essential information was gained on exploratory field visits and by expert discussions on-site. All these insights into air cargo handling and transportation are essential for identifying and characterising the interfaces along the several airfreight transport chains. Based on this information, methodological approaches for analysing the processes along the air cargo transport chains are outlined. Finally, these procedures lead from the interfaces detected to determining application fields on to potential targets for identifying Research, Technology and Innovation RTI-potential. Ultimately, comments are made on these perspectives as to their significance for the future. The interface navigator developed as part of the study can serve as a basis for the step by step implementation of a physical internet along the complex air cargo transport chain.*

Keywords: *air cargo transport chain, system of the interfaces, Air Cargo Centre, RTI-potential, personalisation, formalisation, digitisation, automation, decarbonisation, air cargo interface navigator*

1 Introduction

The study “ACCIA – Air Cargo Research and Capabilities in Austria” (Dörr et al., 2016) was carried out as a research and development service for the Austrian Ministry for Transport, Innovation and Technology (BMVIT) within the frame program “Take Off” and was completed in 2016. The report was worked out by the leading Civil Engineer Office arp-planning.consulting.research, DHL Global Forwarding Austria and the Vienna International Airport.

The background for the study was the assumption that with reference to the year 2010 air cargo traffic will be doubled until 2030 (Take Off, 2014). Mass goods with a low weight per piece and high-quality goods determine the volume of freight in aviation. However, the transport of the goods by aircraft is only a part of the transport chain and must be coordinated with pre-carriage and on-carriage according to the modes of surface traffic.

The following questions were discussed in the research and development phase:

- What are the deficits, gaps, problems and challenges in the field of air cargo processes in Austria?
- Which specific interfaces in the air cargo transport chain are affected?
- How can the deficits, gaps, problems and challenges identified be met with R&D?
- What potentials could be created?

- Which actors should be involved in order to raise these potentials?
- What visionary concepts already exist among the interface logistics/freight traffic/aviation?
- Which visionary concepts should be followed up by R&D?
- What basic conditions (technical, organisational, legal) should be taken into consideration?

2 Air Cargo Transport Chains – A Complex Challenge

Air cargo transport chains are characterised by the various actors involved, by a fiercely competitive market and by a wide range of logistical quality requirements, which are determined by the customers. Nowadays, almost all goods can be flown as airfreight, provided that they do not exceed the mass transport capacity of the aircraft. Shipping and receiving airfreight customers are broadly diversified by sector and region. Nevertheless, major shippers with a high global export shipping volume, the specialists in the forwarding businesses and the air cargo freight carriers symbiotically converge by means of contract logistics. Thus, the cargo belly load in the lower deck of passenger aircrafts meets their economic expediency just as well as transport via cargo aircrafts does. Furthermore, passenger aviation offers scheduled flights departing from economical hot spot regions for spontaneous consignment missions also to remote located destinations (see Figure 1).

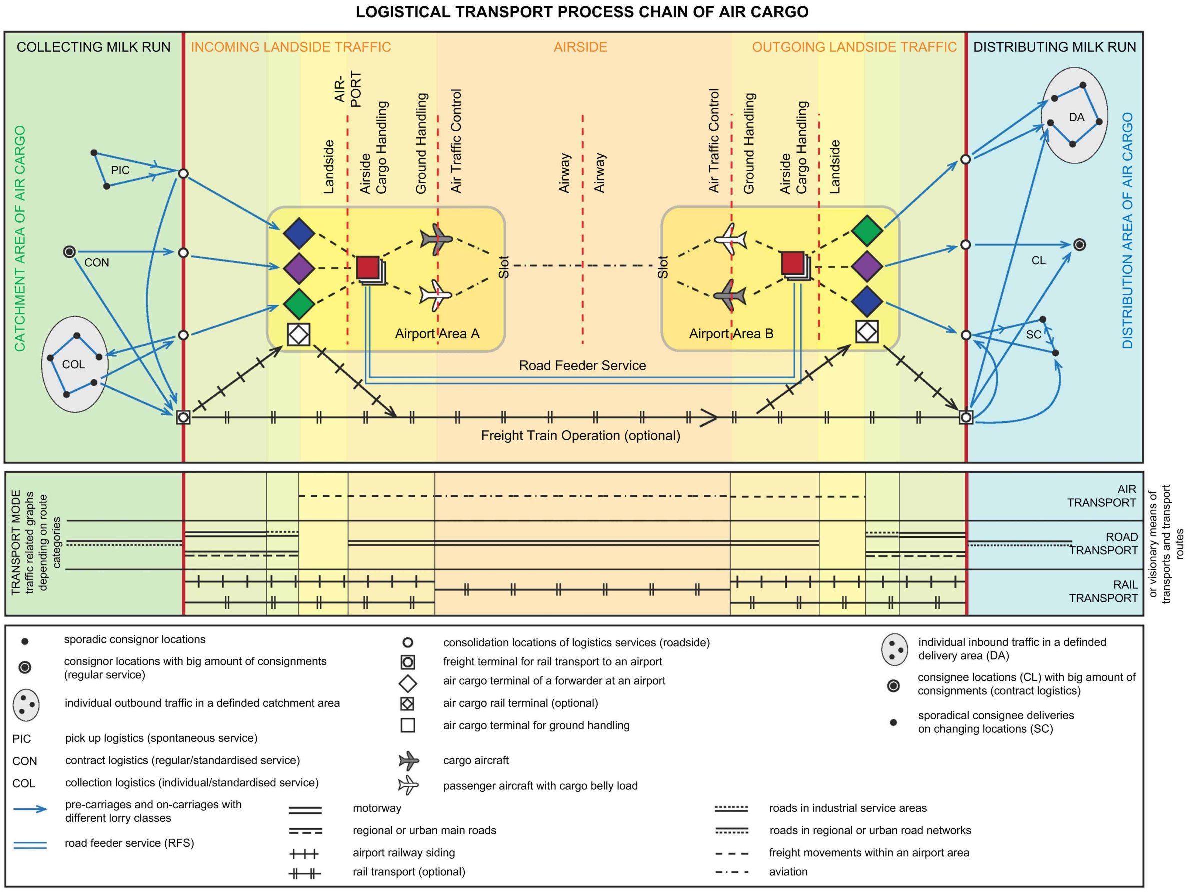


Figure 1: The air cargo transport logistical process chain, sourced from Dörr et al., (2016)

Global hubs, such as Frankfurt/Main (FRA) or Vienna (VIE), achieve their freight volume mainly in both air cargo transport modes — excluding Road Feeder Service (RFS) only as belly load in the lower deck of passenger aircrafts or as transport via cargo aircrafts. In addition, airports with regional or touristic passenger volume, such as Linz (LNZ), Leipzig/Halle (LEJ) or Liège (LGG), have developed as niche players in certain segments of the air cargo business.

3 Airports seen as Locations with Potential

In terms of each airport as a location for itself, the potential for air cargo traffic can be described by three dimensions:
1. the hinterland potential as demanded by the air cargo affine economy,
2. the destination potential based on the quality and quantity of flight connections to and from a hub airport,
3. the location potential (capacity and quality of service) of an airport as a hub and consolidation centre with respect to space and traffic.

The significance of commercial airports cannot be determined solely by considering the dimension and the success factors. In view of globalisation and the integration of the European internal market, these factors are to be understood as a gateway to the world, providing the necessary infrastructure for the economy of the hinterland.

The airports with their handling facilities for airfreight alone do not yet serve as a growth engine for an economic region, but as an important location factor they could indeed greatly facilitate trade relations and industrial development. In this respect, the Austrian commercial airports are analysed qualitatively by the aspects of the historical development and the current status, the importance of the airport by analysing aviation statistics and transport services, the operating infrastructure, the development as an economic location and synergies with the surroundings and the hinterland and the economic catchment area for air cargo. Referring to cargo handling, it is subsequently attempted to assess the potential of the Austrian airports.

To summarize up, air cargo is not just an Austrian phenomenon, but something which is happening globally. Analysing Austrian airports might even show that the problems and challenges are not limited to being national issues. Regional airports are often located near hubs, showing that this might indeed be a European problem, if not an international one.

4 Air Cargo Transport Modes in the Transport System

In the case of air cargo transportation, the overland transport system, almost exclusively road transport, is used to supplement air cargo transport chains in two ways. On the one hand, it provides a pre-carriage and on-carriage transport service to the airports; on the other hand, it functions as a road feeder service between two airports instead of inner continental transport by aircraft. Aside from major customers, the tracks of air freight shipments are lost as soon as they have reached the consolidation logistics warehouses in the vicinity of the airports. This is because these goods’ flows disappear in the general flows of goods transported. The traffic modelling of the inflow and outflow of lorry-borne air cargo transports from domestic airports has resulted only in a marginal share of the entire heavy duty traffic in the road network of long-distance routes. As a whole, significant potential savings of freight runs are to be found elsewhere in the fields of freight transport and vehicle traffic onto road network.

The model of lorry-borne traffic generation of an Air Cargo Center shows the complex ingoing and outgoing movements of various utility vehicles serving air cargo transportation overland and transhipments to main runs by aircraft (see Figure 2). The Air Cargo Center bundles/debundles not only physical goods as well as it works as a focal point for different shaped supply chain processes for various customer´s needs and commodity requirements.

Although lorry-borne shipment per continental land transport of airfreight is notable, it is necessary to mention, that each road-carried ton of payload produces less emissions than each flown-carried ton of payload. However, if a network of railway connected airports could be built up (e.g. Euro Carex), some of the lorry-borne airfreight transports could be shifted to the more climate-friendly railway. In any case, the multimodality of airports is a marginal issue here, so that convincing operations models, which would justify infrastructure investments in the railway connection of the air cargo centres, are sorely lacking.

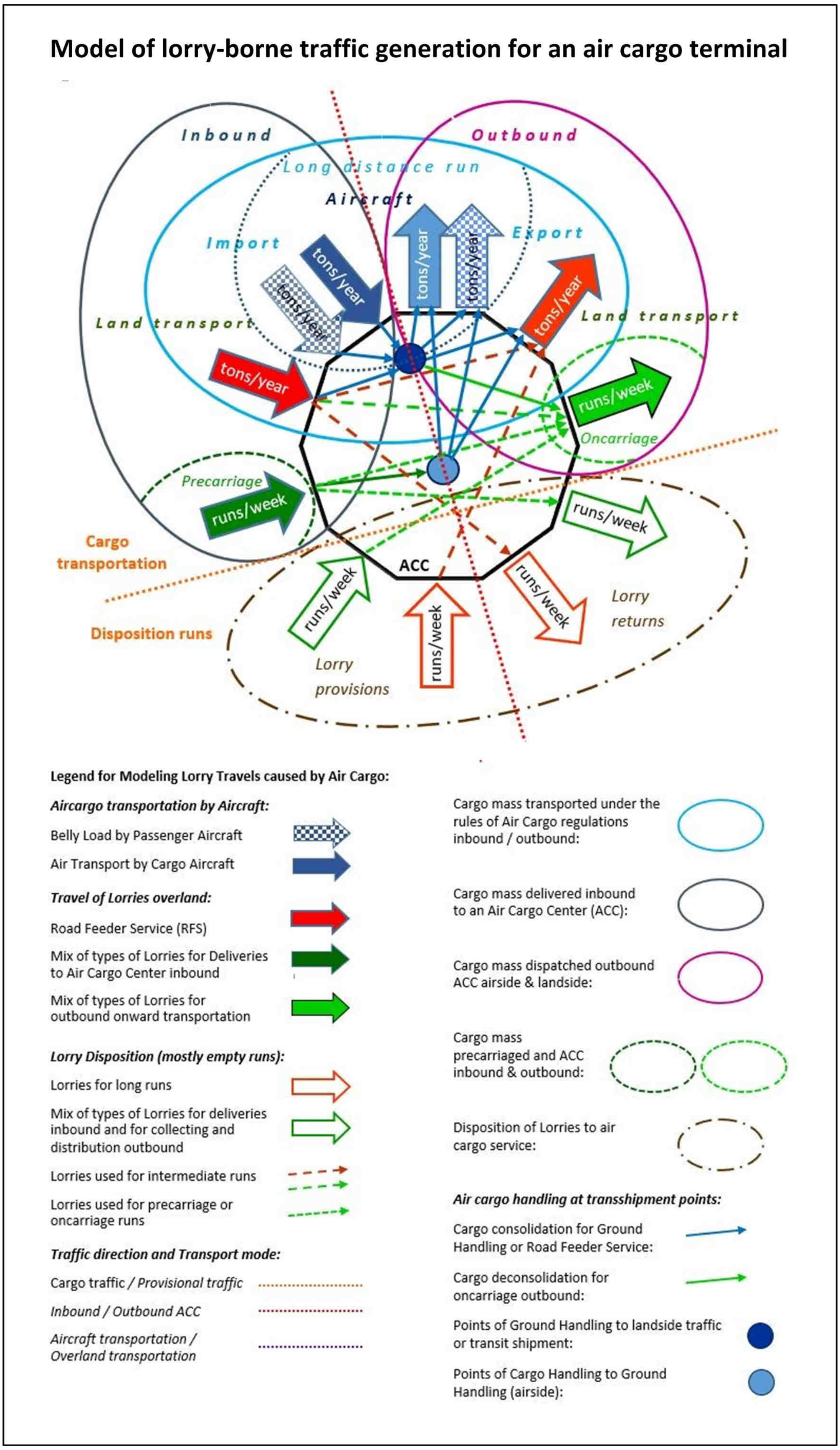
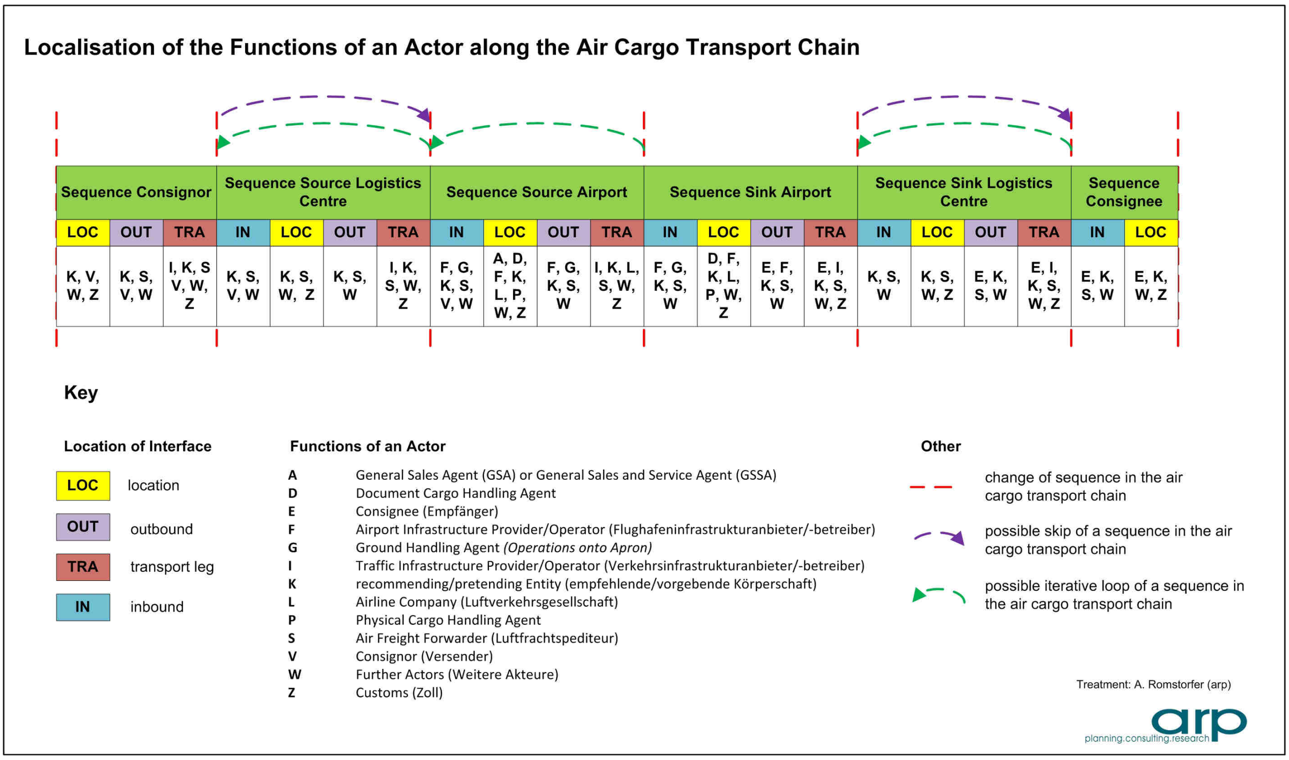


Figure 2: Model of lorry-borne traffic generation for an air cargo terminal, sourced from Dörr et al. (2016)

5 Actors and Functions of an Actor

The actors involved along the air cargo transport chain have different ranges of services; this means that the attribution of a function at an interface is not always unambiguous. This is due to the fact that actors do not carry out only those functions as might be assumed in detailing the distribution of roles between customers, forwarders, cargo handling, ground handing, airlines and so on. For instance, Unit Load Devices (ULD) do not have to be set up by a cargo handling agent in the air cargo terminal of an airport, although this as a rule does occur. Another example is airlines offering air transportation and other additional preceding or subsequent services in addition to their core business. Due to liberalisation in aviation ground handling, several providers originating in different business areas are also able to offer their services at an airport. Consequently, the authors of this study have introduced the term **functions of an actor** to refer to these differences. Hence, a function can be practiced by one or more actors (see Figure 3).



Localisation of the Functions of an Actor along the Air Cargo Transport Chain

Sequence Consignor			Sequence Source Logistics Centre				Sequence Source Airport				Sequence Sink Airport				Sequence Sink Logistics Centre				Sequence Consignee	
LOC	OUT	TRA	IN	LOC	OUT	TRA	IN	LOC	OUT	TRA	IN	LOC	OUT	TRA	IN	LOC	OUT	TRA	IN	LOC
K, V, W, Z	K, S, V, W	I, K, S V, W, Z	K, S, V, W	K, S, W, Z	K, S, W	I, K, S, W, Z	F, G, K, S, V, W	A, D, F, K, L, P, W, Z	F, G, K, S, W	I, K, L, S, W, Z	F, G, K, S, W	D, F, K, L, P, W, Z	E, F, K, S, W	E, I, K, S, W, Z	K, S, W	K, S, W, Z	E, K, S, W	E, I, K, S, W, Z	E, K, S, W	E, K, W, Z

Key

Location of Interface

LOC	location
OUT	outbound
TRA	transport leg
IN	inbound

Functions of an Actor

A	General Sales Agent (GSA) or General Sales and Service Agent (GSSA)
D	Document Cargo Handling Agent
E	Consignee (Empfänger)
F	Airport Infrastructure Provider/Operator (Flughafeninfrastrukturanbieter/-betreiber)
G	Ground Handling Agent *(Operations onto Apron)*
I	Traffic Infrastructure Provider/Operator (Verkehrsinfrastrukturanbieter/-betreiber)
K	recommending/pretending Entity (empfehlende/vorgebende Körperschaft)
L	Airline Company (Luftverkehrsgesellschaft)
P	Physical Cargo Handling Agent
S	Air Freight Forwarder (Luftfrachtspediteur)
V	Consignor (Versender)
W	Further Actors (Weitere Akteure)
Z	Customs (Zoll)

Other

– –	change of sequence in the air cargo transport chain
⤳	possible skip of a sequence in the air cargo transport chain
⤳	possible iterative loop of a sequence in the air cargo transport chain

Treatment: A. Romstorfer (arp)

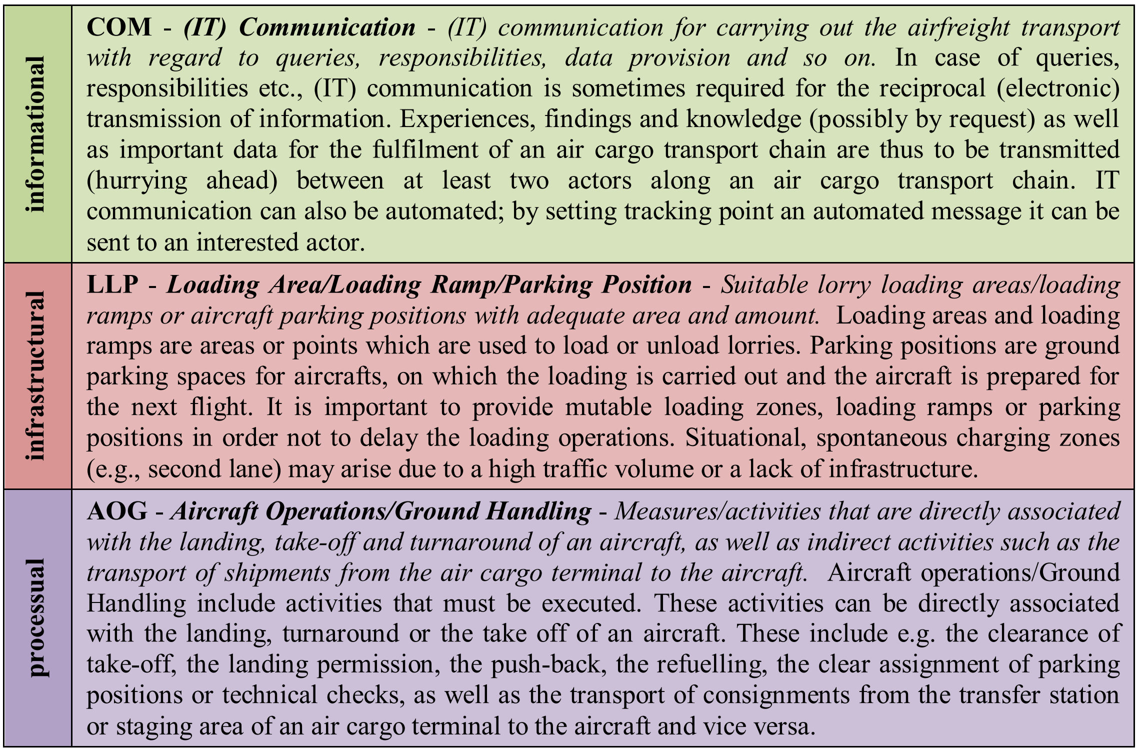
Figure 3: Localisation of the functions of an actor along the air cargo transport chain, sourced from Dörr et al. (2016)

6 Interfaces as a Guideline in the Process Chain

The air cargo transport chain can be regarded from three different points of views. Firstly, there is the *transport geographical view*, which analyses the sources and destinations of transports in the transport infrastructure network. Secondly, there is the *view of responsibility*, which describes the sphere of responsibility of the actors involved. Last but not least, there is the *view of single sequences*, where the locatable process areas (warehouse location, ramp, transport legs, etc.) of traffic logistical functions and processes, such as a loading activity or cargo handling, are explored. These process areas describe the localisation of interfaces as well as the sphere of responsibility of the actors interacting at an interface. In every case the air cargo consignment represents the object to be treated. The treatment which takes places at an interface not only affects the physical process of handing over of the consignments, it also affects the transfer of responsibility.

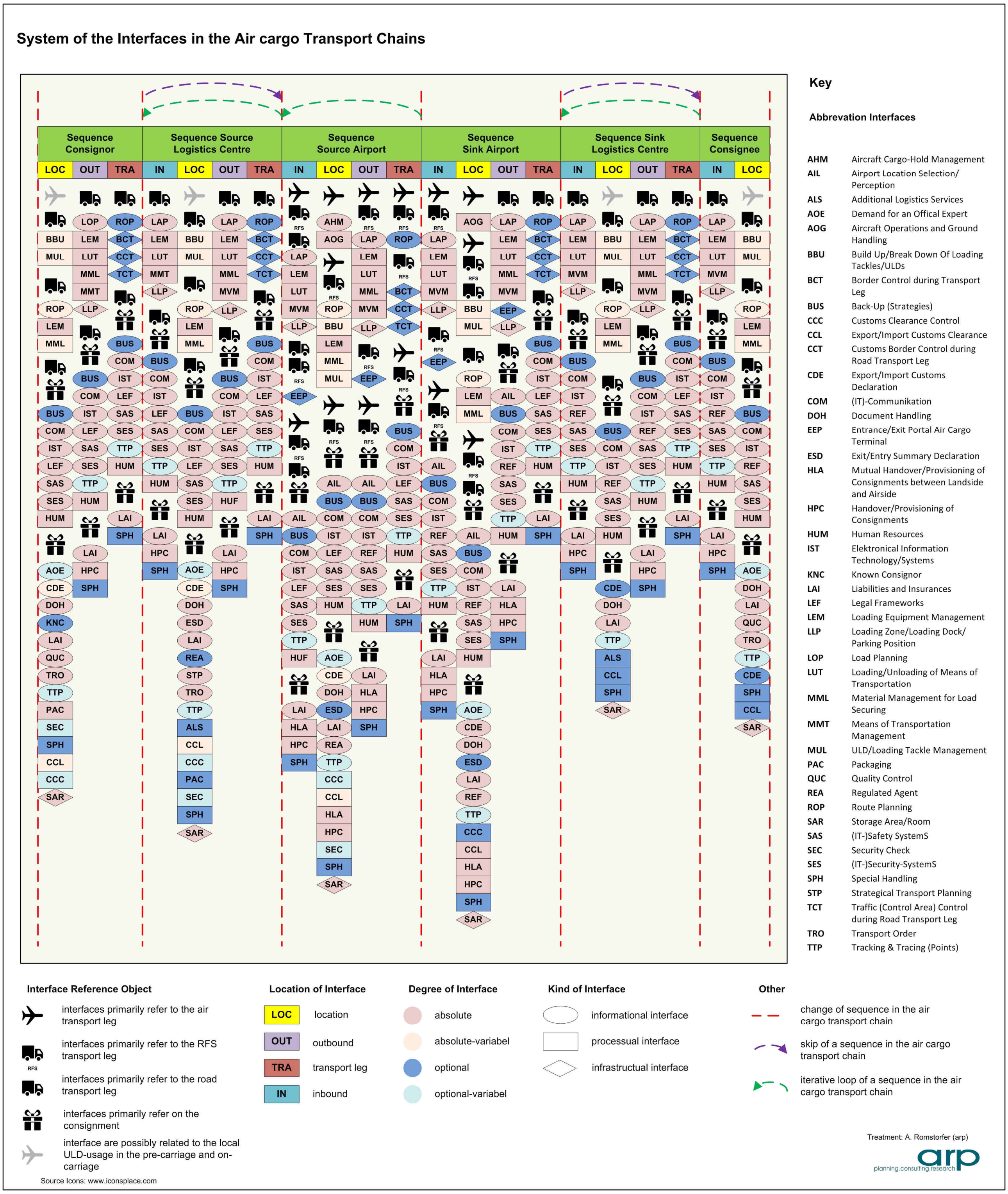
In order to achieve a graphically attractive system for the interface scenery of different air cargo transport chains, the interfaces were initially classified by their technical-related and functional-related characteristics. These characteristics were grouped into *informational* (data flows of organisational relevance), *infrastructural* (performance features of the available transport infrastructure) and *processual* (necessary operating processes based on the consignment structure and the security regulations) interfaces (see Figure 4). Additionally, the interfaces were classified according to their *degree of indispensability*. This was done because some interfaces had to be complied with at a certain location. Others may occur multiple times or in local variations. Last but not least, there are also interfaces, which might be switched on optionally, e.g. due to special consignment requirements.

In the next step, the **chronological-spatial arrangement** of the interfaces was determined. In order to do so, the air cargo transport chain was subdivided into *action-related sequences*. These were then subdivided again into the process *areas "inbound", "location", "outbound"* and *"transport"*. Individual sequences can be left out or can be repeated, depending on the respective airfreight transport chain. Subsequently, the interfaces were arranged according to their **transport modality**, whether they relate on the transport run to the aircraft (✈), on the transport run via RFS (🚚), on the transport run in the pre-carriage or on-carriage to the lorry (🚚), on the consignment itself (🎁) or to a possible ULD service in pre-carriage or on-carriage (✈). The authors of the study called this **interface navigator**, because it can be used as an orientation tool for evaluating, optimizing and estimating the development potentials for the majority of air cargo transport chains (see Figure 5).



informational	**COM** - ***(IT) Communication*** - *(IT) communication for carrying out the airfreight transport with regard to queries, responsibilities, data provision and so on.* In case of queries, responsibilities etc., (IT) communication is sometimes required for the reciprocal (electronic) transmission of information. Experiences, findings and knowledge (possibly by request) as well as important data for the fulfilment of an air cargo transport chain are thus to be transmitted (hurrying ahead) between at least two actors along an air cargo transport chain. IT communication can also be automated; by setting tracking point an automated message it can be sent to an interested actor.
infrastructural	**LLP** - ***Loading Area/Loading Ramp/Parking Position*** - *Suitable lorry loading areas/loading ramps or aircraft parking positions with adequate area and amount.* Loading areas and loading ramps are areas or points which are used to load or unload lorries. Parking positions are ground parking spaces for aircrafts, on which the loading is carried out and the aircraft is prepared for the next flight. It is important to provide mutable loading zones, loading ramps or parking positions in order not to delay the loading operations. Situational, spontaneous charging zones (e.g., second lane) may arise due to a high traffic volume or a lack of infrastructure.
processual	**AOG** - ***Aircraft Operations/Ground Handling*** - *Measures/activities that are directly associated with the landing, take-off and turnaround of an aircraft, as well as indirect activities such as the transport of shipments from the air cargo terminal to the aircraft.* Aircraft operations/Ground Handling include activities that must be executed. These activities can be directly associated with the landing, turnaround or the take off of an aircraft. These include e.g. the clearance of take-off, the landing permission, the push-back, the refuelling, the clear assignment of parking positions or technical checks, as well as the transport of consignments from the transfer station or staging area of an air cargo terminal to the aircraft and vice versa.

Figure 4: Examples for informational, infrastructural and processual interfaces in the air cargo transport chain, sourced from Dörr et al. (2016)



AHM	Aircraft Cargo-Hold Management
AIL	Airport Location Selection/ Perception
ALS	Additional Logistics Services
AOE	Demand for an Offical Expert
AOG	Aircraft Operations and Ground Handling
BBU	Build Up/Break Down Of Loading Tackles/ULDs
BCT	Border Control during Transport Leg
BUS	Back-Up (Strategies)
CCC	Customs Clearance Control
CCL	Export/Import Customs Clearance
CCT	Customs Border Control during Road Transport Leg
CDE	Export/Import Customs Declaration
COM	(IT)-Communikation
DOH	Document Handling
EEP	Entrance/Exit Portal Air Cargo Terminal
ESD	Exit/Entry Summary Declaration
HLA	Mutual Handover/Provisioning of Consignments between Landside and Airside
HPC	Handover/Provisioning of Consignments
HUM	Human Resources
IST	Elektronical Information Technology/Systems
KNC	Known Consignor
LAI	Liabilities and Insurances
LEF	Legal Frameworks
LEM	Loading Equipment Management
LLP	Loading Zone/Loading Dock/ Parking Position
LOP	Load Planning
LUT	Loading/Unloading of Means of Transportation
MML	Material Management for Load Securing
MMT	Means of Transportation Management
MUL	ULD/Loading Tackle Management
PAC	Packaging
QUC	Quality Control
REA	Regulated Agent
ROP	Route Planning
SAR	Storage Area/Room
SAS	(IT-)Safety SystemS
SEC	Security Check
SES	(IT-)Security-SystemS
SPH	Special Handling
STP	Strategical Transport Planning
TCT	Traffic (Control Area) Control during Road Transport Leg
TRO	Transport Order
TTP	Tracking & Tracing (Points)

Figure 5: System of interfaces in the air cargo transport chains, sourced from Dörr et al. (2016)

The complex framework conditions are a daily challenge for all service providers active are in the air cargo transport chain. Consequently, their efforts to standardise and harmonise the processes by providing flexible handling service in keeping with the wishes of the customers and under consideration of safety and security regulations are quite remarkable in a qualitative tensional relationship. Nonetheless, these circumstances make economical rationalisations and technological optimisation difficult to implement, if the market positions of the involved actors are not to be jeopardised.

7 RTI Potentials in intervention points and fields of application

On the basis of a strength and weakness conclusion in the range of air cargo, potential on-site intervention points and fields of applications are identified for possible research and development activities. Therefore, all 43 of the interfaces identified are examined on their suitability for prospective RTI-capabilities by evaluating the localised intervention points in the five fields of applications defined. These fields are Personalisation, Formalisation, Digitisation, Automation and Decarbonisation.

Firstly, this individual valuation results in statements on measures that influence particular locations such as the landside or the airside of an airport or the apron in front of an air cargo centre. However, a list of intervention points for improvements, upgrades or changeovers may never be complete. This is not least due to the fact that operational details in the processes of the respective actors can be very diverse. They may also not always be observed and described on grounds of confidentiality and safety reasons. The summary results for the process areas along the air cargo transport chains, where interventions could be placed, thus seem more revealing. In addition, a ranking were performed to identify primarily RTI-potential. Therefore, the interfaces identified were subjected to a strengths-weaknesses analysis. These strengths and weaknesses were extracted e.g. during expert discussions and/or where they were obvious on on-site inspections. As a next step, the strengths and weaknesses identified were then used to identify intervention points which can influence the process design in the air cargo transport chain. For a closer assessment they were evaluated in the five fields of application defined:

- **Personalisation:** all services provided by human resources in the airfreight transport chain,
- **Formalisation:** all activities that are used to define tasks and structures or configure processes,
- **Digitisation:** networking of objects along the air cargo transport chain by using information and communication technology,
- **Automation:** conversion to automated processes for the support, facilitation and precision of processes,
- **Decarbonisation:** all measures and conversions to encourage post-fossility.

While the intervention points represent the possible or even urgent tasks, e.g. with regard to the climate change or possible integration of the physical internet, the fields of application refer to the solutions and fundamentally show where the competencies in the professional world could be located. However, the evaluation does not provide a general assessment. It rather contains references to the potentials that can be activated.

The qualitative evaluation of the respective intervention points was carried out by using three differently weighted plus symbols (+ for estimated RTI-potential, ++ for significant RTI-potential, +++ for very high RTI-potential). Figure 6 gives an example how such a finding could be figured out and Figure 7 presents a high-score summary of this evaluation procedure. The fields marked red represent the interfaces with the highest RTI potential while the fields marked yellow represent the interfaces where a high potential can been estimated. The Figure also shows the localisation of the interfaces in the sequences and sections along the air cargo transport chains. The term **Degree of Consistency** was used for this. However, whether all of the intervention points for an interface are in fact of significance in each localisation sequence or sector, will have to be subject to additional closer consideration.

Processual interface	Sequences concerned / Process area localisation	Status Quo	R&D-Intervention Points within the Process Chain (selected actions)	R&D-Potentials in application fields				
				Per	For	Dig	Aut	Dek
BBU – Built Up / Break Down of Unit Load Devices (ULD)	1, 2, 3, 4, 5, 6 / STA	-	Action analyses stuffing containers according to flight plans	++	++	++	++	+
			Action analyses built up ULDs according to aircraft load plan	++	++	++	++	+
			Special application of robotics for ULD BuildUp/BreakDown		+++	+++	+++	
			Treatment of goods in export procedures in dependence of climate conditions in their destination´s evironment	++	++	++	++	
			Treatment of importing goods in dependence of their origin	++	++	++	++	
			Technical development of moveable robots for ULD-treatment		+++	+++	+++	

Figure 6: Potential finding matrix: Example for one of 43 identified interfaces, sourced from Dörr et al. (2016)

Ranking	Abbr.	Interface	Plus-Points	Amount Inter-vention Points	Incidence Sequence/ Section
1	**HUM**	Human Resources	90	10	6/21
2	**AIL**	Airport Location Selection/Perception	67	13	2/6
3	**MMT**	Means of Transportation Management	61	7	6/10
4	**LLP**	Loading Zone/Loading Dock/Parking Position	56	7	6/10
5	**BBU**	Build Up/Break Down of Loading Tackles/ULDs	52	6	6/6
6	**ROP**	Route Planning	48	8	6/11
7	**SEC**	Security Check	43	5	3/3
8	**STP**	Strategical Transport Planning for Consignments	42	5	1/1
9	**LOP**	Load Planning	41	6	6/10
10	**IST**	Electronical Information Technology/-systems	38	7	6/21
	HPC	Handover/Provisioning of Consignments	38	5	6/12
	TTP	Tracking & Tracing (Points)	38	6	6/21
13	**SES**	(IT-)Security-Systems	33	5	6/21
14	**COM**	(IT)-Communikation	32	5	6/21
	SPH	Special Handling	32	5	6/21
16	**SAR**	Storage Area/Room	27	5	6/6
17	**LUT**	Loading/Unloading of Means of Transportation	26	5	5/9
18	**PAC**	Packaging	25	5	2/2
19	**ALS**	Additional Logistics Services	22	3	2/2
20	**AOG**	Aircraft Operations / Ground Handling	21	3	2/2
21	**TRO**	Transport Order	19	3	3/3
22	**SAS**	(IT-)Safety-Systems	18	5	6/21

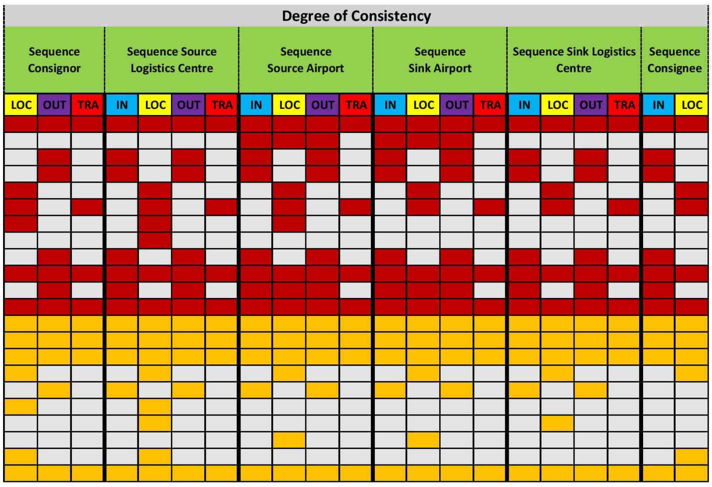


Figure 7: Ranking of the interfaces with high RTI-potential and their localisation in the sequences and sections along the air cargo transport chains, sourced from Dörr et al. (2016)

The aspects of *Personalisation* are a common thread in all fields of application. A dominance of the field of application *Formalisation* was confirmed by the numerous expert discussions. The greatest potential here lies in the continuity and transparency of a process chain, but this requires a screening of all overlapping actors along the process chains, which however would interfere into the internal company structures. In view of the large number of actors involved, such initiatives must be established on a manageable platform, i.e. at least at the levels of sequences. This presupposes the willingness of communication and cooperation of all actors involved in an air traffic hub.

Some weaknesses have been identified in the field of application *Digitisation*, which is dependent on the field of application Formalisation, whereas a great deal of expectations have been attached to the field of application *Automation*. If the automation of processes lies in the proprietary decision-making area of the actors and the public areas or the traffic areas are not used by automated units or means of transportation, such an upgrade or changeover will be practicable immediately. The use of robotics and mechatronics is certainly dependent on the individual location and would be previously realised in varying degrees. The general penetration of the process areas along the air cargo transport chains with automation technology should be illuminated on the basis of quality objectives, because ambivalences, for instance in relation to the use of human resources, will occur.

It has to be assumed, that in the field of *Decarbonisation* it is the air transport itself that mainly produces most of the air pollution and greenhouse gases. All of the other process-related emissions appear less significant, although on-site land traffic and ground handling is able to be set up towards fewer emissions at any time.

In the global air cargo business it is easier to address the actors in the export business than in the import business. On the export side, concrete conceptions with respect to climate protection, environmental relief, conversion in the management of resources and cooperation between the actors have already been able to be realised from the beginning. On the import side, once commodities start their way overseas, the international harmonisation of the processes and the continuity of the timely information flows become more important. At best optimisations here can be achieved along the way from the arrival airport to the supply destinations. In any case, the activation of potentials lies not only in technological measures, but also in the rational mastery of the competitive market pressure and the willingness to use existing technologies in a manner which is oriented towards civilising goals for instance with better working conditions or climate protection. From a present-day point of view, the potentials mainly target the elimination of identified deficits by implementing state-of-the-art technologies.

8 Long-term Context and Visionary Perspectives

Looking even further into future, the assumptions of potentials are by nature speculative. These assumptions include knowledge of the development of new aircraft types and aerodynamic designs. In the ideal utopic case the entire transport chains of certain air cargo consignments could be shifted to airborne transportation. This means that the pre-carriage and on-carriage haulage could also be generally served by cargo-drones or cargo-airships landing almost anywhere. The next generation of aircrafts will not only be much more energy-efficient and produce lower emissions, there might also be less space needed particularly concerning the length of runways for starts and landings. This could mean a chance for decentralised airports in remote regions. Such perspectives would require a planned and regulated rearrangement of near-ground airspace particularly over densely inhabited regions. In land transportation the (partly) automated movement of vehicles in the transportation networks will undoubtedly be established. Furthermore, multimodal transport processes could be carried forward to all other transport modes depending on the interchangeability of air-typical traffic demand.

9 The Meaning of Physical Internet

The term Physical Internet was used for the first time in 2006 on the title page of the British economic journal Economist. However, the content of the related article refers conventional logistics processes. Inspired by the idea of Physical Internet, the Canadian scientist, Benoit Montreuil, decided to develop a concept that actually uses the protocols of sending data packets on the digital Internet to create more efficient and sustainable logistics (Ballot et al., 2014). The Physical Internet is defined as following: Physical Internet is an open, global logistics system based on physical, digital and operational interconnectivity ensured by modularisation, interfaces and protocols (Montreuil, 2012).

In a functional Physical Internet, all warehouse facilities with their current capacities and all means of transportation with a suitable route are available (Zentralverband, 2013). The centrally regulated routing system is coordinated in such a way, that the means of transportation and their drivers meet at hubs. There haulage and hauls can be reconsolidated to avoid transports with empty or partially filled charge carriers and shortens transport times. One particular feature of the Physical Internet are the uniform charge carriers (in the proper sense of modular container), which can be combined to any size (Petersen, 2013).

The objective of the Physical Internet is to achieve a higher utilisation of the transport routes. This is meant to provide significant economical (shorter transport times, less personnel costs) and ecological (traffic reduction, less CO_2-emissions) advantages. A balanced utilisation of storage facilities and distribution centres is also striven for and drivers could be deployed on short hauls as possible (Logistikknowhow, 2015).

It is alleged that the Physical Internet will be more effective the more actors and companies are using this organisational structure (Industriemagazin, 2015). This reorganisation of freight transportation can be made possible by the continuous improvement of the supporting information technology. Consequently, the Physical Internet is a concept which should include freight transportation and information exchange in an equivalent way. Intralogistics is also an important prerequisite for an effective system. Coming straight to the point, the Physical Internet is a highly interdisciplinary topic (see study AIDA-F (Dörr et al., 2015) for interdisciplinary topics), which includes such sub-topics as synchromodality, supply chain resilience, efficient value chains, information transparency, information security and the Internet of Things. The building up of the structure Physical Internet offers new possibilities in logistics, yet it would also create new challenges, which will probably necessitate a fundamental rethinking on the part of all of the actors in logistics networks.

According to the project ATROPINE the "physical internet" consists of 13 characteristics (Schauer et al., 2016):

- standardised, ecological, modular and intelligent containers,
- universal interconnectivity,
- container handling and container storage with PI-containers,
- interconnected containers with integrated smart tags,
- from point-to-point and hub-to-spoke transportation to intermodal traffic,
- a unified multi-layered conceptual model,
- activation and use of an Open Global Supply Web,
- design of products for minimum space requirements,
- transport minimisation and warehouse minimisation through digitisation and local production,
- open performance monitoring and performance certification,
- reliability and failure safety of networks,
- creation of innovative business models,
- creation of an open infrastructure.

The idea behind the Physical Internet is that the entire transport chain, not just certain segments, is to be optimised. The transport chain can be simulated by working on the interface navigator allowing PI-researchers to be able to recognise where PI-potential might occur. This may even span all segments.

10 Conclusion

A central research task has been to present the complexities of air cargo transport chains as completely, comprehensibly and representatively as possible. As defined in the previous chapter, the existing interfaces along a transport chain are an important basis for implementing Physical Internet in logistics. These interfaces have to be served by the actors involved. In this way, almost all existing interfaces and actors involved were dealt with. By means of local inspections and professional discussions the interfaces were able to be identified and positioned along the air cargo transport chain. Furthermore, the functions of an actor were able to be assigned to each interface. As a result, technological and organisational fields of applications were able to be defined. These in turn were provided with (traffic-)logistical intervention points at each interface in which general improvement and development potentials as well as research gaps were set. The interface navigator was developed as a guideline to serve as a basis for implementing Physical Internet along the complex air cargo transport chain step-by-step.

The study ACCIA also found out that there are a great deal of physical elements along the air cargo transport chain, but that these have not yet been completely interconnected. Nevertheless, the air cargo transport chain could become prototypical for a gradual realisation of Physical Internet, not least because of the strict safety and security regulations in aviation business. On the one hand, there would be challenges for Physical Internet to cope with data security, data confidentiality and reliable business relations where information should not or could not be transmitted in an unobjectionable manner. On the other hand, in cases of emergency the transport of commodities which are consignments might prove to be a big chance, when the consistency of information transfer is essential to handle them as preferred and sensitive cargo.

Air cargo transport chains are by no means perfect but they work conveniently for shippers and regional economies. In some way they fulfil basic services and basic democratic functions, particularly for rather remote regions all over the world.

Due to a strict degree of standardisation and open monitoring fully developed Physical Internet might indeed neglect some customers' requirements and expectations concerning service quality and reliance. In the long run this will probably lead to the restoration of a centrally planned economy. Who will be the manager and the controller?

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Hyperconnected Pickup & Delivery Locker Networks

Louis Faugere[1,2,4], Benoit Montreuil[1,2,3,4]

1. Physical Internet Center
2. Supply Chain and Logistics Institute,
3. Coca-Cola Material Handling & Distribution Chair
4. H. Milton Stewart School of Industrial & Systems Engineering
Georgia Institute of Technology, Atlanta, USA

Corresponding author: louis.faugere@gatech.edu

Abstract: *This paper deals with smart locker banks for pickup and delivery in the context of omnichannel business-to-consumer logistics and supply chains. Its main contribution is the conceptualization of hyperconnected smart lockers network designs as an alternative to home delivery for enabling to meet the challenges toward efficiently and sustainably achieving fast and convenient business-to-consumer pickups and deliveries. It gradually explores alternative designs from current practices to solutions exploiting Physical Internet concepts (PI) such as the PI handling containers. The paper identifies key relative advantages and disadvantages of alternative solutions, synthesizes strategic insights for industry, and provides research challenges and opportunities.*

Keywords: *Smart Lockers, Physical Internet, PI-containers, Last Mile Delivery, Hyperconnected City Logistics, Omnichannel Supply Chains*.

1 Introduction

The courier, express & parcel industry's global market size is growing. Buhler & Pharand (2015) notably reported a growth rate of 5% in value over the 2013-2020 horizon, ranging from 5% in Western Europe and South America to up to 9% and 15% respectively in North America and Asia Pacific markets. As the world is experiencing a global urbanization that is projected to reach 66% of the population by 2050 (currently 54%) with highs in North America (82%), Latin America and the Caribbean (80%), and Europe (73%) (United Nations, 2014), urban areas will experience a dramatic increase in freight deliveries. This could lead to unsustainable traffic congestion, greenhouse gas emissions and noise and air pollution at unprecedented levels (MHI, 2017). Many smart city initiatives (*www.smartcitiescouncil.com, www.worldsmartcity.org,* and the U.S. Department of Transportation's Smart City Challenge) aim at understanding the logistics and supply chain challenges of tomorrow's city logistics, developing new application and supply chain innovations in delivery channel, distribution networks, and transportation modes.

The currently emerging pick-at-locker (P@L) business-to-consumer flow alternative, materialized by smart lockers, presents the advantages of being a simple and unstaffed delivery option (B. Montreuil, 2017). Smart locker banks grouping an unattended set of pickup and delivery lockers are a promising solution for last-mile parcel delivery and return, focusing on unsuccessful deliveries and consolidation opportunities. Indeed P@L networks offer convenient pickup locations for consumers, while potentially driving delivery costs down by reducing the number of delivery points and avoiding unsuccessful deliveries leading to multiple delivery attempts. Such networks have the potential of eliminating unsuccessful deliveries, and reducing delivery costs, city congestion, and greenhouse gas emissions (Iwan et al., 2015). This solution is globally emerging and already proven successful in European and Asian markets as a cheaper alternative to home delivery. Figure 1 shows examples of smart locker banks currently operated respectively by DHL (Germany), POPStation (Singapore) Inpost (Poland), and HiveBox (China). Automated and equipped with interactive modules, they allow pickups and deliveries to be performed in a few minutes.

Figure 1: Illustration of Current Smart Locker Banks

One of the challenges of deploying a network of pickup and delivery lockers as an alternative to home delivery is expressed through the uncertainty of the demand. A variable number of packages of a wide range of sizes are to be delivered in a capacity-limited locker bank, making the design and configuration of each bank critical to its capacity (number of lockers and their respective dimensions). In its current form (Figure 1), a smart locker bank has a fixed configuration of lockers of different predefined sizes, aiming at balancing service levels and fabrication costs. It is subject to obsolescence as its design is not flexible. It may also suffer from low space utilization, due to the fact that packages rarely take all the space available in one locker. Indeed, as only a few different sizes of lockers are present in the smart locker banks from Figure 1, it is expected that most packages will not exactly match with the space available in one locker, rapidly decreasing the space utilization of the bank.

This paper aims at conceptualizing smart locker based hyperconnected pickup-and-delivery (P/D) network designs to meet the challenges toward achieving omnichannel logistics efficiently and sustainably while meeting the timely expectations of clients, exploiting key concepts of the Physical Internet (Montreuil, 2011). After the essence of P/D locker networks is defined, four designs are presented in this paper, ranging from current practices to more mature Physical Internet (PI, π) concepts implementation.

2 Hyperconnected Pickup & Delivery Locker Networks

Smart locker banks grouping an unattended set of pickup-and-delivery lockers bring an alternative to home delivery. Currently mostly used for goods ordered through e-commerce channels, providing consumers convenient pickup locations, they could also be used to pre-position items in neighborhood exploiting smart demand predictive analytics. Current customers' expectations in terms of delivery lead time and pickup convenience lead to the need for up to multiple smart locker banks per neighborhood (Montreuil, 2017). Thus, networks of P/D lockers are positioned as a last logistics step before packages reach consumers' homes, and are distributed at the neighborhood level as depicted in Figure 2 in the context of Physical Internet enabled hyperconnected city logistics (Crainic & Montreuil, 2016).

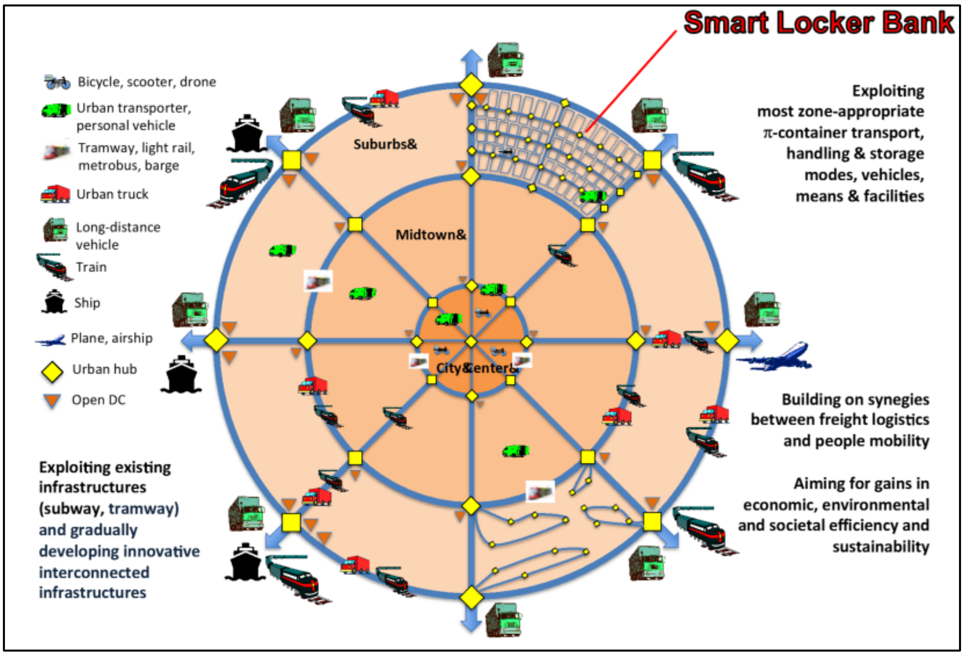
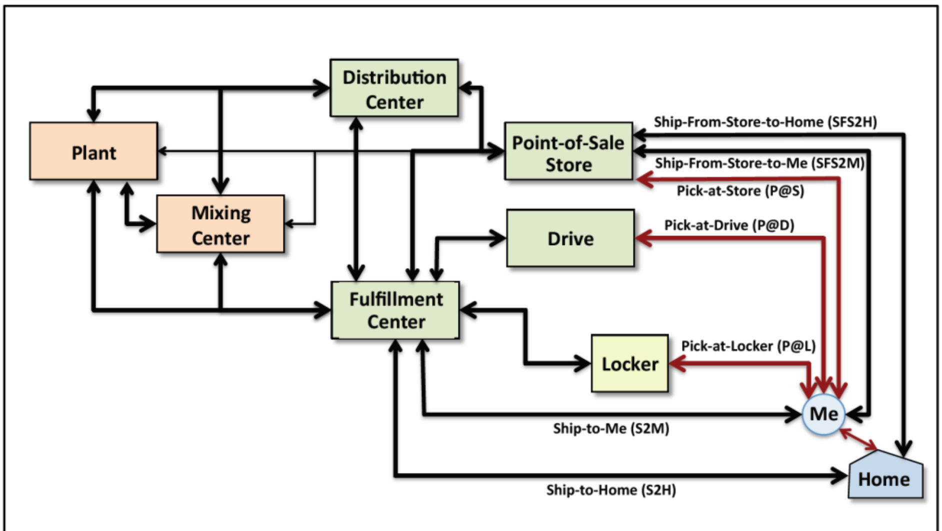


Figure 2: PI Enabled Hyperconnected City Logistics, Highlighting the Role of Smart Locker Banks (Adapted from Crainic & Montreuil, 2016)

Note that smart locker banks are one of the possible alternatives to home delivery proposed in the Physical Internet concepts in the context of omnichannel business-to-consumer logistics and supply chain (Montreuil, 2017). As shown in Figure 3, pick-at-drive and pick-at-store are two other alternatives requiring the final consumer to pick up their goods at some facility. However, smart locker bank networks provide a better level of convenience for some consumers, as they are distributed in neighborhoods, thus closer to homes, and are unattended, mostly accessible at any time.

From a logistic carrier perspective, smart locker banks allow consolidation of deliveries into predictable delivery locations. As P/D points are distributed over a known network, simpler and more efficient routing strategies can be developed to drive both delivery cost and delivery resource needs down, while increasing efficiencies. The potential elimination of unsuccessful deliveries and the need for less delivery resources could dramatically decrease the miles traveled by logistic carriers within urban environment, thus positively impacting city congestion and greenhouse gas emissions.



Even though a single instance of each type of facility/entity is drawn, a networked combination of them may engaged in producing and flowing an order
All lines are bilateral to emphasize the flow of purchased and returned goods
All lines indicate a flow that may be instantiated using multiple modes and being crossdocked/ transshipped through multiple hubs

Figure 3: Omnichannel B2C Logistics and Supply Chains Alternatives (Source: Montreuil, 2017)

Another important aspect of the use of smart locker banks as P/D points in an urban environment is the operating model and ownership associated with lockers. Because deploying an extensive network to cover a city relies on a significant level of infrastructure investment (one bank representing a few ten-thousand USD), and operations cost (maintenance, land cost, utilities, insurance, etc.), one may consider opening a locker to multiple parties through partnerships or charging a per-use cost. Moreover, a multi-operator model has the potential to be more efficient as managing aggregated variations of demand could lead to less capacity required than managing variations of demand individually for each player. Also, as smart locker banks are integrated in public spaces and infrastructures, it seems unlikely that municipalities and city planners allow multiple players to deploy their own private network within the same neighborhood. A multi-operator operations model is illustrated in Figure 4 for e-commerce supply chains composed of multiple retailers, using a set of logistic providers and open pickup and delivery points. We may call such a network of smart locker banks a hyperconnected P/D locker network.

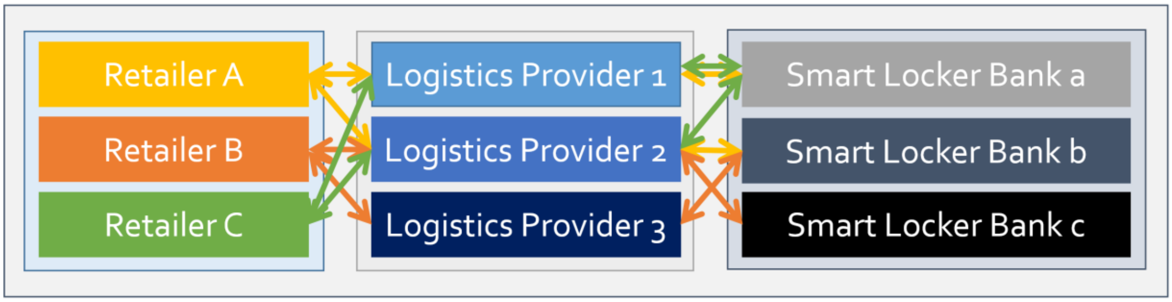


Figure 4: Hyperconnected Multi-Operator Pickup-and-Delivery Lockers (Adapted from Faugere & Montreuil, 2016)

3 Current Practices: Fixed-Configuration Smart Locker Banks

As depicted in Figure 5, smart locker banks in their current form are sets of P/D lockers of predefined sizes arranged in a fixed-configuration bank. Having a network of such banks enables relatively simple implementation. In general the efficiency of a fixed-configuration locker bank shall be highly dependable on (1) homogeneous and consistent demand over time and (2) predictive capability in regard to demand and its evolution, insuring that it may be rightly configured and that this configuration will remain well fitting over time.

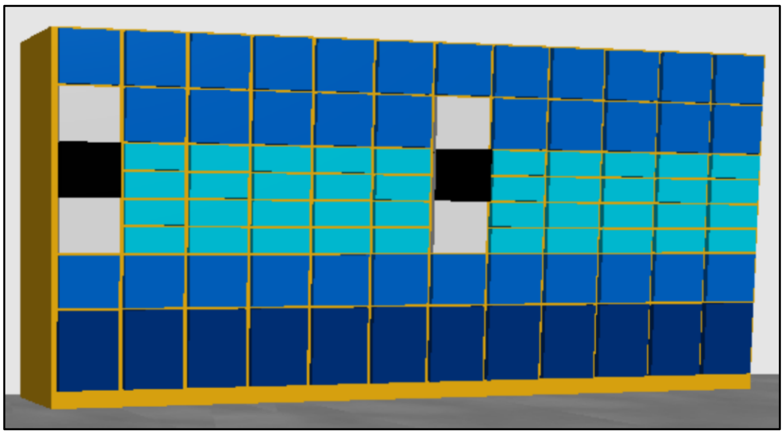


Figure 5: Illustration of Current Smart Locker Bank

The main advantages of this design are:

- It has opportunities for economies of scale relative to design and manufacture standard banks, and to locate them into a network.
- It represents a one-time implementation cost. The network being fixed, there is no need for redesign of the smart locker banks. Moving units to different locations is still possible but will not require structural modifications.

While advantageous in some ways as expressed above, a fixed configuration is constraining when filling up the smart locker bank with packages. Success of delivery will depend on the availability of a locker of sufficient dimensions at the time of the delivery. This is the origin of the main disadvantages of this design:

- It may rapidly become under or over capacitated. Global level of demand may evolve over time, resulting in substantially more or less number of packages to be delivered at a smart locker bank. In such a situation, over time, the design will become obsolete and will see its performance or space efficiency decrease.
- It may not adapt to variation of delivery patterns, punctually and over time, resulting in different package-size mixes. For example, a smart locker bank expecting primarily small-dimension packages will perform well as long as the size mix of packages being delivered stays relatively stable with a strong majority of smaller packages. If the mix changes and the packages being delivered get substantially bigger, the smart locker bank might not have enough lockers of adequate dimensions to receive the new demand, and might have a set of lockers unutilized, too small for the new delivery pattern.

While advantageous in terms of implementation, fixed-capacity smart locker banks can be inadequate when demand evolves or is difficult to predict. The challenge of capacity management and configuration arises, which is the backbone of the next design proposed.

4 Exploiting Modular Towers

Contrasting with the fixed configuration of section 3, we highlight in Figure 6 a smart locker bank conceived as a set of modular towers. The HiveBox locker banks, implemented in large quantities across Shenzhen in China, exploit such modular towers. In Figure 6, each tower is the same width and height, with two columns of lockers having all the same width. The locker bank implemented as a concatenation of such towers. The height of a tower depends mostly on human constraints, as each locker must remain reachable within acceptable levels of effort. The width of a column in a tower may be variable, with the width of its lockers adapted to the column width. This requires more flexible manufacturing than standard-width lockers, columns and towers.

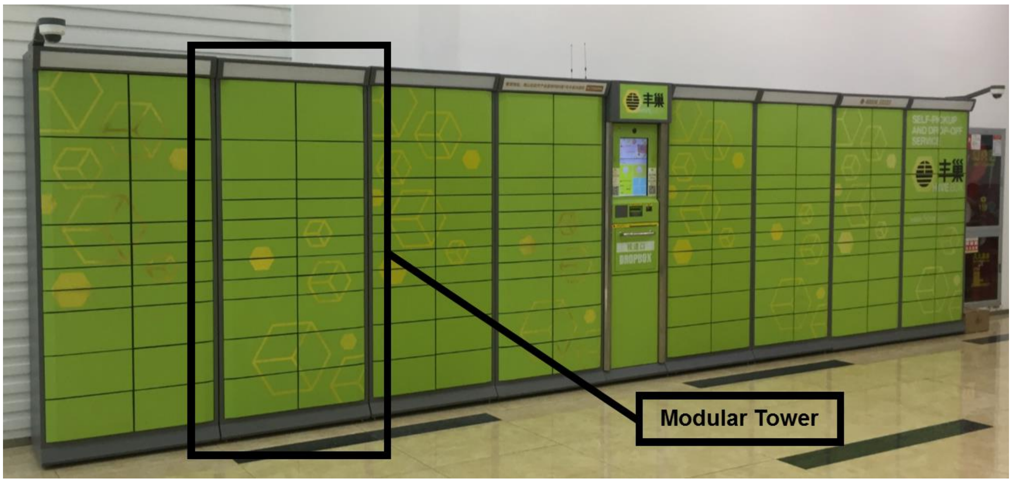


Figure 6: HiveBox Smart Locker Bank, Shenzhen, China, Exploiting Modular Towers

Using tower modularity, the global capacity of a smart locker bank can be adjusted over time by adding/removing modules, within the overall space constraints of the site. Figure 7 shows how the capacity of a smart locker bank can be increased by plugging an additional column module. Note that additional modules can come from a separate source, or simply be moved from a smart locker bank to another within the network when rebalancing its capacity.

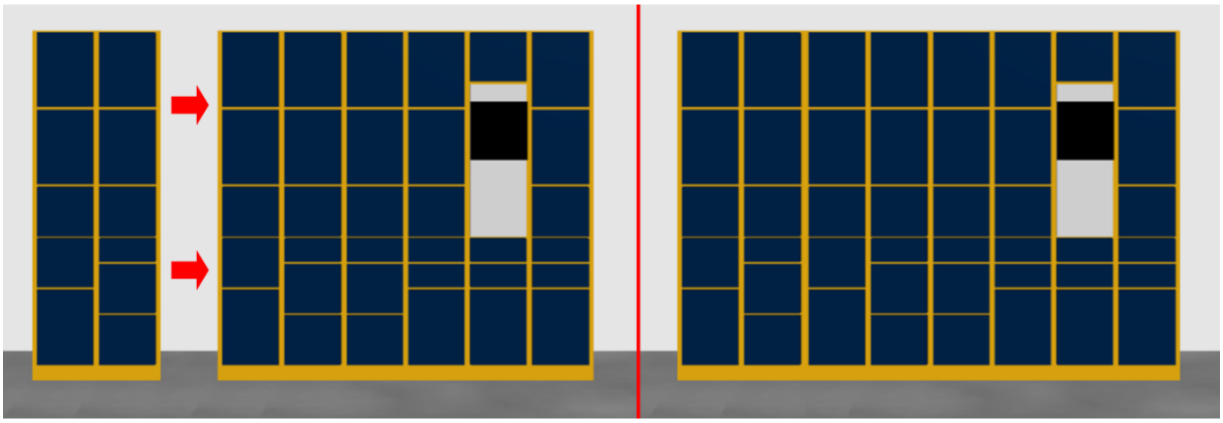


Figure 7: Increasing the Capacity of a Smart Locker Bank by Adding a Modular Tower

This design enables dynamic capacity management over a network of smart locker banks. Smart locker banks with Modular Towers thus offer the following main advantages:

- It can adapt to variations of global demand in modular tower increments: When adequately managed, the network's capacity can be adjusted over time by adding/removing column modules at specific smart locker locations.
- It can be advantageous in highly seasonal markets: For instance, a stock of modular towers can be maintained to enable substantially increase of the network's capacity during peak seasons (Christmas, cyber-Monday, etc.) and ensure minimal footprint during valley seasons.

Note that it would require a slightly more complex system, with the following main disadvantages:

- Assuming significant supply times from modular tower suppliers, it requires a modular tower inventory management system: Modular towers must be held in inventory and distributed over the network in a timely manner as needed; This could represent a significantly high inventory, especially if many types of column modules of different configuration of lockers are held in inventory to enable greater capacity flexibility.
- It needs capacity management policy and frequency: The frequency at which the capacity of the network is adjusted must be defined as well as the policy ruling the addition/removal of tower modules at a specific location; This would also require high visibility on the current configuration of the network and the available inventory.
- It requires distribution capabilities to transport and install/remove tower modules: These tower modules may be heavy and require special handling equipment.
- It can difficultly adapt to variations of demand patterns, such as evolution of the mix of package sizes deployed in the locker banks.

While now accounting for variations of global demand, smart locker banks with modular towers have limited advantages when the mix of package sizes also varies. The next proposed design is adding a level of modularity to account for mix changes.

5 Exploiting Modular Lockers

Taking modularity to the next level, smart locker banks can be composed of individual modular lockers, whether or not the banks exploit modular towers. The locker modules must (1) have modular sizes (as the well-known Lego blocks) harmonized to the bank and modular tower structure dimensions, and (2) have modular connectors enabling their easy addition to, and removal from, a locker bank or tower.

Modular lockers enable a fine-granularity adjustment of the capacity of each locker bank, allowing modifications of the entire configuration, as in illustrated in Figure 8. A locker bank design exploiting locker modularity offers the following main advantages:

- It can adapt to variations of global demand, both in terms of volume and mix, within the limits of the site, the bank structure and/or the tower modules.
- It can be advantageous in highly seasonal markets: a stock of modular lockers can be maintained to enable substantially increase of the network's capacity during peak

seasons and ensure minimal footprint during valley seasons (subject to the same limitations as above.

- It is capable of accounting for variations of delivery patterns: It has the capabilities to adjust its configuration to the change of package size mix over time by adjusting the number of lockers of each modular dimension.

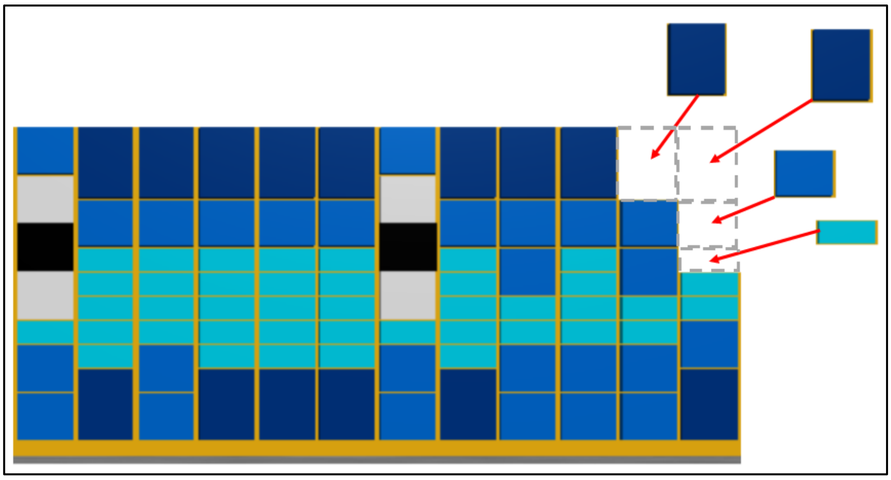


Figure 8: Illustration of a Smart Locker Bank Exploiting Modular Lockers

A smart locker bank design using modular lockers increases the supporting system complexity and has the following main disadvantages:

- Assuming significant supply times from modular locker suppliers, it requires a modular locker inventory management; In this case, modules are smaller than towers yet have a variety of modular sizes.
- It needs capacity management policy and frequency, as induced by modular towers, yet at a more granular level.
- It requires distribution capabilities to transport and install/remove locker modules.

As with modular towers, modular lockers can come from a pooled inventory or be exchanged between smart locker banks when rebalancing the capacity of the entire network.

Note that smart locker banks with modular towers and modular lockers have the potential to mitigate the disadvantages of fixed-configuration locker banks by allowing for capacity management of the network to adjust to variability of demand patterns (global demand and package sizes mix) but are more complex, requiring dedicated inventory, capacity management and distribution systems. Indeed, tower and/or locker modules must be stored, transported, and installed/removed, and the frequency and policy ruling these manipulations must be predefined. It may require a significant amount of resources to manage such a system.

The next proposed design aims at mitigating the resources required by exploiting Physical Internet handling containers (Montreuil et al., 2015).

6 Exploiting Physical Internet Handling Containers

The use of Physical Internet containers as a standard for transportation and storage of physical goods at all levels of supply chains promises significant improvement in space-time utilization of transportation, handling and storage means (Montreuil et al., 2015). Moreover, π-containers and their modular dimensions bring opportunities to develop new logistics designs rethinking the way we deal with physical goods. This section introduces the use of π-containers as pickup and delivery lockers, as an alternative to modular lockers and towers: the π-containers become smart mobile lockers.

In the previous sections, the basic underlying assumption has been that goods to be picked up or deposited were to be done so by putting them from/into a fixed locker, as it commonly used in smart locker banks across the world (e.g. Figures 1 and 6). Here, the proposal is for encapsulating the goods into smart modular π-containers and using these π-containers as smart lockers. As sketched in Figure 9, the π-container lockers can be interlocked to each other, stacked on top of each other or snapped to a simple grid-shape bank structure, using basic Physical Internet concepts and principles as proposed by Montreuil et al. (2010).

As illustrated in Figure 9, smart locker banks have a fixed configuration of lockers of different predefined sizes, aiming at balancing service levels and fabrication costs. The modular designs proposed in preceding sections give some flexibility and enable to modify the configuration of the banks of lockers according to the capacity & configuration management frequency, but are still fixed between the reconfiguration periods. This yields designs good enough for a wide variety of delivery scenarios, but optimal for none, resulting in non-optimal utilization efficiencies and service levels.

Figure 9: POPStation Smart Locker Bank (Singapore Post: www.mypopstation.com)

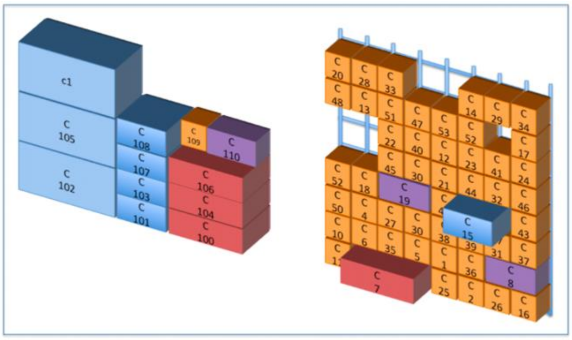


Figure 10: Illustrating π-containers Snapping as Pickup/Delivery Lockers (Source: Montreuil et al, 2015)

A design using π-containers as lockers, exploiting their interlocked stacking and/or grid-snapping capabilities as illustrated in Figure 10, has the potential of eliminating volume utilization inefficiencies and of offering better service levels to users, reaching toward near optimality for each demand scenario. Per the proposed concept, smart π-locker banks, instead of being composed of a set of lockers, are now composed of a basis, a grid-wall of predetermined surface to which π-containers are dynamically snapped as shown in Figure 11. Possible accessories that can be snapped to the grid-wall include interactive modules, protection roof, security cameras and lights.

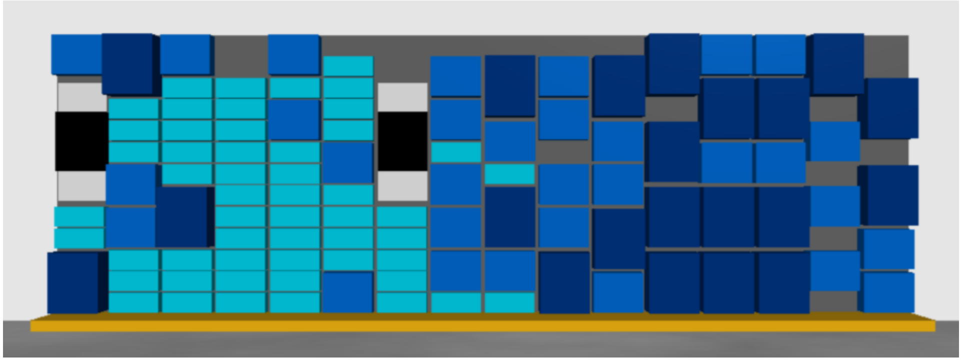


Figure 11: Illustration of a π-Container Based Smart Locker Bank at Some Punctual Time

6.1 Physical Internet Handling Containers

Introduced as one of the core concepts of the Physical Internet by Montreuil (2011), the exploitation of smart modular PI containers represents one of the main technological component of the Physical Internet encapsulation of goods framework. Montreuil et al. (2016) have categorized three levels of PI containers: the PI transport, handling and packaging containers, respectively nicknamed π-pods, π-boxes and π-packs. Gazzard and Montreuil (2015) and Landschützer et al. (2015) have focused on the π-boxes that are notably targeted to replace contemporary totes, boxes and cases as core handling unit loads. In the proposed pickup and delivery locker bank architecture, π-boxes are planned to be used as smart mobile lockers.

The fast snapping and interlocking capabilities of π-containers is the foundation of the proposed design, as π-boxes replace current lockers. Indeed, as they can be easily snapped to a grid-wall, a large number of configurations is possible. In order to be practically accessible, an interspace between consecutive π-boxes is represented in Figure 11, allowing extracting a specific π-box when surrounded by others. Arguing that current physical lockers also are separated by some space required by the support structure of the whole smart locker bank, and by the mounts of the doors, it is conservative to assume these interspaces to be of similar scale.

The structure of π-boxes, being robust, reliable and sealable, as well as their communication capabilities and their eco-friendly nature, make them suitable to be used as efficient and safe pickup and delivery lockers, protecting physical goods from weather conditions and theft, while ensuring monitoring and communication of its content to logistics systems.

6.2 Pickup and delivery mechanisms

To perform a delivery or a return, a logistic service provider or a customer just have to snap a π-box at an empty grid position. The exact position at which a π-box is assigned can depend on a predefined policy, real-time optimization, or be chosen by the person at the time of the delivery to the grid-wall. It is also possible for a return or delivery of loose goods to be made in an empty π-box, which would have been left snapped on the grid-wall from a previous delivery.

When a customer comes to pick up its goods, two options are possible:

- The customer opens the front face of the π-box, and picks up the ordered goods. In this case, empty π-boxes will be picked-up by the logistic service provider during the following delivery and then redistributed in the open system.
- The customer picks up and brings the whole π-box home, and later redistributes it in the system (at a store, click-and-collect drive, locker bank, etc.) or uses it for shipping or returning other goods.

6.3 Capacity modularity

The number, size and configuration of π-boxes constituting the goods storage in such an architecture is variable and offers great flexibility. Additionally, the grid-wall itself can be a modular element adding capacity flexibility. Panels constituting a grid-wall can be added/removed, thus expanding/reducing the area of the zone on which π-boxes can be snapped, thus increasing/decreasing the modular capacity of the smart π-locker bank.

This design offers the following main advantages:

- Thanks to the snapping capabilities of π-boxes, it has the potential of significantly improving the handling efficiency and dynamics of deliveries and pickups at smart locker banks, while ensuring the security of goods.
- Its configuration is decided as deliveries and returns occur, when π-boxes are being snapped to the grid-wall.
- It is highly flexible: its configuration and global capacity can adapt seamlessly in real time to variations and seasonality of demand and delivery patterns.
- It does not require locker bank specific resources; π-boxes are resources moving across different tiers of the supply chain; they are thus to be managed globally.
- It is expected to have minimal footprint and to require less upfront investment.

As this design implements a more mature level of Physical Internet concepts, it has the current following main disadvantages:

- It requires the implementation of π-containers, and notably π-boxes, as a mean of transportation, handling and storage in the omnichannel business-to-consumer industry.
- Regarding capacity management, Physical Internet induced hyperconnectivity is essential to ensure the dynamic circulation of π-containers within the network of smart PI-locker banks, as well as more globally, at an inter-network level.
- It requires to face technology challenges in ensuring the security of goods while stored at a P/D point. The π-boxes must be securely snapped to the grid-wall, be sealed and strong enough to protect goods from damages and theft, and be convenient for handling and transportation (ergonomics, weight).

7 Conclusion

Combining Physical Internet inspired hyperconnected city logistics and hyperconnected omnichannel logistics perspective, this paper contributes to the development of last-mile delivery alternatives in the context of omnichannel supply chains by introducing and contrasting a set of hyperconnected pickup-and-delivery locker network design options for efficiently and sustainably achieving fast and convenient business-to-consumer pickups and deliveries.

The options range from current practice, such as fixed configuration locker banks, to those applicable in a mature implementation of the Physical Internet concepts. The modular tower option has already begun to be used in practice while modular lockers can be fully implemented in the short-term horizon. The last option requires several steps as it relies on the use of Physical Internet handling containers (π-boxes) as smart mobile modular lockers. The proposed designs can provide strategic visions on the evolution of dynamics of last-mile delivery in an urban environment. Overall, four concepts for hyperconnected pickup and delivery locker network designs are proposed, with advantages and disadvantages summarized in Table 1.

Table 1: Comparison of the proposed designs

Option	Main advantages	Main disadvantages
Fixed	• Implementation costs • Economies of scale	• Adaptation to demand variability
Modular Towers	• Adaptation to global demand variations	• Adaptation to delivery patterns variations • Spare modules inventory • Capacity management • Special distribution equipment
Modular Lockers	• Adaptation to global demand variations • Adaptation to delivery patterns variations	• Spare modules inventory • Capacity management • Special distribution equipment
π-Boxes as Mobile Modular Lockers	• Highly flexible configuration and capacity • High P/D efficiency	• Relies on emerging PI containers • Network wise capacity management • Technology challenges

Overall, the following challenges need to be addressed for widespread implementation of hyperconnected smart pickup-and-delivery locker bank networks for omnichannel business-to-consumer supply chains:

- Engineering design: Methods for designing hyperconnected pickup and delivery lockers, locker banks and networks should be defined and tested through analytical studies, optimization and/or simulation based assessments (e.g. Faugere & Montreuil, 2017).
- Efficiency: Demonstration should be made that the proposed designs are increasingly more efficient and are ever more able to fulfill consumers' expectations of faster, cheaper, convenient and reliable deliveries and returns, through analytical, optimization and/or simulation based assessments as well as pilot studies. This should be done at an individual smart locker bank level as well as at a network level.
- Operating policy: Study of the impact of different operating policies on the efficiency of each design should be done through analytical, optimization and/or simulation based assessments.
- Integration: The integration of such designs in a broader omnichannel business-to-consumer logistics and supply chain framework composed of different alternatives such as proposed by Montreuil (2017) should be explored.

The above challenges induce a set of research opportunities. Some of these are to focus on the design of one smart locker bank itself, with various level of Physical Internet concepts. When brought at a network level, there is also need for extending research on business models for the multi-operator use of hyperconnected pickup and delivery networks (e.g. Oktaei et al., 2014) as well as for predictive analytics for last-mile delivery patterns in the context of omnichannel business-to-consumer supply chains.

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Applying blockchain technology for hyperconnected logistics

Wout Hofman, Jacco Spek, Christopher Brewster[1]
1. TNO, Soesterberg, the Netherlands
Corresponding author: wout.hofman@tno.nl

Abstract: *Blockchain technology receives a lot of interest and investments the last three years. It promises a trusted environment for (un)permissioned data sharing. With respect to logistics, enterprises and authorities can (near) real time share state information. Whenever a stakeholder changes the state of one or more objects like discharging a container from a vessel, all that have access will know this change instantaneously. The Physical Internet requires a large variety of stakeholders to optimize their capacity utilization and combine shipments with the objective to reduce costs and emissions compliant with (inter)national regulations. These stakeholders all need to collaborate and share data to reach these objectives. This contribution shows by means of a case that blockchain supports functional requirements for hyperconnectivity, but is not yet mature enough for large scale application by a large number of (autonomous) objects, individuals, and organizations.*

Keywords: *hyperconnected logistics, data transparency, blockchain technology, event ledger*

1 Introduction

Hyperconnection or universal connectivity is mentioned as one of the most important aspects of the Physical Internet (Montreuil, Meller en Ballot 2013). It encompasses 'super-fast connectivity, always on, on the move, roaming seamless from network to network, where we go – anywhere, anytime, with any device' (Biggs, et al. 2012). Examples of the implementation of hyperconnection can be found in city logistics (Crainic and Montreuil 2016). A hyperconnected world not only comprises individuals with embedded sensors in their smart devices, but includes all types of devices (e.g. vessels, trucks, containers, and trains), where these devices can be considered as assets used for value delivery. Different sensors and supporting communication technology are used for the identification and tracking of different assets. Several research papers identify supply chains and logistics as the main areas for implementing Internet of Things (Atzori, Iera and Morabito 2010) (Gubbi, et al. 2013), like done for the Physical Internet (Montreuil, Meller and Ballot 2013). These developments lead to intelligent objects (Whitmore, Agarwal and Xu 2015) or what is known as ubiquitous computing (Weiser 1991). Cars implementing the NVIDIA chipset1 can be considered as computing platforms, thus implementing ubiquitous computing. Automatic Identification System (AIS) with Global Positioning System (GPS) is for instance used for vessels and barges and trucks have on-board units and CANbus acting as sensors. The introduction of LoRa technology (www.lora-alliance.org) and 5G (Boccardi, et al. 2014) for communication extends battery life of sensors that can be used for machine-to-machine interaction or for instance intelligent cargo or – π-boxes (Montreuil, Meller and Ballot 2013). The combination of ubiquitous computing and long battery life provides the capability for intelligent cargo, where each box can find its way through a logistics network.

Hyperconnection is mostly described in terms of businesses collaborating in chains (Schonberger, Wilms and Wirtz 2009) like the Hyperconnected City Logistics (Crainic and

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[1] http://www.nvidia.com/object/tesla-and-nvidia.html

Montreuil 2016) supported by hardware and communication technology providing computational capabilities and level one interoperability (Wang, Tolk and Wang 2009). Neither the information that any two stakeholders have to share, nor their interaction choreography (Schonberger, Wilms and Wirtz 2009) are described. Data integration is required to achieve state awareness (McFarlane, Giannikas and Lu 2016), also known as situational awareness (Endsley 1995). Conceptual interoperability (Wang, Tolk and Wang 2009), which is currently not implemented by supply and logistics stakeholders (The Digital Transport and Logistics Forum (DTLF) 2017), needs to be achieved to support supply and logistics innovations (McFarlane, Giannikas and Lu 2016) (Montreuil, Meller and Ballot 2013). This paper proposes to use blockchain technology for situational awareness because the technology is able to provide a trusted, distributed environment by which agents can share real time state information. Application of blockchain to Internet of Things, which requires processing streaming data, is still in the research phase (Zhang and Wen 2017). First of all, data sharing requirements for the Physical Internet are analyzed, secondly the state of the art of blockchain technology is presented. By means of implementing a case with blockchain technology, the applicability of this technology for logistics is assessed. The case, its implementation by blockchain technology, and a discussion are presented separately. Conclusions will complete this paper.

2 Physical Internet

This section presents a layered approach to the Physical Internet and analyses the requirement for sharing state information in the different layers. A distinction between the physical – and the administrative state will be made, where the administrative state can cause delays in the physical state. Whereas state information is relevant to optimize processes, not all stakeholders are willing to share this data. Data governance is discussed as a separate issue.

This section only addresses the state of a logistics system, not the transaction that leads to a particular state or affects the state (Dietz 2006), although planning the execution of a transaction depends on the state of a relevant part of the logistics system.

2.1 State information and Quality of Service

The Physical Internet combines innovation in logistics by introducing new concepts like bundling and synchromodality, innovation in packaging, the so-called π-boxes, and innovation in autonomous operating assets with innovation in Information and Communication Technology (ICT, (Montreuil, Meller en Ballot 2013)). The Physical Internet is a network of hubs interconnected by corridors for routing of standardized packages (also known as PI-containers) by (semi-)autonomously operating assets like trucks, vessels, and automated guided vehicles. All these objects have particular capabilities and goals, for instance an autonomous truck or barge will be able to transport containers along one or more corridors and a container will have a sensor with (limited) processing capabilities like controlling the temperature setting of the cargo inside and data like its identification and relevant cargo details for handling.

For optimal routing of physical objects in this logistics network and optimal utilization of the network, autonomous objects, hubs, and organizations have to share data (Endsley 1995). Historic patterns of cargo flows and durations of handling by hubs and along corridors, current goals and capabilities, and predicted durations for next legs and hubs for particular cargo need to be available to meet goals of individual packages and at the same time make optimal use of available capacity by bundling. Goals can be related to all objects and cargo, but will differ. Cargo will have a goal to reach a particular destination within a time frame and costs; transport means will have a goal to optimize capacity utilization for trips with minimal emissions. Capabilities relate to logistics services and potentially timetables and spare capacity on particular trips.

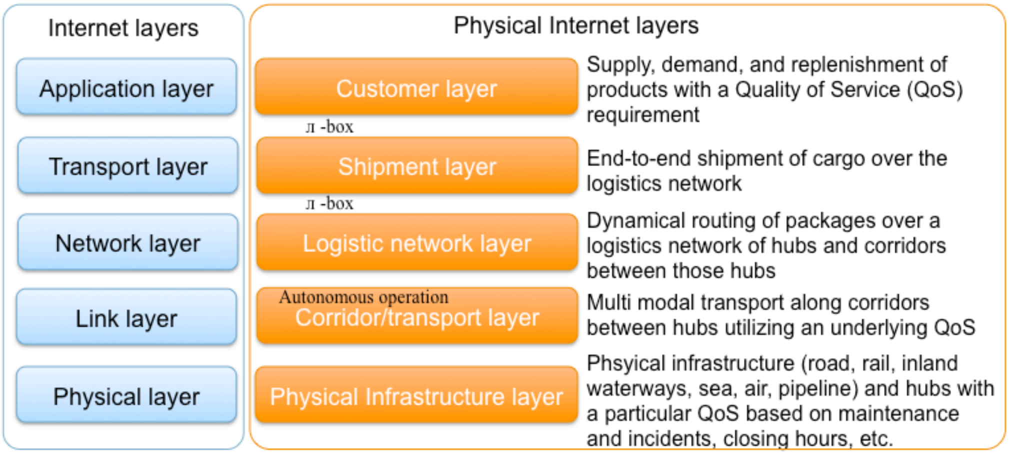

Figure 1: layering of the Physical Internet[2]

Like the Internet (Tanenbaum 1996), various layers can represent the Physical Internet, where each layer adds functionality to the higher layer (figure 1). The concept of Quality of Service (QoS, see also (Tanenbaum 1996)) can be introduced for each layer independent of the implementation of that service by a particular organization. It makes an upper layer service user agnostic of how the service is implemented. For instance, the transport layer provides transport services to the logistics network with different QoS values for each service related to for instance a modality, where the network layer can select the required service based on its QoS. The transport layer hides the QoS of the infrastructure layer, e.g. average delays due to congestion and accidents of a particular modality are hidden to the network layer, thus supporting synchromodality. Standardized Physical Internet – or π-boxes are relevant to the shipment layer; autonomous operation can be in hubs at the network layer and on corridors between hubs with autonomous transport means.

State awareness is applicable to different layers of the Physical Internet. We will distinguish between the physical state of the logistics (sub)system and its administrative state. The state of the physical system is addressed by Intelligent Transportation Systems (ITS). ITS focusses on optimization of infrastructure utilization with vehicle communication (Dimitrakopoulos and Demestichas 2010) like corridor management and optimization of turnaround times (Merrienboer, et al. 2014) combined with autonomous operation of hubs and transportation means, also known as collaborative ITS. The state of the Physical Infrastructure Layer is influenced by its utilization by the Transport Layer. Thus, the Transport Layer affects to the QoS of the Physical Layer. By sharing the goal of a transport means expressed by its position, speed, direction, and expected route of a transport means, the Physical Layer can provide its QoS for that transport means expressed by for instance the Estimated Time of Arrival (ETA) at a destination, a turnaround time at a hub, or vessel departure in a port. ETA and turnaround times are part of the QoS of the Transport Layer on particular corridors or for particular hubs. The Logistics Network Layer utilizes the Transport Layer QoS to decide on routing of cargo through the network. At Customer Layer, individual customers need to be aware of the state of their shipment and have the ability to change shipment flows (McFarlane, Giannikas and Lu 2016).

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[2] Inspired by a presentation of Rod Franklin, KLU, ETP Alice WG3, May 2014.

Not only Transport Layer QoS is relevant for routing, additional state data determines the behavior of the system. These can be clustered under the heading trade facilitation (Rukanova, et al. 2011) and supply chain finance (de Meijer and de Bruijn 2014) for cross-border supply chains. Trade facilitation refers to all types of laws with respect to security, safety, illicit trafficking, and tax evasion that result in customs clearance and coordinated border management between various national authorities (Kieck 2010). Improved state information can result in more targeted risk assessment (Heshket 2010), reducing unnecessary inspections that may affect product quality. Supply chain finance refers to payment and liability resulting in the so-called Incoterms (Malfliet 2011). Trade facilitation and supply chain finance include authorities and financial institutions. Since many cross-border trade still relies on paper documents, practical aspects like opening hours of offices can affect the ETA of a transport means, e.g. a barge delivering goods in Switzerland.

2.2 Data governance

Organizations have different reasons not to share state information (Eckartz, Hofman and Veenstra 2014). These can be clustered as ownership and liability, privacy, laws, and commercial sensitivity. For instance, privacy laws prevent authorities to share the position of a barge, since this is also the home of the skipper. Data ownership refers to the actual owner of the data that decides whether or not to make the data publically available. It refers to trust: what happens when the data is shared with others, how will the data be used, and will the owner be liable to any damage caused by actions of others based on the data. An example is sharing the predicted water depth of a river or canal and actions taken by skippers based on this prediction that may lead to accidents. Ownership also refers to cultural aspects: the (un)willingness to share data. Privacy refers to the ability to trace back data to individuals, like the aforementioned position of a barge. Besides privacy laws, other laws are applicable to goods transport that refer to liability, e.g. the Rotterdam Rules for international container transport and the CMR for road transport stating that a carrier should only be liable for damage based on physical characteristics of the cargo and not the actual content. Finally, commercial sensitivity refers to cargo value and identification of cargo flows between origin and destination. Shipment bundling at the Shipment Layer might require sharing origin and destination, which customers might not want to reveal to competitors.

Besides laws governing data sharing, liability and commercial sensitivity refer to trust, which is addressed by blockchain technology.

3 Blockchain technology – state of the art

This section discusses blockchain developments, with a specific focus on Hyperledger Fabric. For the use case, Hyperledger Fabric[3] blockchain technology is selected, since it is a permissioned blockchain technology supporting access control required for data governance. Firstly, the state of the art in blockchain technology is presented and secondly characteristics of Hyperledger are introduced.

3.1 Blockchain technology

The last three years have seen an explosion of interest in Blockchain Technology (BCT) with a great many companies and research institutions focusing on potential applications of this technology across a range of financial, industrial and social sectors. The breakthrough that led to the current interest in BCT was the work of Satoshi Nakamoto who wrote the white paper on Bitcoin and released the code (Nakamoto 2008). The underlying technology, the Bitcoin Blockchain, is what has subsequently inspired much work on BCT. However, most research and development has occurred in the context of open source projects such as Ethereum,

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[3] https://hyperledger-fabric.readthedocs.io/en/latest/

Hyperledger or BigChainDB, and this work is recorded either in white papers (such as (Wood 2015), (Buterin 2014-2017), (McConaghy, et al. 2016)) or else in blog posts. Specific projects (open and closed source) have also written their own white papers providing details of their approach and sometimes their technical architecture e.g. (Hyperledger 2016) (Greenspan 2015). For example, Provenance.org have described their intention to use blockchain technology as part of their supply chain solution for the agrifood sector (Steiner and Baker 2015).

Characteristics of the technology that have made it so attractive include the following: BCT provides an integration of networks with databases resulting in a peer-to-peer based distributed database spread across multiple entities, with no single owner or single point of failure. It enables to a certain degree an absence of trust because immediate synchronisation ("near real time") across entities means no trusted third party is involved. BCT also provides a permanent record, because due to the inbuilt transparency no record is ever deleted, only appended (hence the "ledger" title some authors use). BCT is distributed and usually decentralised in its conception, meaning there is no single entity that can stop or control operations on the blockchain (specifically true of "permissionless ledgers" where all data is transparent to all users). BCT also makes extensive use of cryptography to prove identity and authenticity using digital signatures, and in some cases to provide perceived anonymity of transactions. The most important technological development since Bitcoin has been Ethereum, which is an attempt to create a blockchain computer to run smart contracts (Buterin 2014-2017) (Wood 2015). The concept of "smart contracts" has been taken up by other platforms such as Hyperledger where they are called "chaincode." One of the key expectations includes the opportunity to develop "distributed autonomous organisations" (DAOs), run by software and entirely outside of the control of any individual or institution, and effectively impossible to "stop".

Putting these characteristics together has made many researchers, entrepreneurs and pundits predict that BCT will revolutionise many different commercial sectors from finance and insurance, through health records and tax collection, to supply chains, the music industry as well as the gambling industry (e.g., it allows the emergence of decentralized casinos and gambling websites (Andrychowicz 2014)).

The use of BCT in logistics has already been proposed, to a limited extent, by a few authors (Smith 2016). Most of the focus has been on the exploitation of BCT to achieve greater supply chain transparency as proposed and implemented by Povenance.org (Steiner and Baker 2015). Badzar has argued for the application of BCT for contract fulfilment (Badzar 2016). Everledger.org has implemented a system for tracking diamonds using a cryptographic fingerprint (Caffyn 2015). Bakker's work showed that experts considered logistics, specifically "smart containers", to be a very good use case for the application of BCT (Bakker 2016). The start-up Blockfreight believes that BCT enables "new era for the digital security, trust, authentication, record keeping and chain of custody data" in logistics. Their solution is built on top of Ethereum and Tendermint and depends on their own cryptocurrency to function.

3.2 Hyperledger Fabric characteristics

Hyperledger Fabric allows for smart-contracts to define function-level access, meaning only certain parties can execute functions within the smart-contract. Hyperledger Fabric uses the term "chaincode" for smart-contracts. This chaincode is a compiled application that is deployed and runs on the blockchain. The goal of Hyperledger Fabric is to be as modular as possible. So in theory it is possible to write smart-contracts for Hyperledger Fabric in any language and compile this to chaincode (a bit like how regular computer applications are often compiled to assembly, a lower level programming language). Currently there only exists a chaincode compiler for the Go language[4].

The technology is implemented as a network of connected peers, like any blockchain application. These peers all maintain a copy of the ledger and validate any incoming transaction. There are three types of transactions in the Hyperledger Fabric: Deploy- Invoke- and Query- transactions.

Deploy transactions are transactions containing the compiled chaincode, and some additional information (invocation arguments necessary to instantiate the contract, and a list of public keys, of which the owners of the private key can access the smart contract). These transactions deploy chaincode to blockchain. When a peer receives a valid deploy transaction, it generates a unique identifier for this contract and starts a secure docker[5] container running this smart contract. This container is inaccessible to anyone and only interacts with the world by exposing Invoke and Query transactions.

Invoke transactions are transactions that can possibly alter the world-state of a smart contract. A smart contract maintains an internal world-state in the form of a key-value pair storage. Invoke transactions are only added to blocks when the validating peers reach a consensus on these transactions, meaning that they are valid and all yield the same result given the input.

Query transactions are transactions that do not alter the world-state of a smart contract**.** Compared to deploy and invoke transactions, they are quick to execute, since these transactions are not stored on the blockchain. This is not necessary because they do not alter the world-state.

To interact with the blockchain, Hyperledger Fabric exposes a REST API (API: Application Programming Interface) using the gRPC[6] protocol (gRPC is an open source Remote Procedure Call framework developed by Google). End-users can develop their own front-end applications that connect to the API or integrate their own back-end systems to this API.

4 The case: container transhipment via a port

By means of a case, the applicability of blockchain and its advantages for realizing the Physical Internet is demonstrated. The example considers sharing the container status amongst autonomously operating enterprises during transshipment via a port. Both the physical and administrative status is considered. Firstly, the current situation is introduced and secondly its implementation by blockchain technology.

4.1 The current situation

At arrival of a vessel in a port like the port of Rotterdam and on-carriage of discharged containers via a terminal to the hinterland, various enterprises are involved utilizing different modalities for on-carriage. In most cases, a container can only be transported from a port to its destination in case sea transport charges are paid (commercial release), the container is actually discharged (container available), and customs has released the container (customs release). This status information is shared amongst the various enterprises by messages according a customer-service provider relation. Figure 2 shows an example of the value chain for transshipment. A shipping line operating the vessel has a contract with a stevedore for loading and discharging containers on the vessel. A shipping line informs a so-called notify of arrival of its containers in a port of discharge. In this example, a forwarder acts as notify. For

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[4] https://golang.org/

[5] https://www.docker.com/

[6] http://www.grpc.io/

this case, the consignee is considered to be the notify and a forwarder acts on behalf of the consignee by subcontracting on carriage to a carrier and arranging commercial – and customs release.

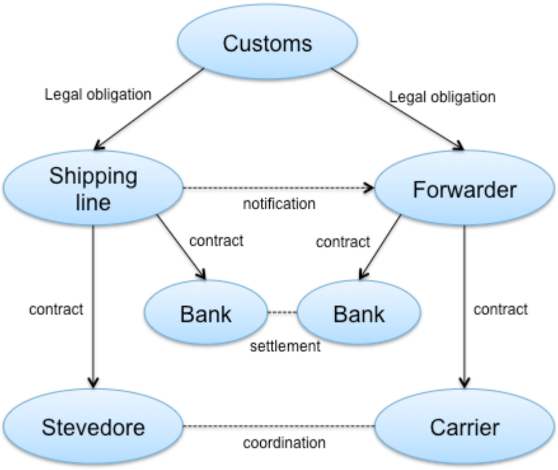

Figure 2: value chain for container transshipment in a port

Both the stevedore and the carrier have to receive the actual status of a container for its on-carriage. However, they don't have the complete status information: commercial release is generated by a bank and known to the forwarder and the shipping line, customs release is generated by customs and known to the forwarder, and the stevedore generates the discharge status to the shipping line. The shipping line can make commercial release available to the stevedore and the forwarder commercial – and customs release to the carrier. The stevedore still has to receive the customs release and the carrier must know the discharge status to be able to perform on-carriage. The carrier also must be known to the stevedore to pick-up a particular container. Messaging causes delays in physical handling due to errors (the wrong carrier got status information), lack of status information (a stevedore is not informed of customs release), and delays in sharing the status (a stevedore currently submits a discharge list to a shipping line after the vessel has left the port). Delays in the physical processes leading to extra container storage at a terminal are currently caused by delays in information sharing and should be planned based on customer requirements. A (port) community system can address these issues by storing the container status, but it requires trust in the system and clearly specified Identification, Authentication, and Authorization (IAA) mechanisms (Johnson 2010).

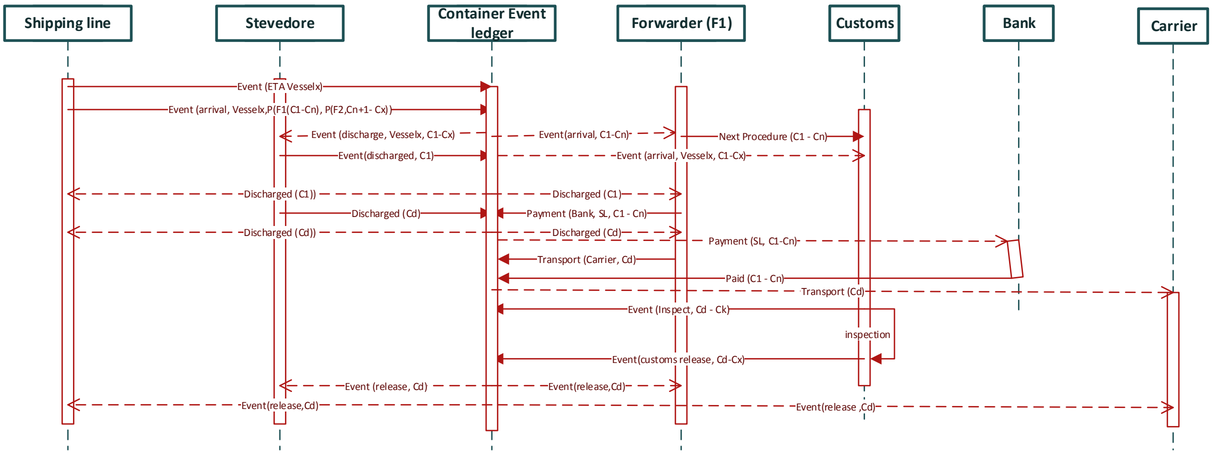

Figure 3: sequencing of operations for a container event ledger

4.2 Implementing the case with permissioned blockchain technology

To illustrate the potential added value of the BCT in this domain, we have developed a proof-of-concept application implementing the aforementioned use-case with Hyperledger Fabric. By sharing real time status data and permissions via a trusted blockchain environment, on-carriage processes can be planned different leading to less storage time at a terminal. Figure 3 gives an example of blockchain for sharing events for transhipment of containers. Each arrow depicts an event with a function and permissions P of containers C to roles like forwarder F. The functions of the event reflect milestones in the processes (Hofman 2017).

The first event in the example is the Estimated Time of Arrival of a vessel, followed by an arrival event. The dotted lines indicate that this information is available to customs and the stevedore, but forwarder F1 only has access to containers C1-Cn based on his permission P. A carrier has to request permission (P-req) on behalf of forwarder F1. By adding the transport order of the forwarder to the event ledger, the carrier could automatically receive the release event and the stevedore would be aware of the carrier picking up container Cd. The permissions would be simplified. Smart Contracts or, in this example, event ledger applications provide functionality to the participants, where they behave according rules agreed in a community and permissions control accessibility. Event data structures specify the data that can be retrieved or written to the blockchain. Generation of events by trusted sensors (IoT, Internet of Things) could provide validation.

Each event in the sequence diagram of figure 3 represents an operation on a data structure. For the sake of simplicity, we have chosen to develop one smart contract supporting the use case. The smart contract includes all relevant data structures and operations on these data structures. Each operation results in an API; a role has a set of APIs representing its operations. All stakeholders have to be registered and assigned roles within this smart-contract. When they are registered, they can trigger invoke- and query transactions associated to these roles according the APIs. Invoke-transactions validate the data entered via the API against the data structure of the smart contract, the proper role assigned to a particular stakeholder, e.g. if in this example a shipping line notifies a forwarder, the notifier has to have that role, and the participation of a stakeholder in the blockchain. For instance, if a stakeholder acting as notify is not registered, an error occurs and the transaction is not added to the blockchain. If this stakeholder is registered as carrier and not forwarder, the transaction is also not added.

For the proof-of-concept we developed a NodeJS[7] web application that connects to the blockchain. This application exposes a traditional JSON (Java Script Object Node) API and has methods for enrolling users on the blockchain, deploying the smart-contract to the blockchain and interacting with our specific smart-contract. For demonstration purposes, we have developed a front-end application with the Angular framework[8].

5 Discussion

We have chosen to develop one smart contract for the case. The smart contract shows that status information and data entered by each stakeholder is immediately available to each other stakeholder based on the APIs of its role. Permissions are implemented by invoke- and query transactions of a particular role. One stakeholder grants permissions explicitly to another based on its invoke-transactions. From the perspective of the Physical Internet, blockchain would best fit data sharing and support interoperability between any given stakeholders.

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[7] https://nodejs.org/en/

[8] https://angular.io/

Aspects of Hyperledger Fabric that we have not yet explored, seem to support local data sharing, thus distributing data only to members of a community.

The approach taken for development of smart contracts reflects the current implementation of interactions between stakeholders in a port community. The smart contract can be extended to implement all roles and rules of container transhipment via that port, with each interaction by a particular stakeholder modelled as a data structure of that smart contract. A Port Community System like Portbase could develop such a smart contract for the Rotterdam, the Amsterdam and other ports of the Netherlands. The smart contract will manage all contracts and parties in one application with distributed data storage. This smart-contract does not interact with other smart contracts, which simplifies version management. The smart contract can however be very complex and therefore difficult to develop and to test. The smart contract for the use case is already over 3.000 lines of code and still captures only a small part of the functionality. There is no estimate yet of the number of lines of code required to support all procedures and data sharing in a port like the Rotterdam port. Another complexity is the lack of flexibility. When a (small part of a) procedure in the port changes, the entire smart contract will have to be revised, and all data stored in the smart-contract will need to be migrated to the revised version of the smart contract. This data is required by the new smart contract to support operations on relevant data.

Another approach is development of a smart contract representing container and a smart contract for every role interacting with the container smart contract. Whenever a new container enters the port community, its smart contract is instantiated. It results in very flexible smart-contracts for each role. Each role can utilize its concepts and language in its smart contract that is matched to the concepts representing ‘container’ in this example. Transhipment of every new container can be based on the latest version of the smart contract source-code. A downside of such a design is that over time it will be difficult to keep each smart contract compatible with all the versions of contracts that it has to interact with, unless there are uniform rules for interaction between any two stakeholders specified according a choreography (Hofman 2012), (Dietz 2006).

We have only considered a particular community with its rules. Whenever a stakeholder participates in more than one community or has more than one role in a community, it has to implement the smart contract of its role in each community. Consider for instance a forwarder shipping cargo via Rotterdam and Antwerp port via sea and Schiphol via air. Each smart contract provides a set of APIs for a role, where commonality between those APIs is not guaranteed since smart contracts have different developers. Unless agreements can be made on data semantics and choreography for logistics that are implemented in smart contracts, the costs of implementing blockchain to support the Physical Internet will be too high for individual stakeholders and hyperconnection is not feasible. Development of smart contracts for roles based on agreed semantics and choreography also simplifies testing: each smart contract can be validated against (the part of) the choreography it supports, including data shared. Many validation rules of smart contracts can thus also be generated. It also allows various stakeholders to develop these smart contracts, thus rapidly increasing the deployment. Potentially, each community can add its particular smart contract for a role to a generic smart contract of that role, thus supporting localization. It would allow for instance different procedures for container pickup and drop off by a carrier per port.

BigChainDB takes a more fundamental approach to managing data objects representing for instance ‘container’ and ‘vessel’ (McConaghy, et al. 2016). It considers each data objects as ‘asset’ with a particular owner with its particular permissions. Ownership of these assets can be transferred to other stakeholders that will thus have a right to change a particular asset. We have still to investigate the possibilities of this approach combined with smart contracts running on the database.

6 Conclusions

This contribution has taken a functional perspective with respect to the utilization of blockchain technology to support interoperability for the Physical Internet. It illustrated that for container transhipment a smart contract can be developed and deployed, where each stakeholder with a role has immediate access to state changes based on a set of APIs implemented by the smart contract. From a functional point of view, blockchain can provide hyperconnectivity for the Physical Internet. This paper did not discuss non-functional requirements like performance and scalability, complexity of data structures, etc. These are still for further research.

We have discussed two approaches for development of smart contracts, a community and a role based approach. Another approach would also be that of a dominant player providing particular functionality to its suppliers or customers (see also (Choudry 1997), that identifies three approaches for inter-organizational systems). Eventually, they all result in bilateral solutions for each stakeholder involved, thus not addressing the issue of large-scale interoperability required for the Physical Internet. As we have argued, the level of conceptual interoperability (Wang, Tolk and Wang 2009) is required based on agreements of semantics and choreography.

Besides the development of smart contracts, there is also the issue of permission operations on data objects or assets called in BigChainDB. A combination of BigChainDB with smart contracts needs further research into data ownership and permissions.

Considering these requirements, we can argue that blockchain technology is not yet mature to support interoperability for the Physical Internet, where potentially a large number of autonomous objects, individuals and organisations need to share state space data. There is no development, testing, and validation environment for of smart contract development by different stakeholders, which is also required from a software engineering perspective. ‘Smart contract stores’ allowing different developers of smart contracts to offer their solutions, similar to the Apple store or Google Play for apps on smart devices, are also not yet feasible. There are already industry initiatives to apply blockchain technology for secure document exchange, thus providing paperless transport[9]. However, these applications do not necessarily represent the state of a logistics (sub)system, nor are they compatible with other solutions like Blockfreight.

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Simulation-based Assessment of Hyperconnected Mixing Center Capacity Requirements and Service Capabilities

Nayeon Kim [1,2] and Benoit Montreuil [1,2,3,4]
1. H. Milton Stewart School of Industrial & Systems Engineering,
Georgia Institute of Technology, Atlanta, United States
2. Physical Internet Center
3. Supply Chain & Logistics Institute
4. Coca-Cola Chair in Material Handling and Distribution
Corresponding author: nkim97@gatech.edu

Abstract: *Deployment through hyperconnected distribution and fulfillment networks that are proposed in Physical Internet exploits openly shared logistic centers at all levels. This paper focuses on the hyperconnected mixing center (MC) from which multiple manufacturers store and consolidate goods to serve retailer distribution centers (DCs). Compared to current logistics services based on plant warehouses or dedicated MCs, the hyperconnected storage and shipping service offered from the hyperconnected MC can potentially improve the efficiency of logistic operations of its clients and respective retailers served by them significantly. However, the size of the benefit can vary by numerous factors such as client sets of the MC. In the perspective of a logistic service provider aiming to implement a hyperconnected MC, we propose a generic simulation-based methodology to assess the capacity requirement and service capabilities of the MC and illustrate the operations of a hyperconnected MC with empirical study.*

Keywords: *Physical Internet, hyperconnected distribution, open shared storage, storage capacity, delivery frequency, service capability, simulation*

1 Introduction

The Physical Internet aims to enable highly efficient and sustainable hyperconnected logistics systems (Montreuil, 2011). Such systems encompass moving, deploying, and producing goods. Here, we focus on deploying goods through hyperconnected distribution and fulfillment networks exploiting openly shared centers. For example, for over a decade ES3 (www.es3.com) has been successfully operating such an openly shared distribution network center around its York facility in Pennsylvania, U.S.A. Amazon (services.amazon.com/fulfillment-by-amazon/benefits.htm) has opened its network of 100+ fulfillment centers in North America, becoming the first large-scale asset-based hyperconnected fulfillment service provider. In the spirit of AirBnB.com, Flexe.com has developed a hyperconnected on-demand warehousing platform allowing centers to offer their available space to businesses in need of such space to store their goods. The emergence of such services lead businesses to shift their warehouses, retail distribution centers (DCs) or manufacturing mixing centers (MCs) from being dedicated to their internal use toward becoming hyperconnected centers. Such hyperconnected MCs/DCs can potentially enable higher storage space utilization and reduce warehousing cost by mitigating inventory variability of individual companies while increasing service level and truck fill rate through better consolidation among companies storing in the same openly shared facilities.

Mixing centers differ from warehouses as they are not intended for deep extended storage but rather intended for short term flow storage. In that spirit, they are similar in intent to DCs that are used by retailers and distributors, yet they are rather used by manufacturers to consolidate products made in their multiple plants and/or stored in their warehouses so as to efficiently serve retail DCs, fulfillment centers, and/or outlets in their region.

We distinguish three types of mixing centers: dedicated, collaborative, and hyperconnected. Dedicated MCs are used by a single manufacturer. Collaborative MCs are used by a closed group of partnered manufacturers. Hyperconnected MCs (HMCs) are open on demand to any manufacturer. There are two extreme orientations for HMCs with myriads of variants: spot HMCs and steady HMCs. The spot HMC is focused on short term spot demand from manufacturers. For example, a manufacturer may deploy some products in a given HMC for a few weeks and then not use that HMC for months or years in the future. The steady HMC focuses on steadily serving manufacturers on a yearly or multi-year basis, seamlessly absorbing their seasonal, weekly and daily demand variations.

In this paper, we focus on a business aiming to implement a steady hyperconnected mixing center to service target clients that are manufacturers in consumer goods industry aiming to secure a steady facility from which to serve their customers (e.g. retail distribution/fulfillment centers, retail stores, e-drives) within a territory. In order to determine the new facility size, the business needs to assess its capacity requirements under different scenarios such as overall throughput and configurations of clients. Also, in order to assess and demonstrate its value added to prospective clients in its quest to grow its market share, it needs to estimate potential service capabilities that its clients will be in position of offering to their own clients, such as delivery frequency to targeted retailer DCs.

In this paper, we introduce a simulation-based methodology for performing potentiality assessments for steady HMCs. As shown in Figure 1, we explicitly contrast three alternatives operating schemes: manufacturers serving DCs of retailers (1) directly from their plants' warehouses, (2) from a dedicated MC, and (3) from a hyperconnected MC.

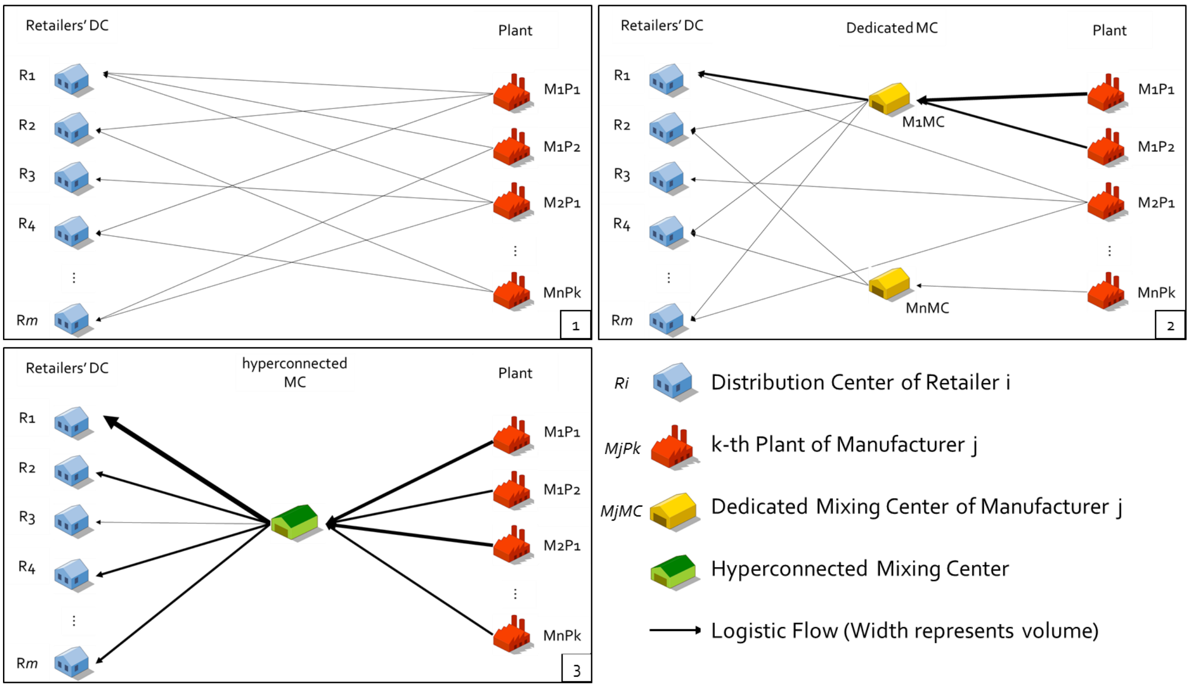

Figure 1: Contrasting Alternative Operating Schemes
No MC (1), Dedicated MCs (2), and Hyperconnected MC (3)

The paper is organized as follows. Section 2 provides a brief review of relevant literature. Section 3 describes the methodology. Sections 4 and 5 provide the description of an experimental case and simulation results for the sample case. Lastly, section 6 concludes by summarizing findings and suggesting future research avenues.

2 Literature Review

Sharing storage (warehousing, distribution) space and services between different firms who may or may not compete with each other has been proposed as a solution to improve logistics efficiency and sustainability. In general, three types of benefits are targeted: pooling inventory space, pooling throughput handling, and consolidating logistics flows. Pooling aims to smooth business-specific peaks and valleys as well as to reduce global safety stocks to deal with uncertainty induced risks. Flow consolidation aims to reduce transportation costs, energy consumption and greenhouse gas emissions, and to enable fast crossdocking operations (e.g. Balan, 2010).

Two types of sharing have been proposed in the literature: first collaborative then, more recently, hyperconnected storage (warehousing, distribution).

Collaborative storage is about sharing storage space and services among a group of partnering businesses. In collaborative storage, the storage facilities are not dedicated to each business, but rather dedicated to the group of partners. Franklin and Spinler (2011) address the efficiency and positive social and environmental impact of collaborative storage obtained through economies of scale and distributed investment. Pan et al. (2013) report on an optimization based study of the impact of collaborative (pooled) storage on the environmental performance of supply chains. Recently, Makaci et al. (2017) combine a literature review and interviews to outline the characteristics and advantages of collaborative warehousing. Reported advantages include decreased warehousing and transportation costs and increased shipping frequency. They also emphasize that collaborative warehousing partners often rely on a third-party logistics service provider (LSP), as the partners' core business may well not be in logistics. It is well known that manufacturers can improve their logistics efficiency and capabilities by utilizing 3PL services without making significant investments or internal innovation (Sinkovics and Roath, 2004). In collaborative warehousing, the 3PL expertise can resolve operation complexity issues and partner heterogeneity (Makaci et al., 2017). The role of a third-party LSP can be critical in hyperconnected MCs/DCs operations as well to handle the operational complexity and dynamics with increased diversity of products and the number of SKUs in the facility. The horizontal storage collaboration can also be extended to collaborative inventory management. For example, in the context of disaster relief supply chain, Toyasaki et al. (2016) show the impact of horizontal cooperation between humanitarian organizations on improving inventory management.

Core to the Physical Internet, hyperconnected storage is about openly sharing storage space and services, available on demand to any business (Montreuil, 2011; Montreuil et al., 2013). Storage service users are clients of storage service providers. Any business may be both a storage service client and provider, offering access to its storage space to clients in low internal-demand periods and relying on external storage services in peak periods. Other businesses may build and operate facilities devoted to offering on-demand hyperconnected storage services. While collaborative warehousing and distribution is about a stable network of facilities exclusive to a group of partners, hyperconnected warehousing and distribution is about a web of open facilities, allowing users high agility in dynamically adapting their deployment of products to evolving demand. With hyperconnected storage, clients may rely on a facility's services for dealing spot storage space demand surges, or engage in contracts for longer periods of time (weeks, months, seasons, years). Crainic and Montreuil (2016) embed hyperconnected distribution into their conceptual framework for hyperconnected city logistics, building on a thread of innovation and research on urban distribution/consolidation centers (e.g. Van Duin et al. 2010; Browne et al., 2011). Sohrabi et al. (2016a, 2016b) respectively contrast through an optimization-based investigation the economic and environmental performance of dedicated, collaborative and hyperconnected distribution, under distinct levels of delivery time offers to customers.

The hyperconnected mixing center studied in this paper provides steady hyperconnected storage service to its clients. Although many researchers such as Crainic and Montreuil (2016) and Sohrabi et al. (2016a, 2016b) addressed the potential benefits of hyperconnected storage, this paper aims at providing more rigorous insights on the operations and benefits of a hyperconnected MC. Also, this paper addresses the potential variations on the size of benefits of the HMC by the client sets which induce different throughput, number of SKUs, inventory variation and distinct delivery locations assuming the service contracts are based on longer period of time (e.g. years).

3 Methodology

We introduce hereafter a simulation-based methodology for assessing the required size for a hyperconnected MC operated by a logistics service provider (LSP) and the advantages to potential clients and for estimating the impact on the logistics operations of the players who are directly or indirectly affected by the service. The methodology is generically described, yet illustrations and descriptions focus on manufacturers serving retailers, be they brick-and-mortar, brick-and-click or pure-play e-commerce players.

The methodology can be synthesized as follows:

1. Define the set of key players as well as their operations and interrelationships;
2. Define the alternative operation scenarios to be contrasted;
3. Define the set of key performance indices (KPIs) for comparing the alternatives;
4. Define the simulation framework;
5. Define experimental scenarios;
6. Perform the experimentation and analysis.

Hereafter we address the first five steps in this methodology from a generic perspective, then we proceed with an empirical application of the methodology.

3.1 Defining the set of key players

The first step is to identify the set of key players. Depending on the context, there may be several types of such players. Here we focus on four types: manufacturers, retailers, carriers and a logistics service provider. Manufacturers are the potential clients of the hyperconnected MC. Retailers are the clients of the manufacturers, each manufacturer serving many retailers and each retailer being served by many manufacturers. Carriers ship products for manufacturers under contracts, from plants to the mixing center, the mixing center to retailers' distribution or fulfillment centers. The LSP aims to provide hyperconnected storage service to manufacturers from a new HMC in a target region.

There are a few typical contexts leading to a center-MC assessment study. First, a LSP leads the study. Second, a key manufacturer leads the study as such a center may provide a smart alternative to a dedicated center. Third, a group of manufacturers leads it, looking for a smart alternative to dedicated centers or a collaborative center. In the latter two contexts, a LSP may or not be with the manufacturer-s at the origin of the study, but one eventually gets engaged in the study. These alternative contexts affect the knowledge about the key player sets.

In context one, the LSP generally conducts a survey of manufacturers and retailers active in the targeted territory. When the LSP has experience in retail logistics, it usually has access to facts and data from its client manufacturers and retailers, and from its logistics operations. For these, the LSP may well have deep knowledge while for others its knowledge may be much thinner. In context two lead by a manufacturer, this player knows a lot about itself and its retail clients in the territory, yet may know much less about other manufacturers and non-served retailers. Context three is similar to context two, yet with a broader base of manufacturers from whom to gather facts and data.

This said, it is generally feasible to gather the entire set of retailers active in the territory, with the location, size and throughput of their distribution and fulfillment centers as well as stores when pertinent. Relative to the potential set of manufacturers, there exist databases listing those active in the territory, with the largest indeed being active in many territories around the world. These databases provide key statistic about the manufacturers. E-commerce data mining enables to track offered brands and products. This means that large sets of retailers and manufacturers may be identified, with varying degrees of available information.

Among the targeted information necessary to support simulation modeling, here is a typical non-exhaustive set:

- Overall revenue and throughput of manufacturers and retailers in the territory;
- Product portfolio of manufacturers, from their top categories down to their product families and models, notably with their dimensions and relative demand;
- Client-supplier relationships between manufacturers and retailers, including their mutual business volume and, ideally, logs of their transactions, orders and shipments as well as the policies regulating the reorder process in terms of quantity, frequency and delivery leadtime expectations;

Detailed information such as delivery frequency and minimal order quantity are important to gather. For example, under current dedicated operations, manufacturers ship independently, so often their delivery frequency to a retailer varies in function of demand size, with a aim to ship full truckloads as much as possible. Hence small retailers often face very low delivery frequency and are forced to order in long-lasting large quantities and to keep high safety stock. For most of them, increasing delivery frequency is desirable and is a negotiation target with manufacturers.

Knowledge about the carriers is also important. Carriers ship products for manufacturers under contracts, either in truckload (TL) mode or in less-than-truckload (LTL) mode. Based on the operating policy of a carrier or a contract, a carrier may deliver in a single-stop lane or a multi-stop lane. Also, a carrier may consolidate shipments from multiple manufacturers who are independently contracting with it to increase fill rate and reduce empty miles. Knowing this is key to understand and assess the overall costs, energy consumption and greenhouse gas emissions induced by the current situation. When assessing the introduction of a HMC, typical carrier contracts adapted to the pooled consolidation of multi-manufacturer goods in the MC have to be defined to allow fair comparison of alternatives.

Relative to all the above types of required information, there are two fundamental situations: either the information is available and can be readily used for modeling purposes, or it is totally or partially not available and thus must be generated through estimation techniques so as to feed the simulation modeling.

3.2 Defining the alternative operation scenarios

The simulation models each key player operating in the targeted territory: manufacturers, retailers, a LSP, and carriers. Each retailer may operate one or more DCs. Each manufacturer may own one or more plants. Orders are placed from a retailer DC to a MC, from a DC to a plant, or from a MC to a plant. Products are shipped from a plant to a MC and a DC, or from a MC to a DC.

As illustrated in Figure 1, it is methodologically proposed to assess the operations of the key players under at least three alternative scenarios: No MC, Dedicated MCs, and Hyperconnected MC. In context three of section 3.1, a fourth scenario would be a Collaborative MC dedicated strictly to the core group of manufacturers. Each scenario must be systematically described, notably in terms of operations, process, flows and transactions.

When operated without a MC, retailer DCs are typically served directly from plants or plant warehouses. The lead time to retailer DCs can be long under this scenario due to the induced distance between plants and retail DCs. Delivery frequency is often bounded due to lack of shipping volume induced by limited consolidation opportunity.

Operating with dedicated MCs usually improves customer proximity, reducing the lead time between shipping from the MC and receiving at the retailer facilities. Also, the manufacturer operating a dedicated MC is better poised to consolidate at the MC where products from all plants are available. The improvement becomes more significant as the number of plants increases and as each plant has a distinctive product mix as contrasted with other plants. However, achieving the improvements typically requires large capital investment by the manufacturer. Only large manufacturers can usually afford and justify such investment through their own economies of scale.

Similar to the dedicated MC scenario, the hyperconnected MC scenario can potentially reduce leadtime through increased customer proximity and more consolidation. However, the consolidation level can be increased significantly as the aggregated multi-manufacturer throughput is higher than that of any single manufacturer. Moreover, there is potential to improve inventory operation at retail DCs. For example, assume that two manufacturers each shipped one truck to a retail DC per week in the previous scenarios and that these two manufacturers now jointly ship two trucks per week in this scenario. Although the same number of shipments is received by the retailer in both scenarios, the hyperconnected scenario reduces the lead time by half. This can notably help retailer facilities to reduce safety stocks. Also, unlike the dedicated MC scenario, no or very little capital investment is required to the manufacturers as they use the service of the HMC as clients.

The scenarios illustrated in this section are the high-order scenarios. Usually they are complemented and enriched by sets of scenario variants testing the impact of key hypotheses. Examples are the expectations of retail clients in terms of delivery frequency, the degree of open consolidation of inbound transportation for supplying the MC and of outbound transportation for delivering to the retail client sites. Each scenario variant must be specified a priori to insure that the modeling will be accommodating its peculiarities,

3.3 Defining key performance indices

The next step in the methodology is to specify the set of key performance indices (KPIs) that are to be used to assess and contrast alternative scenarios. Usually the set of KPIs covers economical, environmental and social efficiency and sustainability. Performance needs to be assessed for the entire business ecosystem within the targeted territory, as well as from the perspective of each key stakeholder.

Examples of typical KPIs include required investments and induced costs; induced travel on roadways and railways; loading of transportation vehicles; inventory requirements (average, variability, peak); MC requirements in terms of space and throughput capacity; induced energy consumption and greenhouse gas emissions; service capability expressed in terms of leadtime, frequency, minimal quantities and in-stock availability. For each KPI must be determined how it is to be explicitly and formally measured.

3.4 Defining simulation framework

To correctly model and assess the operations of a hyperconnected MC using simulation, the scope, key decision makers and key operations must be defined. This step corresponds to the conceptual design of a simulation.

The simulation scope must span all players and operations that are directly and indirectly affected by a HMC. The four key players - retailers, manufacturers, carriers and a LSP – and their pertinent operations and facilities such as retail DC, plants, MCs must be modeled. The carriers need to be modeled explicitly if the carrier make consolidation routing decisions. However, when it only performs delivery operations without making independent decisions, it is sufficient to just model its operations.

Key decision makers can be different from key players. For example, in the HMC, the service provider needs key decision makers such as an order manager, an inventory manager and a shipment manager who respectively receive/place orders, manage inventory, and receive/consolidate shipments. Using an agent oriented simulation approach, each critical decision maker of each key player is modeled as agent. Each agent dynamically makes its own decisions, interacts with the environment and communicates with other agents. The supply chain players, their agents and their relationships are described as a simple class diagram in Figure 2.

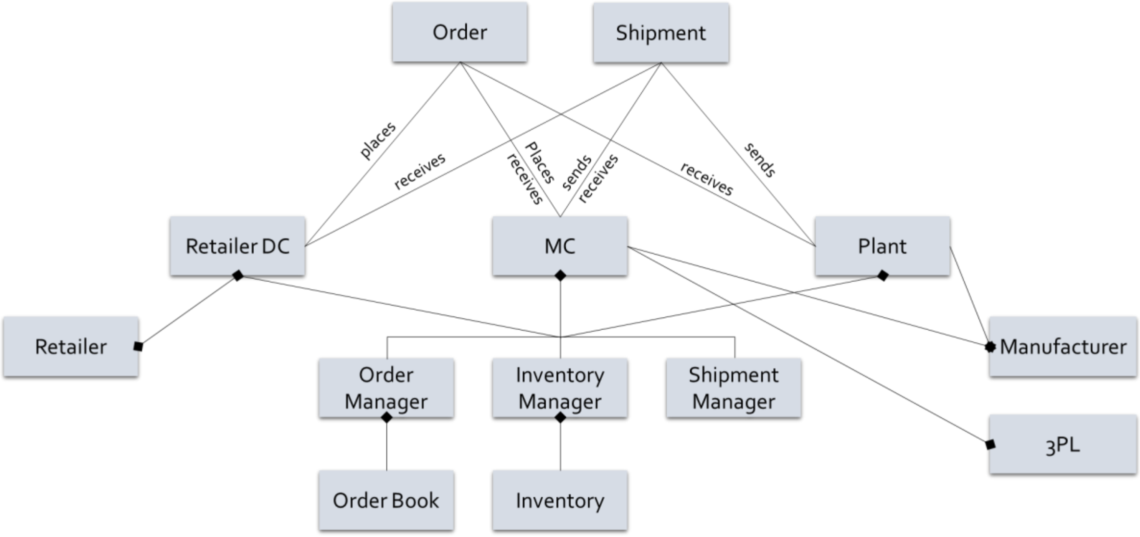

Figure 2; Class diagram of hyperconnected MC simulation

The key operations are the operations that are affected by or constitute the operations of the HMC. It includes inventory operations at the dedicated/hyperconnected MC, plant warehouses, and retail DCs and transportation operations from plant to a MC, from plant to retail DCs, and from a MC to retail DCs. In this case, it is unnecessary to model the transportation operation from retail DCs to retail stores, and to model production at plants. Defining the key operations include setting operational policies such as base stock inventory policy or routing mechanisms.

3.5 Defining experimental scenarios

The experimental scenarios are distinguished from the operation scenarios described in the previous section. The operation scenario defines operational specifications such as logistics network and shipping strategies. Experimental scenarios, on the other hand, are the particular instances for which all operation scenarios are simulated. The experimental scenarios enable to compare operation scenarios by the value of variables of interest. For example, the experimental scenarios can be defined by a different realization of client sets or by a different location of the HMC. When the realization of client sets is the main variable to compare the impact of hyperconnected operation, scenarios can be constructed by selecting clients from potential client pool using different selection rule: randomly selecting certain number of clients, randomly selecting clients until reaching a target throughput, or randomly selecting clients with different selection probabilities. Multiple scenarios can be explored to understand the potential variability on key measures.

4 Case description

As an empirical illustration of the application of the methodology, a specific case is designed. The region encompassing the U.S. western states is set as the target service region for the planned steady hyperconnected MC. This region includes Oregon, Washington, Idaho, Montana, Wyoming, Utah, Nevada, New Mexico and California. Especially, many northwest states such as Montana and Wyoming are typically serviced poorly due to sparse demand that hardly justifies a significant capital investment into a dedicated MC by individual manufacturers. We also limit the potential clients of the HMC to consumer goods manufacturers who would serve retail DCs in the target region from the MC. Plants of a few selected manufacturers and customer DCs served by them are shown in Figure 3 for demonstration.

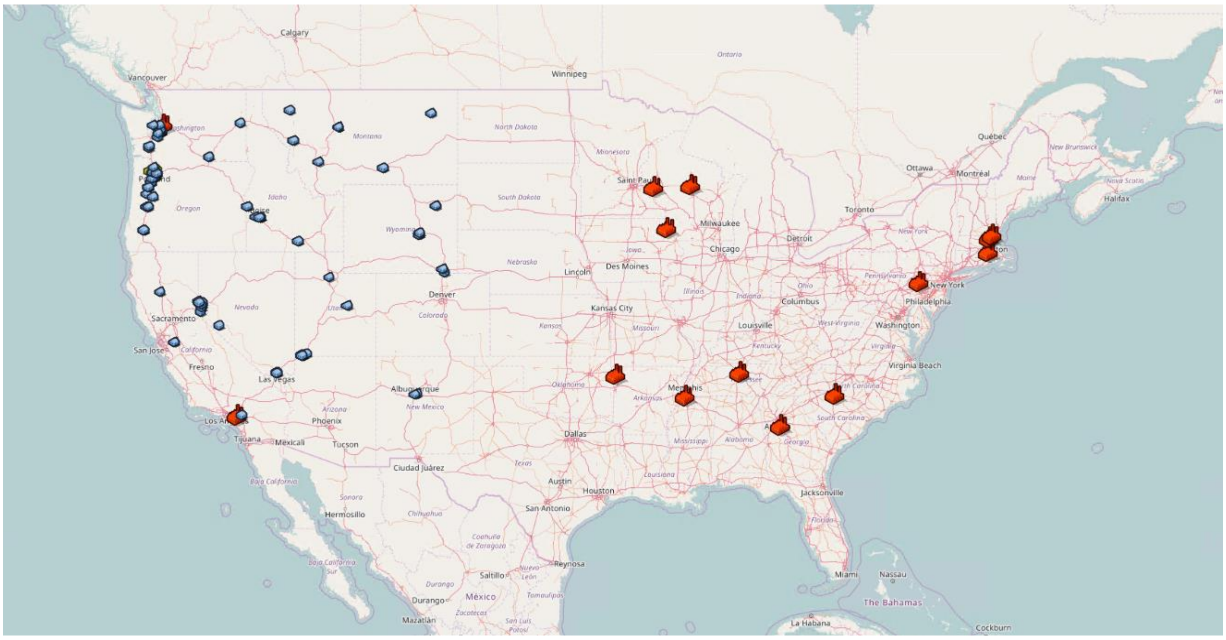

Figure 3: Facility Locations on a Map

4.1 Key players: manufacturers and retailers

A total of 150 manufacturers and 200 customer DCs were designed as active players in the target region. SKU-level demand was generated for each of them. The annual pallet throughput of each manufacturer is shown in Figure 4 together with their number of SKUs. Figure 4 also depicts the annual demand of each customer DC. The SKU portfolio of each entity and their respective demand were carefully constructed from a Pareto-type distribution.

Demand seasonality and stochastic variability were are generated to be in line with industry reality.

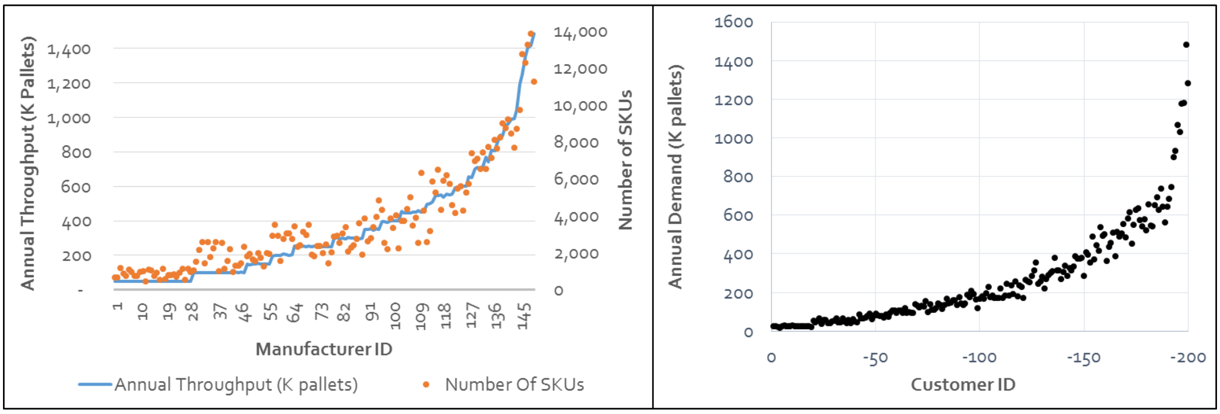

Figure 4: Annual Throughput and # SKUs by Manufacturer (left) and Annual Throughput by Customer (right)

Manufacturers are categorized into small (78), medium (56), and large (16) manufacturer based on their annual pallet throughput according to the following ranges (0,300K), [300K, 800K) and [800K, 1500K).

The demand of customer DCs and manufacturers must be matched for complete market generation. The map in Figure 5 shows relative demand intensity between each manufacturer-customer DC pair: some being zero while others vary in terms of demand intensity. Here demand intensity is colored coded, with the low values being blue while the higher values are intense red. Distinct selections of manufacturers as targeted clients of the HMC would form distinct scenarios.

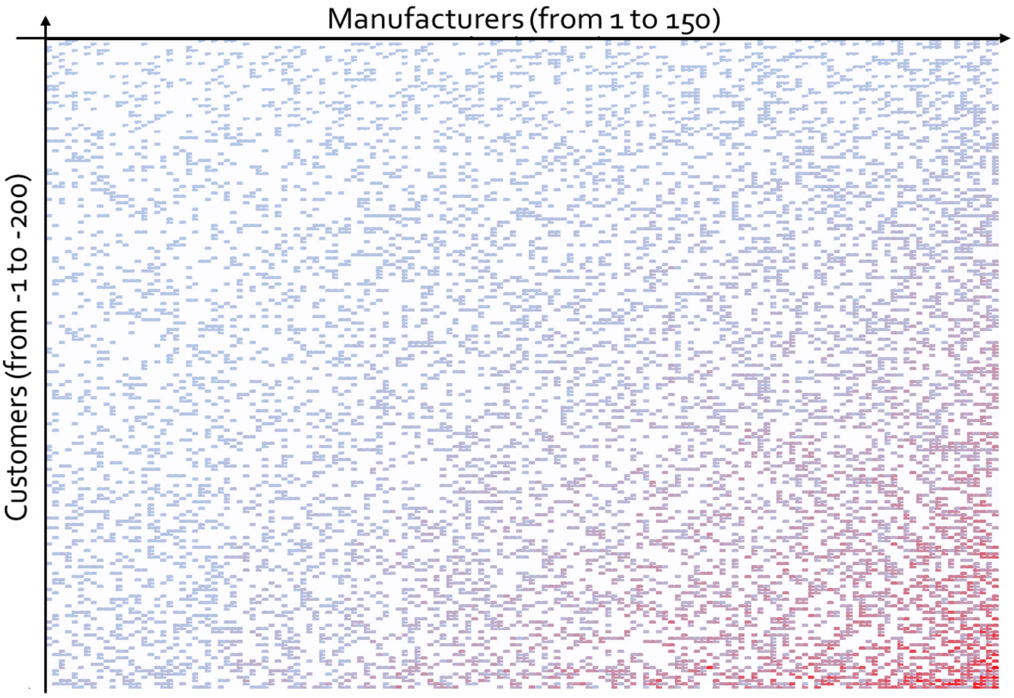

Figure 5: Demand between Manufacturers and Customers (Blue:low demand, Red:high demand, White:no demad)

The locations of manufacturer’s facilities are determined by referring to disclosed supply chain networks of large consumer goods companies such as 3M, Nestlé and P&G. The locations of customer DCs are also determined by matching existing DC locations.

4.2 KPIs: capacity requirements and service capabilities

The scenarios are compared primarily in terms of capacity requirements and service capability. The KPIs are selected to measure them. Also, in this section are listed the assumptions on inventory and transportation policies significantly affecting the KPIs.

Storage capacity requirement is measured as the number of pallet spaces required to address inventory peaks with a given level of confidence (e.g. 99%). Each manufacturer and retail DC is assumed to respectively use a (s, S) inventory policy and a base stock policy. It is also assumed that inventories are reviewed on a daily basis.

Service capability is here measured as the average inter-delivery time to retail DCs and inventory peak and variation at retail DCs. Inventory peak and variations at retail DCs are measured as 0.99 percentile and average coefficient variation of on-hand inventory level respectively. These can be an indirect indicator of the space utilization and safety stock level at retail DCs. These KPIs are significantly affected by transportation policies, so here we list several assumptions on inbound and outbound transportation operations, in line with typical operations of consumer goods manufacturers. The transportation policy has impact on the inventory of manufacturers and therefore on the pallet space requirement as well.

For both inbound and outbound transportation, we assume to use 53’ trucks and double-stack pallets. In case of inbound transportation, if the truck is less than 80% full, other products, which are also supplied from the same plant and their expected time of next order is less than 4 days away, are shipped together to increase a fill rate. For outbound operations, we assume orders are received on a daily basis, but shipping is delayed to achieve outbound fill rates higher than 80% or up to 28 days. As used by many manufacturers in practice, we assume single-stop routes. From the HMC, shipments of different manufacturers are consolidated together as long as they are shipped to the same retail DC.

4.3 Operational and Experimental Scenarios

The three operation scenarios illustrated in Figure 1 – no MC, dedicated MCs, and a hyperconnected MC - form the alternative operations to compare the service level improvement and capacity requirements at each experimental scenario. The dedicated MC operation is only simulated for the manufacturers who have multiple plants. Experimental scenarios are defined by a set of clients of the HMC. In each experimental scenario, the MC faces different throughput, inventory level and variation, number of clients, and number of distinct outbound destinations. The capacity requirements and service capability of the MC are to be estimated and compared. In this paper, we explored six experimental scenarios described in Table 1. A more detailed description of the experimental scenarios is attached in Appendix A.

Table 1: Experimental Scenarios

Scenario ID	# of Clients at MC (# Manufacturers)	Average Annual Throughput (M pallets/year)	# of distinct outbound destinations (Customer DCs)
1	2	~2.8	139
2	5	~2.8	173
3	8	~2.8	180
4	12	~5.8	194
5	8	~3.4	195
6	13	~1.0	172

The simulation models are developed in AnyLogic 7.3.7 (University Version). Each simulation runs for three years, from 2017 to 2019, and the 2017 results are excluded from analysis, considered as a warm-up period.

5 Experimental results

The results of simulation experiments are compared using different KPIs in this section.

5.1 Capacity requirements

In each scenario, annual throughput and capacity requirement of the MC to handle 0.99 percentile of inventory peak are measured. Capacity requirement is measured assuming that the pallet storage is not consolidated and therefore at least one pallet space is required for each SKU. This independent pallet space requirement is compared to that of the two alternative operations: no MC and dedicated MC operation. The reduction percentage of capacity requirement for each manufacturer at each scenario is calculated by comparing the responsible pallet space at hyperconnected DC and capacity requirement of the no-MC or dedicated MC operation. A responsible pallet space for manufacturer Mi is calculated by following equation:

$$Responsible\ Capacity\ of\ Mi = Capacity\ Requirement\ of\ MC * \frac{PS(Mi)}{\sum_j PS(Mj)}$$

In above equation, PS(Mi) is 0.99 percentile of pallet space used by Mi at the hyperconnected MC. The responsible capacity charges for average inventory level as well as the variation. We also calculated 0.99 percentile of on-hand inventory (OHI) level that corresponds to the pallet space requirement under perfect storage pallet mix in Table 2.

Table 2: Capacity Requirements of Hyperconnected MC by Scenario

Scenario ID	Annual Throughput /# Clients (M pallets)	Capacity Requirement (K Pallets)	Average Capacity Requirement Reduction		0.99 percentile of OHI (K Pallets)
			From No MC to Hyperconnected	From Dedicated to Hyperconnected	
1	~2.8 / 2	200	0%	2%	185
2	~2.8 / 5	232	0%	0%	217
3	~2.8 / 8	241	5%	6%	222
4	~5.8 / 12	440	6%	7%	408
5	~3.4 / 8	281	13%	14%	259
6	~1.0 / 13	103	16%	16%	94

As seen in Table 2, the capacity requirement is not exactly proportional to annual throughput or the number of clients. Also, the average capacity requirement is reduced by having a HMC in general by pooling effect although the reduction rate of pallet space requirements varies by scenario. Therefore, the service provider must understand the inventory operation of potential clients to better estimate capacity requirements.

The 0.99 percentile of OHI tends to be about 10% smaller than a capacity requirement. This implies the LSP can reduce capacity requirement by consolidating products for storage.

5.2 Service capability

Service capability can be measured by various KPIs. In this paper, we estimate average inter-delivery time to customer DCs and average inventory level and variation at customer DCs.

5.2.1 *Average inter-delivery time*

Average inter-delivery time and its complement, the average delivery frequency, is one of the indicators of service level. Shorter average inter-delivery time or higher delivery frequency indicate more responsive services and can potentially improve inventory operation at customer DCs. The distribution of average inter-delivery time to customer DCs of selected manufacturers is described in Figure 6. Same graphs for dedicated MC operation scenario and hyperconnected MC operation are attached in Appendix B.

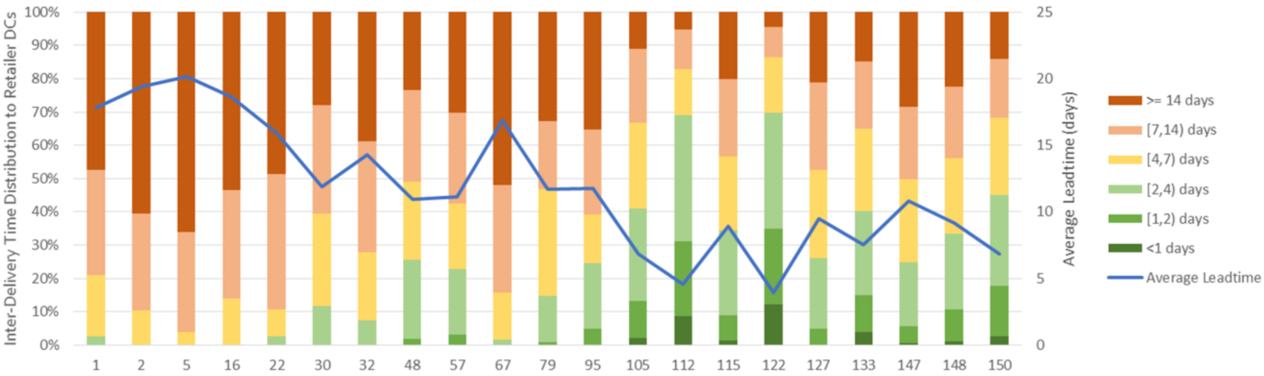

Figure 6: Average Inter-delivery Time to Retailer DCs by Manufacturer (No MC Operation)

In Table 3, it is shown that the average inter-delivery time to customer DCs is reduced significantly with HMC in all scenarios. The consolidation index represents the average number of manufacturers shipping together to same customer DC, over all outgoing trucks.

Table 3: Average Inter-delivery Times and Marginal Reductions

Scenario ID	Consolidation Index	Average Inter-Delivery Time in Days and Marginal Reduction				
		No MC	Dedicated MC		Hyper MC	
1	1.4	8.8	2.6	71%	2.1	18%
2	1.8	6.4	6.4	0%	3.4	46%
3	2.6	13.7	11.4	17%	4.7	59%
4	3.8	11.1	9.1	18%	2.3	75%
5	3.1	12.6	11.4	9%	4.3	62%
6	2.2	16.1	14.9	7%	9.7	35%

By adding a dedicated MC, manufacturers can reduce inter-delivery time when they have multiple plants. However, significant marginal reduction has been again achieved by a HMC in all scenarios. There is a tendency that marginal reduction percentage is larger when consolidation index is larger. In other words, when clients of the HMC have more outbound destinations in common, deliveries can be consolidated better and more benefits from economies of scale be obtained. That is, when defining a target client pool, the service provider can expect to maximize service level improvement by including manufacturers who tend to have more overlapping customers when single-stop routing is used.

The changes in distribution of inter-delivery time and benefits by individual manufacturers in scenario 3 is described in Figure 7. In general, small manufacturers reduced inter-delivery time more significantly. However, larger manufacturers who already have economies of scale on their own also improved inter-delivery time significantly. This results again show the motivation for manufacturers to utilize HMC regardless of their size. Although scenario 3 is selected for demonstration in Figure 7, similar patterns are found in all scenarios.

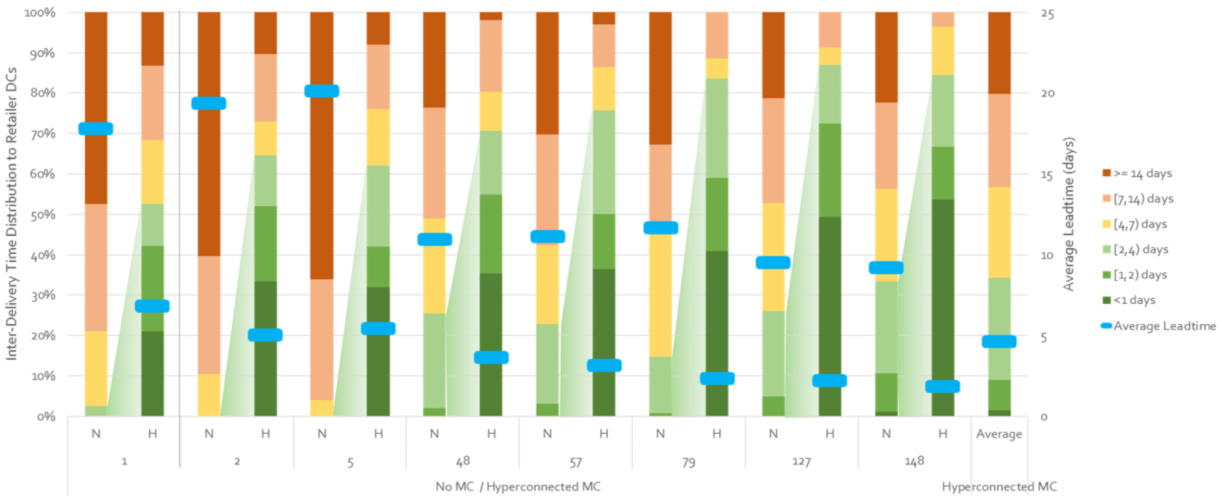

Figure 7: Average Inter-delivery Time to Retailer DC in No MC Operation (N) and in Hyperconnected MC Operation (H) in Scenario 3

In traditional distribution, an increase in delivery frequency is achieved at a cost induced by increased travel distance. However, the reduction in average inter-delivery time is reduced without any significant additional outbound travel distance in the case of HMC over all scenarios. Instead, the outbound travel distances are even reduced. The average marginal reduction in outbound distances by having dedicated MC and having open MC is summarized in Table 4. Here, only the outbound travel distance is compared as the inbound travel distance varies significantly depending on the location of plants of each manufacturer. The relationship between travel distances and shipping cost is less direct for inbound transportation due to potential mode of transportation, e.g. rail transportation can be used for most of the inbound volume which is cheaper than road transportation.

Table 4: Average Marginal Reduction in Outbound Travel Distances by Scenario

Scenario ID	No MC	From No MC to Dedicated MC	From Dedicated MC to Hyper MC
1	-	67%	1%
2	-	0%	59%
3	-	27%	40%
4	-	24%	39%
5	-	18%	51%
6	-	19%	55%

5.2.2 Inventory operation at customer DCs

The increased delivery frequency can lead to more efficient inventory operation at customer DCs. Firstly, consider the equation for base-stock level at customer DC shown below:

$$BS(L) = D * L + 3 * \sigma * \sqrt{L}$$

L is average inter-delivery time, D is average daily demand, and sigma is standard deviation of daily demand. From the equation, it can be seen analytically that when average inter-delivery time is reduced to p*L from L for some 0<p<1, the base-stock level is decreased by more than square root of p. This is shown below analytically.

$$BS(pL) = D * p * L + 3 * \sigma * \sqrt{p * L} \leq \sqrt{p} * BS(L)$$

This implies that inventory peak requirements can be reduced by lowering inter-delivery time. In addition to the analytical bound, the inventory level at customer DC is modeled and tracked in simulation. In Table 5, reduction in average of 0.99 percentile of OHI at customer DCs and in average inventory variation measured as coefficient of variation (COV) compared to no MC and dedicated MC operations is summarized by scenarios.

Table 5: Reduction in Inventory Peak and Variation at Customer DCs with Hyperconnected MC Operation Compared to the Two Alternative Operations by Scenario

Scenario ID	Reduction in 0.99 Percentile OHI at Customer DC		Reduction in Inventory Variation (COV) at Customer DC	
	No MC	Dedicated MC	No MC	Dedicated MC
1	16%	0%	62%	27%
2	15%	15%	46%	46%
3	10%	3%	69%	59%
4	10%	5%	76%	71%
5	9%	6%	70%	68%
6	6%	3%	52%	49%

In all cases, the variations as well as inventory peak at customer DCs are reduced significantly as shown in the Table 5. The results implies that the service capability of the HMC is not limited only to the delivery operation to customer DCs, but also capable of improving the internal logistic operations of customer DCs.

6 Conclusion

This paper has achieved multiple objectives. It has proposed a methodology to assess the potentiality for a logistics service provider to implement a steady hyperconnected MC in a target region. It has provided insights on HMC facility sizing. It has assessed advantages of using the service of the HMC for potential clients. It has demonstrated the benefits that the HMC can potentially bring into logistics operations of the players who are directly or indirectly using the services. The proposed methodology can help understand and assess the impact of hyperconnected storage and distribution.

Analysis of the experimental results has provided insights on potential advantages. Results show the potential of a HMC to improve the operations of manufacturers that currently supply their products from their plants/warehouses or their own dedicated MCs to their customer DCs, by enabling better storage space utilization and consolidation of outbound shipments without substantial capital investment of individual manufacturer. By simulating the operations of such HMCs, capacity requirements of the facility are assessed under different client sets.

The simulations provide insights on HMC service capability. HMCs enable to increase delivery frequency to customer DCs, inducing lower inventory requirements at customer DCs with no significant additional outbound travel. Unlike the common expectation that large manufacturers will not observe significant improvement due to their own scale, the results show that even large manufacturers can benefit as well. As most of logistics operations throughout the entire supply chain are required to be ever more agile and responsive, the service capability can attract many potential clients.

The key limitations of the study are as follows. First, the simulation-based experiments are limited to a single HMC case, limiting the genericity of the results and insights. Second, it does not address the coordination cost to handle the complexity and dynamics of HMCs operations, notable in terms of information and communication technology and service capability. Third, the long term, multi-year evolution of the clientele of HMCs is not addressed. Fourth, it does not model the pricing mechanisms for HMC services which may affect the behavior of clients and the attractiveness of the HMC. Fifth, it does not model competition between HMCs in a region. Sixth, we have limited the study to steady HMCs, not addressing spot HMCs. Seventh, we have not addressed the potential of hyperconnected logistics facilities that encompass the spectrum of mixing and distribution centers as exemplified by ES3 in York, Pennsylvania, USA. Each of these limitations provides avenues for further research.

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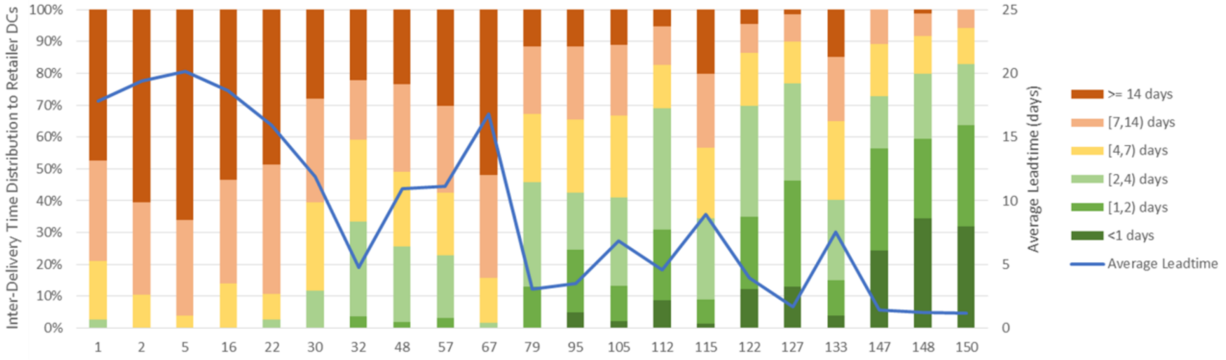
Appendix A: Scenario Description

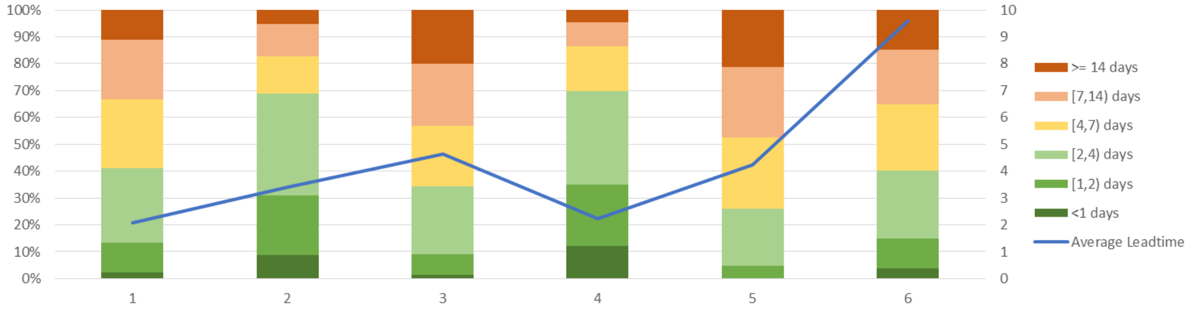
Scenario ID	# of Clients at MC				Expected Annual Throughput (M pallets/year)	# of distinct outbound destinations (Customer DCs)	Client IDs
	Small	Med	Large	Total			
1			2	2	~2.8	139	147, 150
2		5		5	~2.8	173	105,112,115,122,133
3	5	2	1	8	~2.8	180	1,2,5,48,57,79,127,148
4	5	5	2	12	~5.8	194	1,2,5,48,57,79,105,112, 122,127,147,150
5	7	1		8	~3.4	195	1, 5, 16, 22, 30, 32, 67, 79,95,105,112,115,122
6	7	6		13	~1.0	172	2,5,16,22,30,32,67,95

Appendix B: Inter-delivery Times

Inter-delivery time to retailer DCs from a dedicated MC (same to no MC operation for manufacturers with a single plant):



Inter-delivery time to retailer DCs from a hyperconnected MC by scnearios:



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Simulation Based Study of the Effect of Competition on the Operations of Hyperconnected Crossdocking Hubs

Shannon Buckley[1,2], Benoit Montreuil[1,2,3,4], and Zachary Montreuil[5]
1. H. Milton Stewart School of Industrial & Systems Engineering,
Georgia Institute of Technology, Atlanta, United States
2. Physical Internet Center, Georgia Institute of Technology, Atlanta, United States
3. Supply Chain & Logistics Institute, Georgia Institute of Technology, Atlanta, United States
4. Coca-Cola Chair in Material Handling and Distribution, Atlanta, United State
5. The Createch Group, Quebec, Canada
Corresponding author: Sbuckley8@gatech.edu

Abstract: *The current way that supply chains move, handle, store, realize and supply physical objects is unsustainable. To significantly improve supply chain sustainability worldwide, the Physical Internet was proposed as a paradigm breaking model for how supply chains should operate. This new system takes advantage of open flow consolidation across multiple parties in hyperconnected hubs to produce fuller truckloads, and more optimal routes with respect to social, economic and environmental objectives. As can be seen, hyperconnected hub networks are central to the Physical Internet. But, how will modular containers flow through them? How will each hub communicate with the other players in the system? How will demand be split between competing hubs? These are the types of questions that will need answers so that the hubs and the Physical Internet can become a reality on a large scale. In this paper, we exploit a previously developed hub design and create a simulation model in order to examine how different hubs would interact in a competitive environment.*

Keywords: *Physical Internet; Simulation; Hub; Crossdock; Facilities; Competition*

1 Introduction

The Physical Internet (PI) was proposed as a solution to the unsustainability caused by the inefficient, congested and segmented supply chains of today (Montreuil 2011 and Ballot et al. 2014). In the Physical Internet, physical objects are encapsulated in modular containers and then routed through a network of hyperconnected hubs until they reach their destination. Within this new system, the hubs leverage open flow consolidation across multiple parties resulting in fuller truckloads, and more optimal routes with respect to social, economic and environmental objectives. These hyperconnected hubs play a central role in the Physical Internet. In this paper, we examine the road-based crossdocking hubs that were first described by Montreuil et al. (2012).

The purpose of this paper is to explore how multiple hubs within the same region will interact with each other and with the other main players in the Physical Internet. Specifically, we focus on hubs in the peri-urban region of a city and examine how demand for hub services will be split between competitors. We also examine how the main players, such as shippers, truckers and hub operators, behave under this competitive hub landscape. We claim that understanding how these interactions take place is a very important step towards enabling hyperconnected hubs can become a reality on a large scale, a key to full Physical Internet implementation and adoption.

The paper is organized as follows. In section 2, we provide background information on the function of contemporary crossdocks, and highlight the differences with the hyperconnected crossdocking hubs envisioned by the Physical Internet. In section 3, we discuss the roles and motivations of the shippers, the truckers and the hub operators. In section 4, we present the different topologies under which we examine the interactions of the main players. We also explain the decision processes that each player will execute within our simulation. In section 5, we discuss our simulation-based investigation of the player's interactions under each topology. Finally, in section 6, we conclude our investigation and discuss future research avenues.

2 Hyperconnected Crossdocks

2.1 Crossdocks

To appreciate how hyperconnected road-based crossdocking hubs are utilized within the Physical Internet, it is important to first have a basic understanding of a crossdocking hub (also known as a crossdock). A crossdock is defined as a high-speed warehouse (Bartholdi et al. 2016). They are usually rectangular warehouses with truck docks along opposing walls. This allows for shipments to be carried from arriving trucks on one side, across the warehouse, to departing trucks on the opposite side. Crossdocks also have buffer areas in their center, so that when the departing truck has not arrived yet, the shipment may be stored for a short period of time. Figure 1 from Bartholdi (2016) shows a typical crossdocking hub layout.

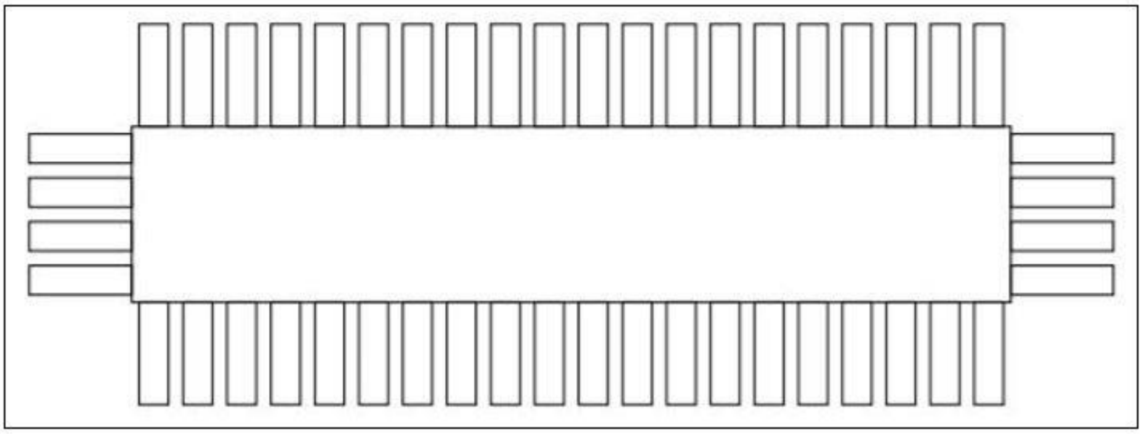


Figure 1: View from above of a typical high-volume crossdock. The large center rectangle is the crossdock and the outer rectangles are truck trailers. Source: Bartholdi (2016)

A core benefit of crossdocks is that they provide the ability to consolidate Less-Than-Truck-Load (LTL) shipments into Truck-Load (TL) shipments. For example, imagine a group of m suppliers, supplying n stores. Assume each supplier has a set of LTL shipments, one for each store, that combine to a TL shipment in total. Instead of paying to ship partially full trucks to each store, each supplier can send their total shipment amount as a TL shipment to a third party crossdock where the LTL shipments from all suppliers are consolidated into TL shipments and then shipped to each of the n stores. This not only decreases the rates that must be paid for shipping, but it also reduces the amount of truck trips needed from $m*n$ to $m+n$. This can be a considerable reduction in total trips, when m and n are large.

2.2 PI Hubs

In the road-based hyperconnected crossdocking hubs (PI Hub or hub) envisioned by the Physical Internet, the practice of consolidating shipments for cost and travel reduction is taken a step further. For instance, using the scenario from the previous example, the *m* suppliers would no longer just arrange for the third-party LTL company to transport their shipments to the third party crossdock where the shipments from the *m* suppliers would then be consolidated and sent to the *n* stores. In the Physical Internet, each supplier would transport their shipments to the closest PI Hub, where they would then be routed by contracted, PI verified truckers, from one independently operated hub to the next, until they reached their destination. These hubs would form a network where a shipment would never journey more than about 4 hours until reaching its next hub. At each leg of the journey, the shipments would be reconsolidated with other shipments going in their direction for that leg, maximizing transportation efficiencies and reducing costs. Also, each hub would only send shipments in a small number of directions, to the hubs in surrounding regions, resulting in better consolidation and space savings within the hub.

The inner workings of the proposed hyperconnected crossdocking hubs have been presented by Montreuil et al. (2014). Figure 2, sourced from Montreuil et al (2014), shows the consolidation process at a PI Hub.

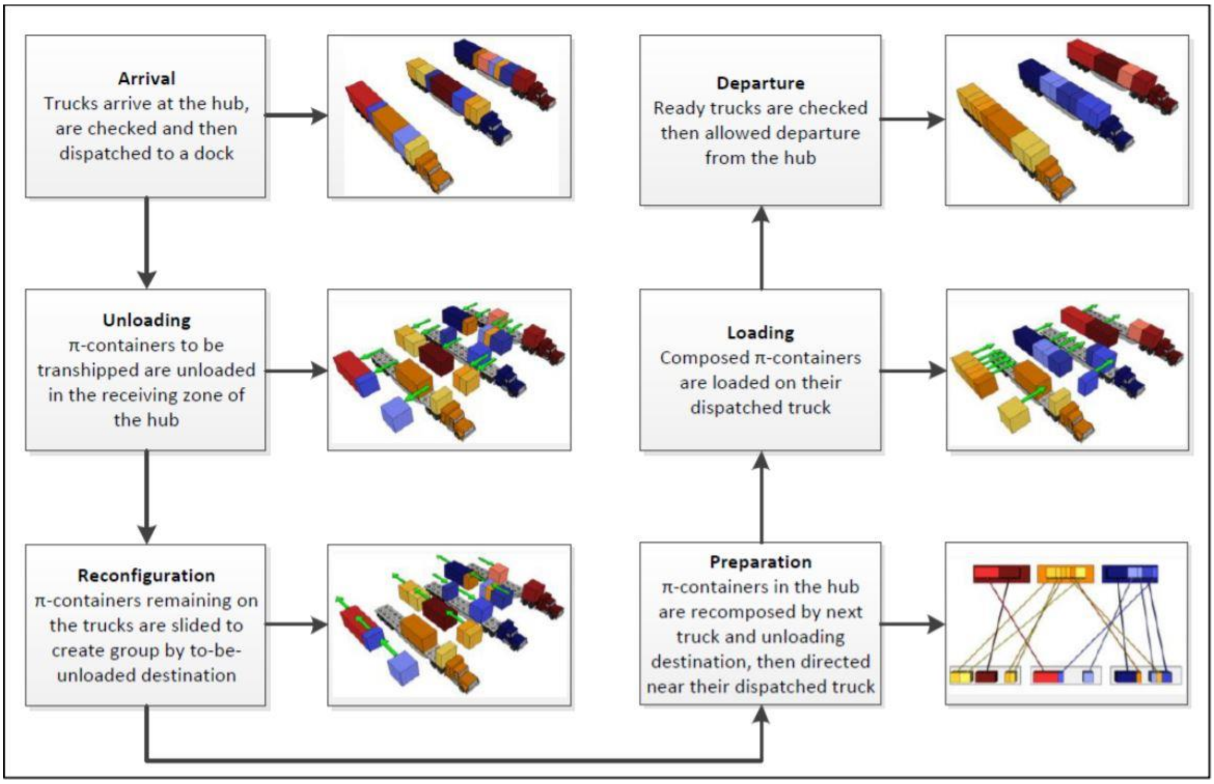


Figure 2: The crossdocking process and its key sub-processes
(Omitting the internal layout of the PI Hub) Source: Montreuil et al (2014)

Later in the paper we will go deeper into the decision processes, but the generalized process for how a shipment travels through the Physical Internet to its destination would be as follows:

1: Shipper contracts local trucker to transport shipment to nearest PI Hub.
2: Trucker delivers shipment to nearest PI Hub where it enters the Physical Internet Hub network.
3: Shipment is given preliminary route through hubs to its destination.

4: Hub management system consolidates its current shipments for efficiency and contracts trucker to take shipment to its next hub.
5: Contracted trucker delivers shipment to the next hub on its route.
6: Steps 4-5 are repeated until the shipment reaches its final hub.
7: Final hub contracts local trucker to deliver shipment on a milk run to its destination.

Here we can see that the shipping process using the hyperconnected crossdocking hubs involves three main players: the shippers, the truckers and the hub operators. In order to gain a perspective on how each player makes decisions, we will explore each of these players' roles and goals in the next section.

3 The Main Players

3.1 Shippers

In the hyperconnected goods transportation section of the Physical Internet, the shippers are a large source of demand for PI Hub services. They supply the shipments that need to travel through the network of PI Hubs. Once a mature Physical Internet is realized, the shippers will need to do nothing more than tell their shipments when and where to go and their budget, and the rest will be taken care of (Montreuil 2011). As described in Montreuil et al (2015), Physical Internet containers come in three varieties; packaging, handling and transport. Transport is the largest and resembles modern day shipping containers in functionality. They are able to withstand harsh environmental conditions and are stackable. Their cross-sections are 2.4m x 2.4m and their lengths are 12m, 6m, 4,8m, 3,6m, 2,4m or 1,2m. In this paper we deal only with transport containers. Another option gives the shippers more control, where they can preemptively plan their shipments routes through the network of PI Hubs, and make dynamic decisions as needed along the journey (Montreuil 2011). These decisions could be things such as choosing truckers who meet performance criteria and are going to the desired next hub, or choosing which hubs their shipments pass.

In this system, the shipper's objectives are to make sure their shipment is delivered and to make sure it is delivered on time. In this paper, we focus on these objectives as part of the shipper's decision making process.

3.2 Truckers

In the Physical Internet, the truckers drive the trucks that transport the encapsulated shipments from PI Hub to PI Hub (Montreuil et al 2012). In general, the player is the transport provider which ranges from a large scale company, such as Schneider, to an individual freelance trucker. In the simulations performed in this paper, we work with individual truckers for simplicity purposes so as to focus on the key concepts. They operate independently, similar to the drivers working for the ride-sharing companies of today. They must be PI certified and have their performance profile available to the Physical Internet community. In this way, PI Hubs and shippers could contract their services based on their past performance (Montreuil 2011). In addition to their performance profile, the trucker also makes their preferred final destination available so that they may be requested for shipping routes that bring them closer to that goal. In this paper, we will assume that their goal destination is their home location. If the trucker accepts the delivery request, they will pick up the load and move it to the next PI Hub in its journey.

In the Physical Internet, the trucker has multiple objectives. First, they want to make money by being hired for deliveries. This entails spending most of their time moving shipments and not waiting idly at hubs. Second, they want to maintain a certain quality of life. Part of this quality of life is to end up at their home location at the end of the day. For the purpose of this paper, we focus on these objectives and how they influence the trucker's decisions of which loads to take and which hubs to travel to.

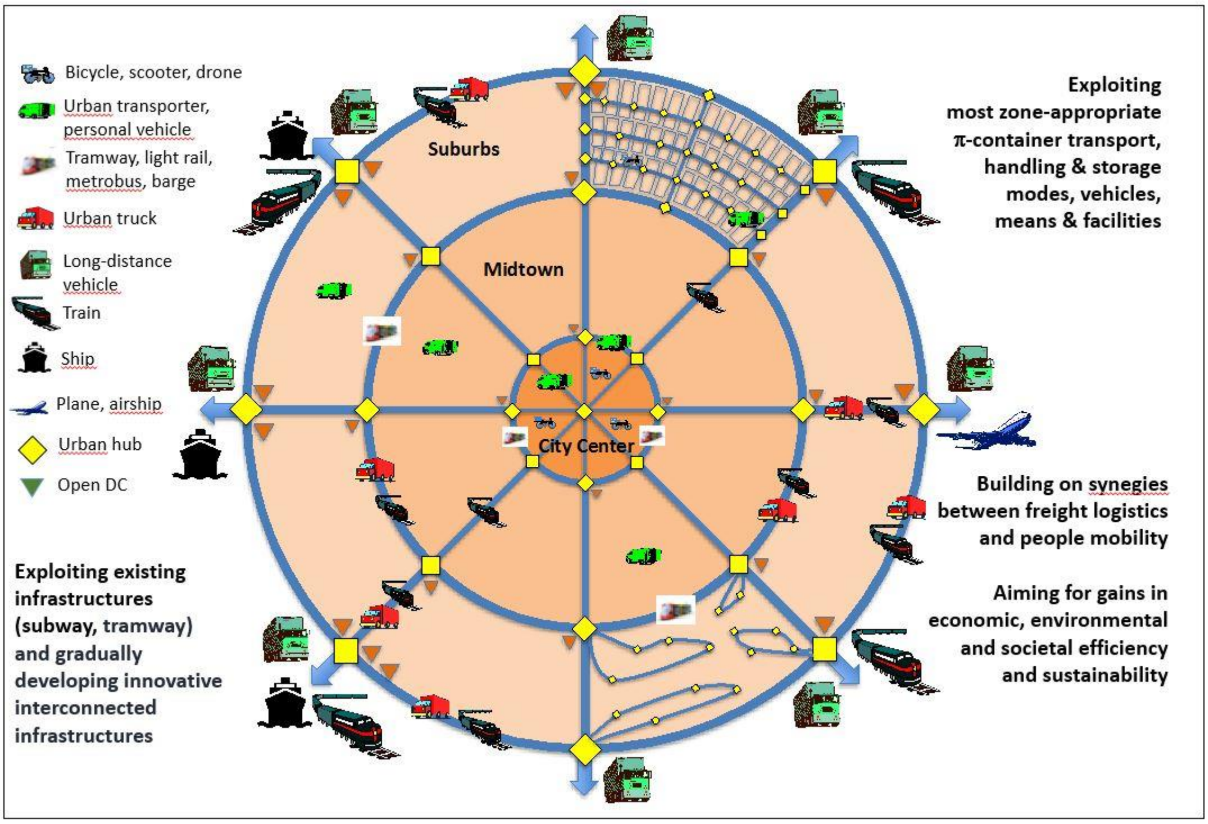
3.3 Hub Operators

In the Physical Internet, the hub operators are the entities that control the flow of goods through the PI Hubs. Similar to the truckers, they are independent entities working within the Physical Internet. They must be PI certified and make public their KPI's so that truckers, and shippers could contract their services based on fact-based services (Montreuil 2011). These KPI's would be things like, trucker and container throughput time and percentage of trucks departing in preferred direction (Montreuil et al 2012). The hub operators manage the hub like managing a business. They make sure that the PI Hub and its facilities are working and able to service their clients, the truckers and the shippers, at the highest levels possible. At the same time, they want to make money.

The hub operators make their money by charging for allowing containers to pass through their facilities and so they would like to obtain as much demand for their facilities as possible. In this paper, we focus on this objective and how it affects the hub operator's decision process.

4 Peri-Urban Hyperconnected Hub Topologies

Now that the main players and processes of this paper have been described, we can begin to examine scenarios in which multiple hubs occupy a shared region around a city. Figure 3, from Crainic et al (2015), shows an imagined city in the Physical Internet, with hubs around the outside.



Exploiting most zone-appropriate π-container transport, handling & storage modes, vehicles, means & facilities

Building on synegies between freight logistics and people mobility

Aiming for gains in economic, environmental and societal efficiency and sustainability

Exploiting existing infrastructures (subway, tramway) and gradually developing innovative interconnected infrastructures

Figure 3: Hyperconnected City Logistics in the Physical Internet. Source: Crainic et al (2015)

For our simulation-based investigation, we assume that trucks are only able to travel around the outside of the city limits and do not travel through a city. For example, if a truck needed to get from a hub on the west perimeter of a city, they would need to travel around the perimeter to get to a hub on the east perimeter of the city. We also make the assumption that the hubs only locate on the North-South and East-West axes of the city. Under five different topologies, we will examine the decision processes of the three key players, specifically the decisions that must be made regarding their routes through the region. We also discuss the different influences affecting these decisions.

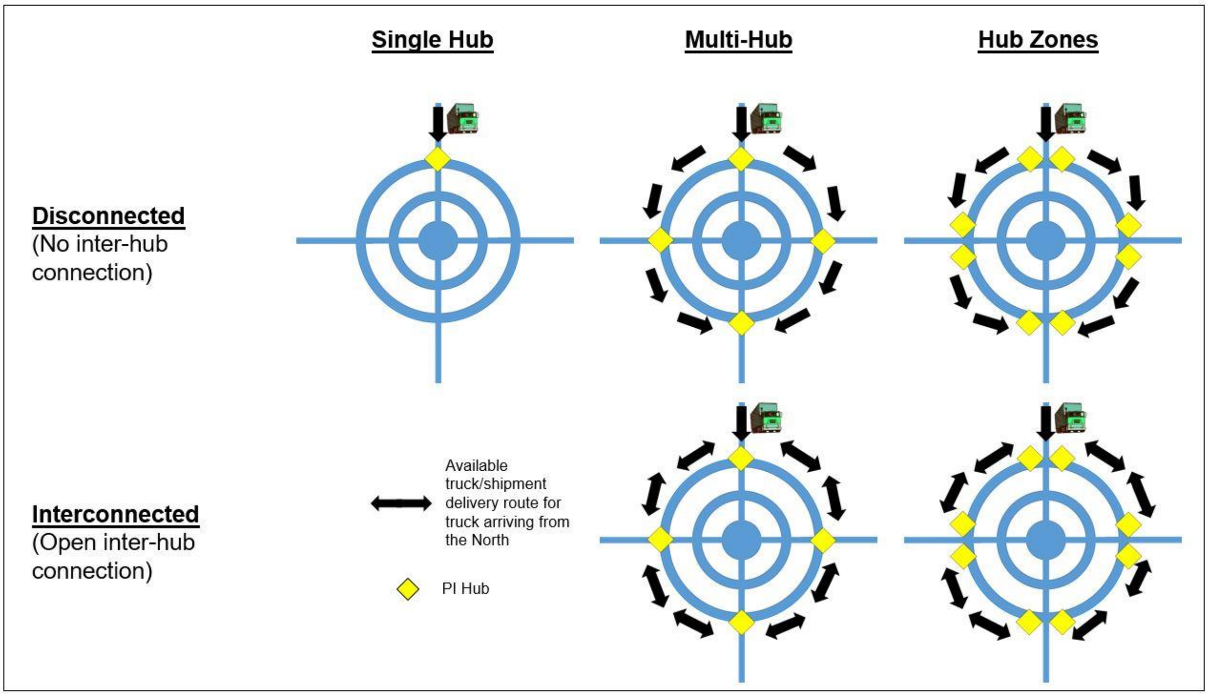


Figure 4: Five topologies for peri-urban hub-based routing, depicted assuming a north-origin truck

The topologies have been split between the disconnected scenario, in which there is no available shipping routes between the different hubs in the region, and the interconnected scenario, in which trucks and goods my flow between every hub in the region. We have also split them within the two scenarios into single-hub, multi-hub and hub-zones scenarios.

4.1 Single-Hub

In this topology, there is only one hub in the region around a city. It can be at any of the four axis points around the perimeter, but we will assume in our illustrations that it is located on the north side. In this design, there are no decisions to be made about which hub to travel to, as there is only one hub in the region. If a shipment is routed through this region, it will pass through the hub. If a trucker accepts a request to transfer shipments to this region, it will stop at the hub. The hub operator also does not need to make any decision with regards to gaining a larger share of demand passing through the region because they have a monopoly. This is the scenario implicitly modeled by Montreuil et al. (2014).

4.2 Disconnected Multi-Hub

In this topology, there are four hubs in the region around the city. One positioned at each major direction; North, East, South and West. There is no connection between the different hubs in the region. This means that if a truck or shipment passes through one hub in the region, they will not be able to pass through another in this region on their way to their next destination. Also, since we have multiple hub options for the truckers and shipments passing through the area, this is a scenario in which the truckers and the shippers must choose which hub to visit. However, because there is no connection between hubs, they must choose a single hub.

The decisions that must be made in this topology for the trucker are: which hub is the preferred hub, and whether to wait for a shipment travelling to its preferred hub or to just take a shipment because it is ready now.

The decisions that must be made for the shipper are: which hub is the preferred hub. In our investigation, because we do not deal with pricing, the hub operators are restricted to only take decisions on assigning containers to departing trucks.

4.3 Disconnected Hub-Zones

This topology is similar to the disconnected multi-hub case. There are hubs at each of the four major directions around the city and there is still no connection between the different hubs in the region. However, the difference is that in this topology, at each of the four major directions, there are now two hubs competing for demand, whose location we call a hub zone. The decision space is the same as described above, except that now the truckers and shippers have more hubs to choose from.

4.4 Interconnected Multi-Hub

This topology is set up in the same way as the disconnected multi-hub topology, with the difference being that now there is inter-hub connection. This means that truckers and shipments may visit one hub, e.g. the North hub, and then travel to another hub, e.g. the East hub, before they depart the region.

Because of this physical similarity to the disconnected multi-hub topology, the decisions from that section are still valid for each player. The difference is now there is full inter-hub connection that allows for trucks to make stops at multiple hubs within the region, consolidating inter-hub shipments. In our simulation, this allows for additional decisions that the truckers can make, but does not change the decision space for the shippers or the hub operators.

The additional decision that the trucker must make is: should they take each shipment to its preferred hub while travelling more and more empty along the way, or should they only deliver to one hub.

4.5 Interconnected Hub-Zones

This topology is similar to the disconnected hub zone topology, which allows for the decisions from that section to still be valid for each player. The key difference between the two topologies is the interconnectedness of the hubs. This interconnectedness allows for additional decisions that the truckers can make, but does not change the decision space for the shippers or the hub operators. Specifically, the new decision is: should they only deliver to one hub, or deliver to multiple hubs while travelling more and more empty along the way. This second option will bring more shipments to their preferred hubs.

5 Simulation Decision Processes

In this section, we discuss the decision processes that the players make in our simulation.

For the shipper, the decision process will be influenced by their objectives of making sure their shipments are delivered on time. For this reason, a hub with a fast average throughput time will be very desirable to a shipper. Also, to eliminate extra travel time and cost, a shipper will prefer a hub closer to their next destination. For example, if a shipment is travelling through the Atlanta region, and its next destination is to the East, then the value of passing through the East hub increases.

For the trucker, the decision process will be influenced by their objectives of making money and maintaining a quality of life. Their decision of preferred hub will be influenced by the hub's KPI's, such as average throughput time. Hub's with faster average throughputs will be preferred. This is because first and foremost, the trucker needs to make a living. They desire to spend their time on the road making money instead of sitting idly at a hub. For example, if the east hub has a shorter average throughput time than the west hub, the trucker might desire the east hub more. However, if their shipment is not willing to pass through their preferred hub, the trucker will choose to take their shipment to a hub that is the best compromise.

As we discussed in section 3, a hub operator is motivated by obtaining the most demand for its services, which in turn will generate it the most money. However, in our simulation, we assume all hubs have the same equipment and facilities, and so their KPI's, such as throughput times, that attract the shippers and truckers, are determined by how many shipments they have waiting. Thus, dynamic decision processes for the hub operators are limited to container assignment to outgoing trucks in the simulation. The hub operators make their decisions by deciding which topology to operate under.

6 Simulation Based Investigation

In order to evaluate the interactions between the three main players of the hubs, we designed a model for each topology listed in Section 4. Because this topic has not been studied before, these models are meant to provide an exploratory first look into the subject and so simplifying assumptions have been made. Our models each have four sources representing the four directions coming into a city; North, South, East and West. These sources generate trucks having a set of 5 transport containers, with each container's next destination chosen randomly from the remaining three directions. The truck and containers then follow the decision process outlined in Section 6 and choose a hub around the city to travel to. The hubs in these models are based on the structure of the model in Montreuil (2012). Once inside the hubs, the trucks drivers attempt to find a load going back to their home direction. If after a set time threshold, they cannot find a shipment heading in their preferred direction, they will take any available shipment heading in a different direction. Once the trucker accepts a shipment, they load the containers and start the journey to their next destination, effectively starting the process over again.

The assumptions made in the models are as follows. We assume that the hubs have infinite capacity for truckers and shipments, and are positioned around the four axis of a perimeter highway to a city. This highway is similar in size to I-285 around Atlanta. We assume the trucks are able to travel at about 60 miles per hour and that each quarter of the highway is about 15 miles long. Thus, travelling from one zone of hubs to the next will take a trucker about 15 minutes. We also assume that the distance between the perimeters of two cities is 250 miles. For our models, we also set the time waiting threshold for a trucker to 30 minutes, before they are willing to take a shipment heading in a different direction.

The KPI's that we observed for each topology focused on the truckers were, distance travelled, time in hub and percentage departing in non-preferred direction. The KPI that we observed for the shippers is the shipment time from hub. The KPI that we observed for the hub operators is the number of shipments in hub. This is defined as the number of shipments in the hub within the hub waiting to be picked up by a trucker and taken to their next destination. We ran each model ten times for a time period of one week, with a warmup period of 50 hours so that the hubs could become saturated with truckers and containers. We also ran each model under a low flow and high flow scenario with each source generating a truck according to an exponential random variable with a mean time of 15 minutes and 30 seconds respectively. This was done to get a sense of how extreme differences in flow volumes would affect the KPI's under the different topologies.

Tables 1 and 2 show the results of our simulation experiment, respectively for low and high flow scenarios.

Table 1: Results from low flow scenario

Topology	***Avg. Dist Travelled***	***Avg. # Shipments in Hub***	***Avg. Truck Time In Hub (mins)***	***Avg. % of Truckers Departing in Non-Preferred Direction***	***Avg. Shipment Time In Hub (hrs)***
Single Hub	*261*	*145*	*5.4*	*0.48%*	*1.85*
Disconnected Multi Hub	*270*	*99*	*28.2*	*63.08%*	*5.03*
Disconnected Hub Zones	*270*	*99*	*28.2*	*63.02%*	*4.95*
Interconnected Multi Hub	*280*	*98*	*30.6*	*73.71%*	*4.66*
Interconnected Hub Zones	*272*	*73*	*29.4*	*71.64%*	*7.93*

Table 2: Results from high flow scenario

Topology	***Avg. Dist Travelled***	***Avg. # Shipments in Hub***	***Avg. Truck Time In Hub (mins)***	***Avg. % of Truckers Departing in Non-Preferred Direction***	***Avg. Shipment Time In Hub (hrs)***
Single Hub	*261*	*2,705*	*4.8*	*0%*	*1.13*
Disconnected Multi Hub	*270*	*7,909*	*20.4*	*22%*	*13.54*
Disconnected Hub Zones	*270*	*8,473*	*19.2*	*18%*	*14.11*
Interconnected Multi Hub	*272*	*7,319*	*23.4*	*33%*	*13.14*
Interconnected Hub Zones	*271*	*4,175*	*21*	*26%*	*14.42*

We have also gathered the data into 6 charts for comparative purposes. Figures 5 to 7 show the results for each topology under low flow and high flow scenarios.

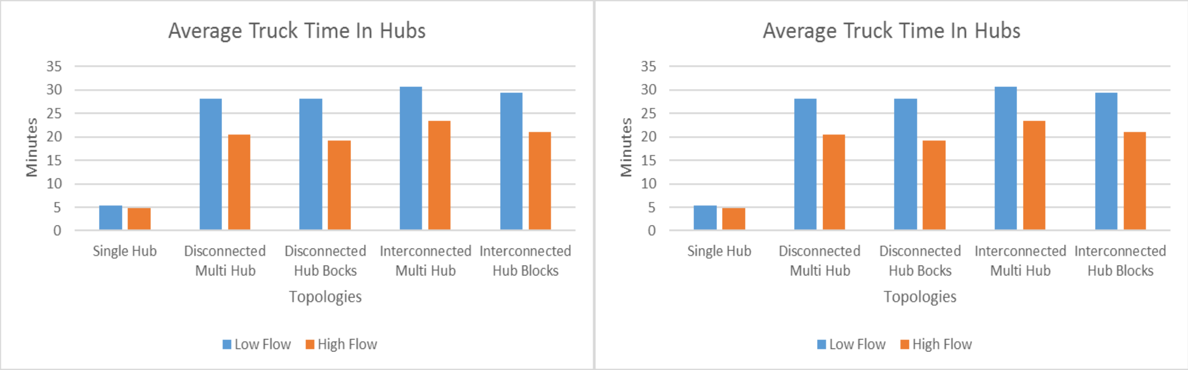


Figure 5: Average Driver Distance Travelled (Left) and Average Trucker Time in Hubs (Right)

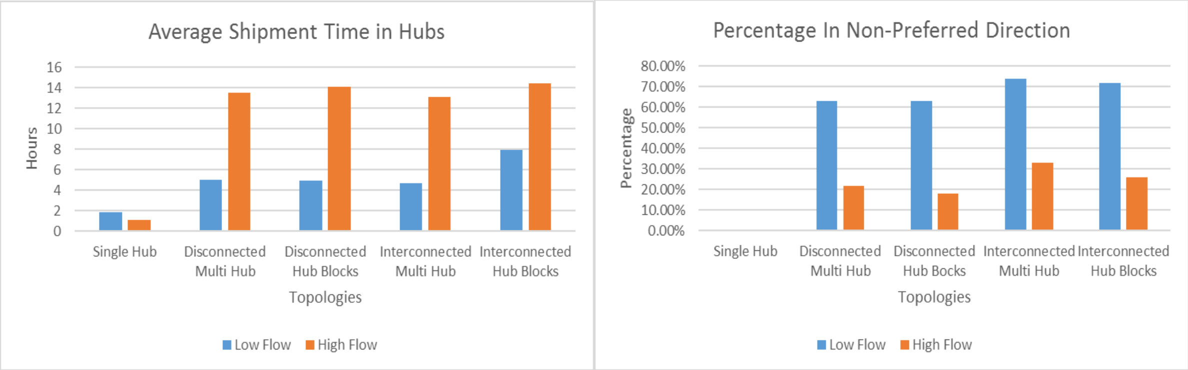


Figure 6: Average Shipment Time in Hubs (Left) and Average Percentage of Truckers Taking Loads in Non-Preferred Direction (Right)

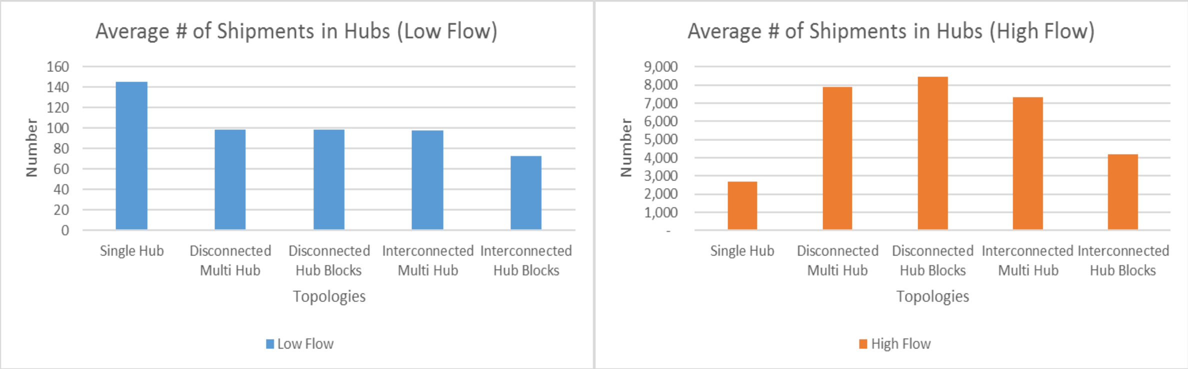


Figure 7: Average Number of Shipments in Hubs under Low Flow Scenario (Left) Average Number of Shipments in Hubs under High Flow Scenario (Right)

From our results, we can see that according to our simulation-based investigation, under the low flow scenario, the single hub topology would be preferred. This is because the average time in hub for both shippers and truckers is much shorter and almost no trucker ever departed in a non-preferred direction. This result makes sense, because under the same rate of flow, the multi-hub and hub-zone scenarios would spread the shipments out too thin acoss the hubs, and so at each hub it would take longer for shipments heading in the driver's preferred direction to appear. This is what caused the leap in average time in hubs and percentage departing in on-preferred direction between the single hub topology and the multi-hub and hub bock topologies.

However, when we examine the multi-hub and hub zone topologies under high-flow, as we would expect, the percentage of truckers departing in non-preferred directions and average truck time in hubs sharply decreases compared to the low flow scenario. This is because we now are starting to have enough flow through the hubs so that shipments heading in the driver's preferred direction appear more frequently.

What we see that at first seems counterintuitive, is that for the multi-hub and hub zones topologies, under the high flow scenario, the average number of shipments in hubs and the average shipment time in hubs greatly increases compared to the low flow. What is happening here is that because we do not have a capacity limit set for the hubs, the number of shipments can build up. We also do not have a time limit set on how long a shipment can wait until it is expedited, thus a shipment can wait for many hours before a trucker picks it up. Also, do not allow truckers to travel to a different hub to pick up their return load, which would help reduce this buildup of shipments.

Still under the high flow scenarios, the single hub topology has the shortest average time in hubs for truckers and shipments and no truckers departing in a non-preferred direction, but this makes sense, because there is so much demand for truckers that they can always find a shipment heading in their preferred direction. In a more realistic setting, however, one hub would challenged to be able to efficiently handle such a large flow of truckers and shipments and so a multi-hub or hub-zone topology would make more sense.

We also notice that in the interconnected multi-hub and hub -one topologies, the truckers in the low flow scenario were willing to travel farther and to more hubs than in the high flow scenario, so that they could find loads. This further supports our observation that in the low-flow scenario, single-hub topology would be preferrable because there is not enough flow to support mutiple hubs or hub zones.

Finally, we observe that in interconnected multi-hub and hub zones topologies, the truckers are allowed to travel to more hubs making deliveries which allows them to ideally deliver the shipments to hubs located closer to their next destination so the shipments spend less time in transit.

7 Conclusion

In conclusion, in order to further develop the Physical Internet and bring it to reality, we explored the interactions between PI hubs and other key Physical Internet players. Specifically, we examined how demand for hub services would be split over the competing hubs in the peri-urban region of a city. To do this, we described the main players of interest; the shippers, the truckers and the hub operators. Then we developed their objectives and decision processes, and examined these processes under five different hub topologies. As a further investigation, we ran a simulation of the topologies and discussed the results.

The topologies and scenarios presented in this paper have never before been explored. So far, the concepts of splitting demand between competing PI Hubs within the same region have not been studied. As such, our research is important as a basis to build upon, with the goal of creating a full description of the processes and operating models of PI Hubs. This in turn will further the progress towards a mature realization of the Physical Internet.

We believe the key learnings are that in a low flow scenario, it makes the most sense to operate under a single-hub topology. This is because when the flow of shipments is not large enough, a multi-hub topology will cause much greater hub waiting times and larger percentages of truckers to depart in non-preferred directions. However, in a high-flow scenario, when there are enough shipments to efficiently disperse them among multiple hubs, we believe that allowing truckers and shipments to visit multiple hubs, as in the interconnected topologies, will allow truckers to deliver shipments to hubs closer to their destination, thereby reducing travel time.

The key limitations of our research are that we did not place hub capacity limits on the number of truckers and shipments, nor capacity related efficiency and responsiveness correlations, and we did not allow for expediting of shipments if their waiting time exceeded a certain threshold. These limitations caused us to see very large average shipment times in hubs and number of shipments in hubs.

Given our key learnings and key limitations, the research in this paper provides good insight into the basic interactions between the players involved with PI Hub operations, and presents many future research avenues.

A first avenue to be explored is the case where capacity limits are in place on the number of trucks and shipments able to utilize a hub. This will give us a more accurate picture of the levels of flow at which it makes sense to transition from a single hub topology to a multi-hub topology, and will allow us to observe hub utilization.

Another avenue is to analyze the effect of pricing on the decisions of the shippers and truckers. In this scenario, truckers might charge more to go to less desirable PI Hubs, and shippers could arrange deals with hub operators to gain bulk discounts for large quantities of shipments sent through their hub. This is an interesting direction because it starts to explore business scenarios necessary for understanding how to operate a PI Hub, in the spirit of the conceptual work performed by Oktaei et al. (2015).

Lastly, another avenue of research is to examine the set of topologies where PI Hubs around a city collaborate. In this scenario, a truck coming in from the East, for example, would always go to the East Hub, then the shipments would travel on a smaller inter-hub truck to the PI Hub closest to its destination location. Then, from that PI Hub, it would depart the city on a truck towards its destination. We believe this to be a rich area for exploration because open consolidation and asset sharing are at the heart of the Physical Internet.

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Towards the Physical Internet with Coloured Petri Nets

Angela Di Febbraro[1], Davide Giglio[1] and Nicola Sacco[1]
[1]DIME – University of Genova, Genova, Italy
Corresponding author: davide.giglio@unige.it

Abstract: *Coloured Petri Nets can be a valuable and powerful tool to design, analyse, and control the subsystems composing the Physical Internet, as they are able to capture the precedence relations and interactions among events which characterize the facilities and infrastructures (multimodal logistics centres and hubs, transit centres, roads and railways) through which π-containers are delivered. In this paper, the use of Coloured Petri Nets in the field of the Physical Internet is discussed and an example of the application of such a modelling tool to a multimodal hub in the PI is provided. The multimodal hub consists of four areas: a port area at which vessels arrive and depart, a train terminal for rail transportation, a road terminal for truck-to-X (and vice-versa) transhipment, and a storage area. The storage area and the road terminal are considered in detail, and two nets representing a section of a π-conveyor and a π-sorter/π-composer are proposed to illustrate the applicability of the CPN formalism to the Physical Internet paradigm.*

Keywords: *multimodal hubs; π-containers management; modelling tools; coloured Petri nets; simulation tools*

1 Introduction

In the next decades, the road to the Physical Internet (PI) will change drastically most of the production and logistic processes that actually characterize the supply chain. New multimodal logistic centres able to handle modular containers, open networks in which the various actors of the supply chain share transport services, delivery of disaggregated goods through alternate paths in analogy with data packets transmitted through the digital internet, are some of the newly features provided by the PI (Montreuil, 2011). In this framework, technicians and scientists are working together to provide enabling technologies and powerful ICT services, and a big challenge of researches is to provide effective modelling tools which allow analysing the performance of such kind of interoperating systems.

Most of the subsystems composing the PI are actually discrete-event systems (DESs) as they are characterized by the presence of concurrent and asynchronous events which influence their states (Cassandras and Lafortune, 2010). Among the modelling tools for DESs, Petri nets (PNs) have been proven to be a valuable and powerful tool for design, analysis, and control of DESs (Murata, 1989). PNs have been defined in the 1960s by Carl Adam Petri (Petri, 1962) and since then hundreds of researchers have adopted such a modelling tool to represent, analyse and control specific classes of DESs such as manufacturing and production systems (Desrochers, 1990; DiCesare et al., 1993, Zhou and DiCesare, 1993), communication protocols (Suzuki et al. 1990; Berthomieu and Diaz, 1991; Billington and Han, 2007), indoor transportation and outdoor traffic systems (Castillo et al., 2001; Ng et al., 2013, Di Febbraro et al., 2016), and so on. Among the applications of PNs, the digital internet and the flow of data packets through the net have been often considered in the literature. When switching from the digital world to the physical one, from data packets through the net to physical goods in a logistic system, PNs can be still a valuable modelling formalism and an efficient tool to analyse the performance of the system. Indeed, focusing the attention towards the physical internet, Petri nets seems particularly appropriate to represent the dynamics of π-containers within the PI, as they are able to capture the precedence relations and interactions among events which characterize the facilities and infrastructures (multimodal logistics centres and hubs, transit centres, roads and railways) through which π-containers are delivered. Among the several classes of Petri nets that have been defined in the past, Coloured Petri Nets (CPNs; Jensen and Kristensen, 2009) are especially suitable to model the different kinds of π-containers and the operations required by them and carried out by PI facilities such as π-movers, π-conveyors, π-stores, and so on.

Since their introduction in early ’80s, CPNs have been extensively adopted to model the behavior of complex systems, and several examples can be found in the fields of manufacturing (such as Feldmann and Colombo, 1998; Hsieh and Chen, 1999; Chen and Chen, 2003; Dotoli and Fanti, 2004; Baruwa et al., 2015) and transportation (such as DiCesare et al., 1994; van der Aalst and Odijk, 1995; Dotoli and Fanti, 2006; Huang and Chung, 2008). For what concerns the specific field of logistics, the use of CPNs to model and analyse logistic system has been considered since early 1990s (van der Aalst, 1992) and a review of Petri net-based approaches (including those relevant to CPNs) for logistic system has been proposed in Chen et al. (2006). In van der Vorst et al. (2000), a generic food supply chain is considered and the timed CPN defined by the authors is used to simulate the model; the simulation of a logistic and manufacturing system with CPNs is considered also in Piera et al. (2004) with the objective of optimizing the performance of the system, whereas in Hanafi et al. (2007) the formalism of Fuzzy CPNs is employed to forecast the volumes of returns in a reverse logistics scenario. In Gallash et al. (2008) a CPN is used to model a military logistics system. In Zhang et al. (2009) the coloured Petri net is adopted to configure a supply chain on the basis of customer orders. Optimization through simulation by adopting the CPN formalism is again considered in Narciso et al. (2010), and supply chains are further considered in Zegordi and Davarzani (2012) in which the Petri net model is used to analyse the impact of disruption events. Two recent works are Zhao et al. (2015) and Park et al. (2016), that are both relevant to the simulation of a port logistics system by exploiting a CPN model of the system.

In this paper, CPNs are applied to a multimodal hub in the PI, with the aim of providing a formal model to be used for analysis and optimization purposes. The multimodal hub consists of four areas: a port area at which vessels arrive and depart, a train terminal for rail transportation, a road terminal for truck-to-X transhipment, and a storage area. The rail and the road terminals are equipped with specific devices (e.g., π-composers) in order to facilitate the load and unload operations of trains and trucks; the storage area includes a finite number of π-stores and the four areas are connected through π-conveyors and/or π-movers. In the paper, the storage area and the road terminal are specifically taken into consideration, and the two coloured Petri nets representing an example of π-conveyor and an example of π-sorter/π-composer are described in detail.

The structure of the multimodal hub here considered has been inspired by the Physical Internet Manifesto (Montreuil, 2012) and by its subsequent work about the impact of adoption of the PI on logistics facilities (Montreuil, 2011). In recent years, the interest on the Physical Internet has grown and many works appeared in the literature aimed at formalizing the working principles of items and resources involved in a PI, both from the technological point of view and from the logical/functional one. The formalization of π-containers, their movements and storage within a PI, and the way they can be merged into larger composed containers, have been considered in Landschützer et al. (2015) and Montreuil et al. (2016) that provide several examples of π-containers and also report some results coming from the European project MODULUSHCA; the active role of π-containers within next-generation supply chains is also discussed in Sallez et al. (2016). Instead, for what concerns PI facilities, the physical elements serving as the foundation of the Physical Internet infrastructure have been introduced for the first time in Montreuil et al. (2010), whereas the functional design of specific kinds of hubs and transit centres have been taken into account in Ballot et al. (2014), Meller et al. (2014), and Montreuil et al. (2014).

The proposed model can be used, in general, both for analysing the structural properties of the system (first of all, to check if the system is deadlock-free or not) and to optimize some parameters of the system (via simulation, that is, by using the PN as an intermediate model between real world and simulation tools). However, it is worth observing that the primary aim of this paper is to show the applicability of the Petri net formalism to the Physical Internet paradigm, without being exhaustive. Besides, according to our best knowledge, this is the first work on the application of Petri nets to the Physical Internet.

2 The model of the multimodal hub

The multimodal hub consists of π-nodes and π-movers which interact with the objective of optimizing logistics operations on the standardized π-containers. The part of the multimodal hub considered in this paper is illustrated in Figure 1.

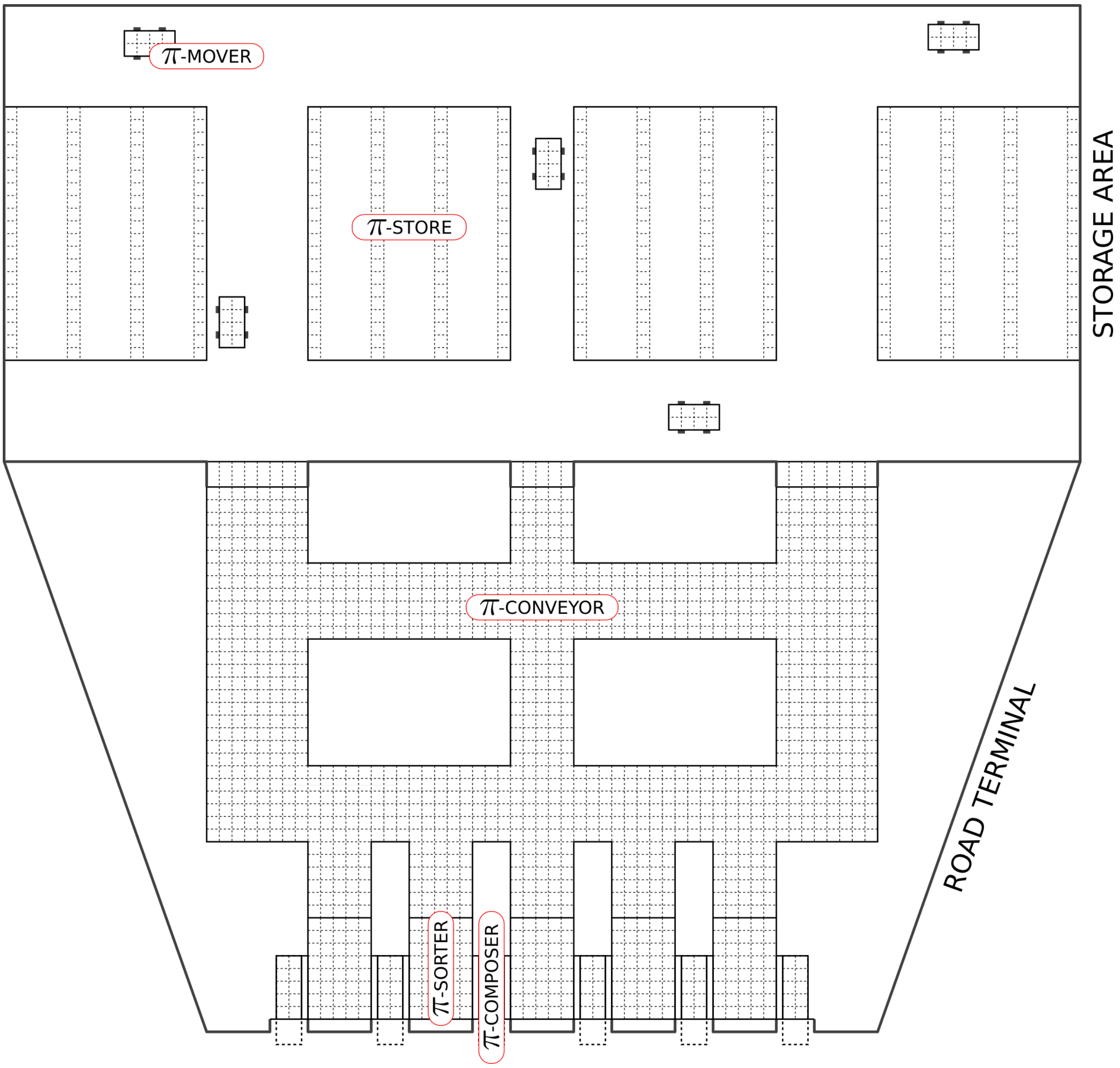
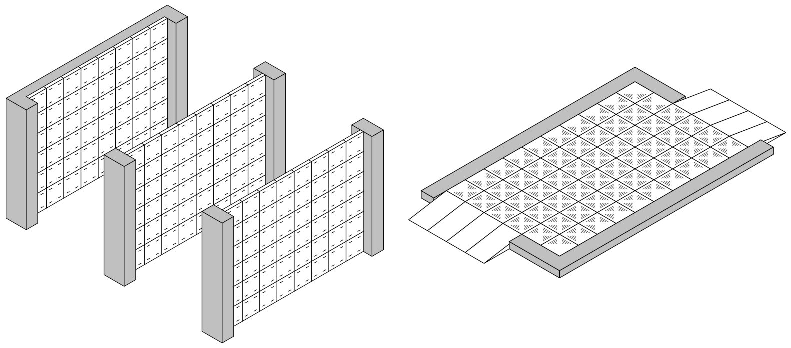


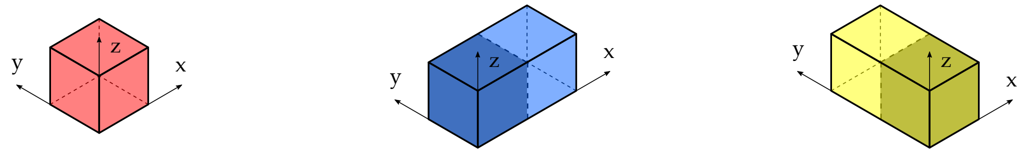
Figure 1: Sketch of the system layout.



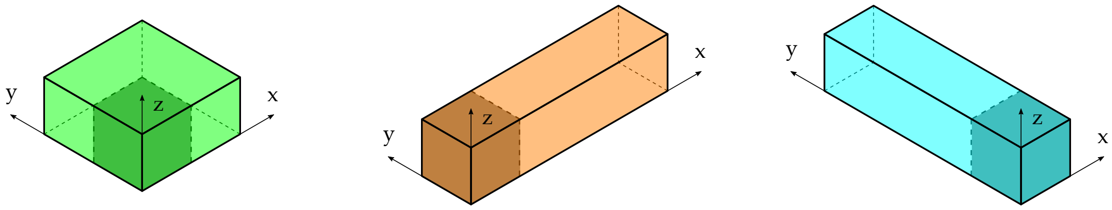
(a) (b) (c)

Figure 2: Details of the physical model of (a) π-store, (b) π-conveyor, and (c) π-sorter.

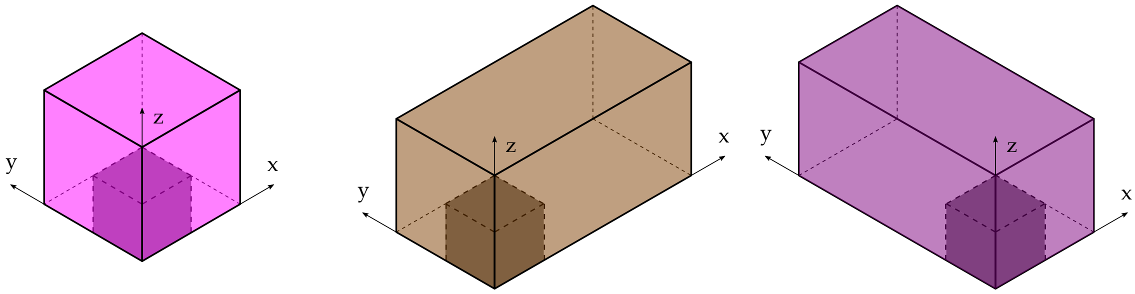
The storage area consists of some snapping π-stores which are served by a set of automated-guided π-movers which handle the π-containers from the storage area to the road terminal; an example of π-store here considered is in Figure 2(a). Within the road terminal items are handled with a π-conveyor which moves the π-containers from the border of the storage area to the π-sorters which manage the π-containers of the various sizes so that they can be aggregated by means of the π-composer and delivered by road with a π-carrier. An example of a section of the π-conveyor is reported in Figure 2(b) whereas Figure 2(c) illustrates the physical part including a π-sorter and two π-composers. The section of the π-conveyor and the π-sorter with the two π-composers will be represented with Coloured Petri Nets in Section 3.



(a) size 111: 2.4x2.4x2.4 m^3 (b) size 211: 4.8x2.4x2.4 m^3 (c) size 121: 2.4x4.8x2.4 m^3



(d) size 221: 4.8x4.8x2.4 m^3 (e) size 411: 9.6x2.4x2.4 m^3 (f) size 141: 2.4x4.8x2.4 m^3



(g) size 222: 4.8x4.8x4.8 m^3 (h) size 422: 9.6x4.8x4.8 m^3 (i) size 242: 4.8x9.6x4.8 m^3

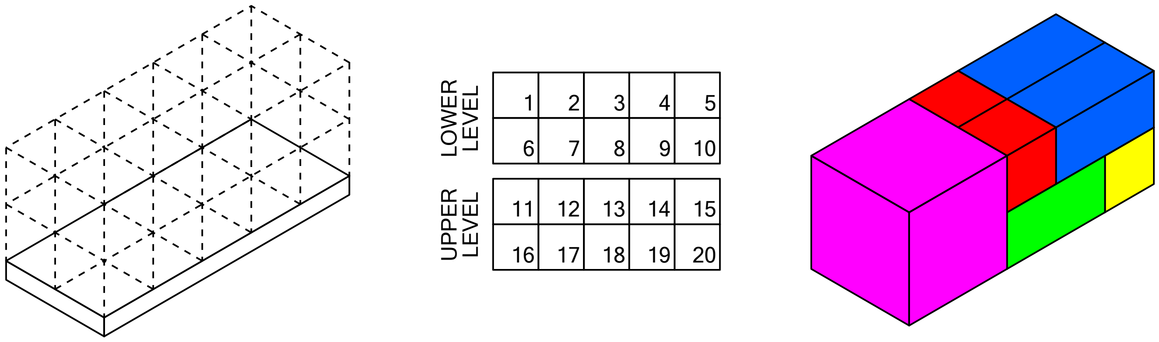
Figure 3: Types of π-containers.

In this paper, 9 sizes of π-containers are taken into consideration; they are illustrated in Figure 3. It can be assumed that smaller π-containers (such as those with sizes ranging from 0.12 m to 0.6 m), if present, are suitably encapsulated within the π-container of Figure 3(a) that, in the following, will be often referred to as "π-container of unitary size" or "basic π-container" (instead, for what concern larger π-containers, the proposed approach can be easily generalized in order to take into account π-containers of any standardized size). Moreover, it can be observed that the second and the third type of π-containers (provided in Figures 3(b) and 3(c), respectively), the fifth and the sixth (Figures 3(e) and 3(f)), and the eighth and the ninth (3(h) and 3(i)) have the same size; in this work, they are considered as different in order to help the representation of the system dynamics with Petri nets. Finally, the concept of "π-core" is here introduced; basically, the π-core is the "dark cube" of unitary size which is inside the π-containers of Figures 3(b)÷3(i); as illustrated, the π-core is conventionally located at the origin of the 3-dimensional Cartesian axes which identify the size and orientation of a π-container.

2.1 π-core

In the new logistics facilities and material handling systems that are compatible with the PI paradigm, many π-nodes and π-movers will be built exploiting the concept of π-cell, that is, a "structure" of unitary size that, for example, can help π-containers to move along the π-conveyors or can allow π-containers to hold on to the racks of a π-store. It is evident that all the resources depicted in Figure 1 and Figures 2(a), 2(b), and 2(c) (π-stores, π-movers, π-conveyor, π-sorters and π-composers) are made of several cells. When a π-container uses one of such resources, it occupies one or more cells: a π-container of unitary size occupies a single cell whereas larger π-containers occupy 2, 4, or 8 cells, depending on their size.

In the proposed CPN model[1], the concept of π-core allows representing a π-container with a single coloured token, keeping in this way the model simple. As it will be shown in the following section, each π-cell is represented by a place and a coloured token inside the place means that the π-core of a π-container with size specified by the colour of the token is occupying the π-cell.



(a) (b) (c)

Figure 4: π-containers (composed): (a) structure, (b) logical scheme, and (c) example.

2.2 π-container (composed)

Another fundamental aspect in the Physical Internet paradigm is the possibility of composing containers of standard size by suitably attaching π-containers of different sizes. In this paper, it is assumed that the trucks leaving the road terminal carry containers whose size is 12x4.8x4.8 m^3 which corresponds to the composition of 20 π-containers of unitary size or a lower number of larger π-containers. In Figure 4(c) a container composed by one π-container of size 222, one of size 221, one of size 121, two of size 111, and two of size 211 is illustrated.

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[1] It is assumed that the reader has a basic knowledge of the Petri net formalism; otherwise, he/she can refer to Murata (1989) for a detailed presentation of PN's definitions, rules, and properties. Instead, for what concerns Coloured Petri Nets, the reader can refer to Jensen and Kristensen (2009). In any case, the definition of the adopted class of CPNs is given in Section 3.

In the proposed CPN representation, the composed container will be modelled with a single coloured token whose colour is a vector of elements describing the way the container is composed. Such a vector contains 20 elements and its i-th element correspond to the i-th cell of the logical scheme illustrated in Figure 4(b). Each element of such a vector can be either 0 or one of the allowed sizes (namely, 111, 211, 121, and so on): in the latter case, it means that a π-container of the specified size has its π-core in the i-th cell. As an example, the composed container illustrated in figure 4(c) is represented by the following vector:

$$(0,0,0,0,0,222,0,221,0,121,0,0,111,211,0,0,0,111,211,0)$$

that corresponds to the scheme

0	0	0	0	0
222	0	221	0	121

LOWER LEVEL (cells #1÷#10)

0	0	111	211	0
0	0	111	211	0

UPPER LEVEL (cells #11÷#20)

in which the magenta π-container of size 222 has its π-core in cell #6 (lower level), the green π-container of size 221 has its π-core in cell #8 (lower level), the yellow π-container of size 121 has its π-core in cell #10 (lower level), the two red π-containers of size 111 have their π-core in cells #13 and #18 (upper level), and the two blue π-containers of size 211 have their π-core in cells #14 and #19 (upper level).

In connection with composed containers, it is also necessary to know the sequence of loads of the single π-containers carried out by the π-composer. Such a piece of information is used in the CPN representation to define the guard functions of some transitions in the CPN which models the π-composer, and can be defined as an ordered sequence of integer numbers in the range $[1,20]$; in this way, a number i in the j-th position of the sequence means that the π-container whose π-core has to be placed in the i-th cell of the composed container must be the j-th in the loading sequence. As an example, the sequence of loads for the composed container illustrated in Figure 4(c) is $(6,8,10,18,13,19,14)$. It is worth noting that, all possible loading sequences can be a-priori defined on the basis of the allowed structures of composed containers.

3 CPN representation

In this paper, two Coloured Petri Nets are proposed with the aim of showing the applicability of such formalism to an example of multimodal hub compatible with the Physical Internet paradigm. The first net is relative to a generic section of the π-conveyor whereas the second net models one of the available π-sorter/π-composer. In both cases, the behaviour of the CPN is illustrated through an example. The adopted class of CPN is the following.

Definition 1 (Jensen and Kristensen, 2009) – A (non-hierarchical) Coloured Petri Net is a nine-tuple $CPN = (P, T, \mathcal{A}, \Sigma, \mathcal{V}, \mathcal{C}, G, E, I)$, where:

1. P is a finite set of places;
2. T is a finite set of transitions ($P \cap T = \emptyset$);
3. $\mathcal{A} \subseteq P \times T \cup T \times P$ is a set of directed arcs;
4. Σ is a finite set of non-empty colour sets;
5. $\mathcal{V}$ is a finite set of typed variables such that $\mathrm{Type}[v] \in \Sigma$ for all variables $v \in \mathcal{V}$;
6. $\mathcal{C}: P \to \Sigma$ is a colour set function that assigns a colour set to each place;
7. $G: T \to \mathrm{Expr}_V$ is a guard function that assigns a guard to each transition t such that $\mathrm{Type}[G(t)] = \mathrm{Bool}$ (true/false);
8. $E: A \to \mathrm{Expr}_V$ is an arc expression function that assigns an arc expression to each arc a such that $\mathrm{Type}[E(a)] = \mathcal{C}(\mathrm{p})_{MS}$, where p is the place connected to the arc a;
9. $I: P \to \mathrm{Expr}_\emptyset$ is an initialization function that assigns an initialization expression to each place p such that $\mathrm{Type}[I(p)] = \mathcal{C}(\mathrm{p})_{MS}$.

Some guard functions and arc expressions, as well as the set of typed variables and the colour set functions, will be defined in subsections 3.1 and 3.2 for the coloured Petri nets representing the π-conveyor and the π-sorter/π-composer. Instead, for what concern the colours sets, they are relevant to the size of π-containers and to the structure of composed containers leaving the road terminal; then,

$$\Sigma = \{\mathrm{BSIZE}, \mathrm{BSIZE0}, \mathrm{STRUCT}\} \tag{1}$$

with

$$\mathrm{BSIZE} \;= \{111,211,121,221,411,141,222,422,242\} \tag{2}$$

$$\mathrm{BSIZE0} \;= \mathrm{BSIZE} \cup \{0\} \tag{3}$$

$$\mathrm{STRUCT} = BSIZE0^{20} = \mathrm{BSIZE0} \times \mathrm{BSIZE0} \times \mathrm{BSIZE0} \times \ldots \times \mathrm{BSIZE0} \times \mathrm{BSIZE0} \text{ (20 times)} \tag{4}$$

3.1 π-conveyor

The considered section of the π-conveyor is illustrated in Figures 5 (physical model) and 6 (logical representation). The flow of π-containers is both from left to right and vice-versa but they can also change position by moving up and down (in order to optimize the flow of goods on the conveyor). The entry points are located in the example in the top left part and in the bottom right part areas, but any border cell can be a cell of entrance to the conveyor. In any case, apart from borders, π-containers can move freely when handled by the π-conveyor.

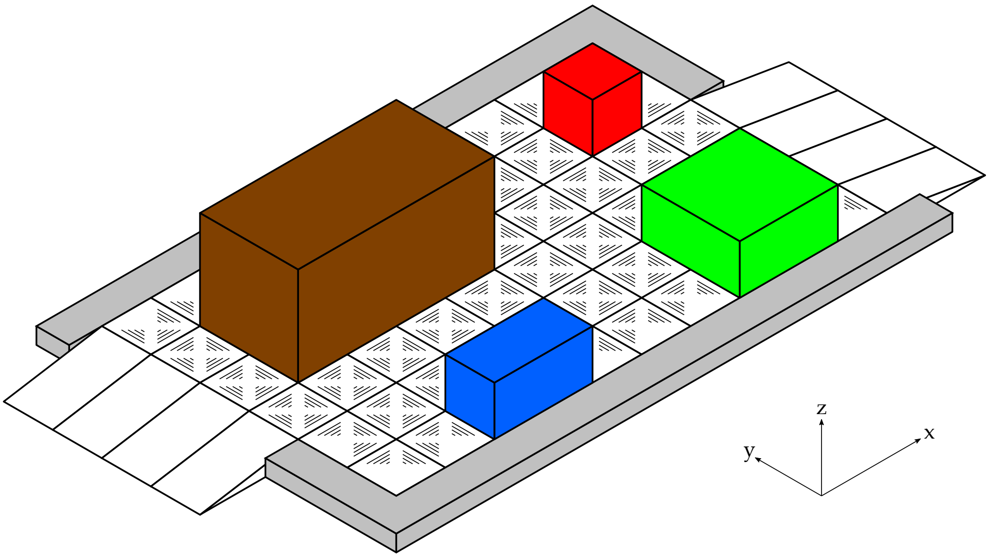


Figure 5: Physical model of a section of the π-conveyor.

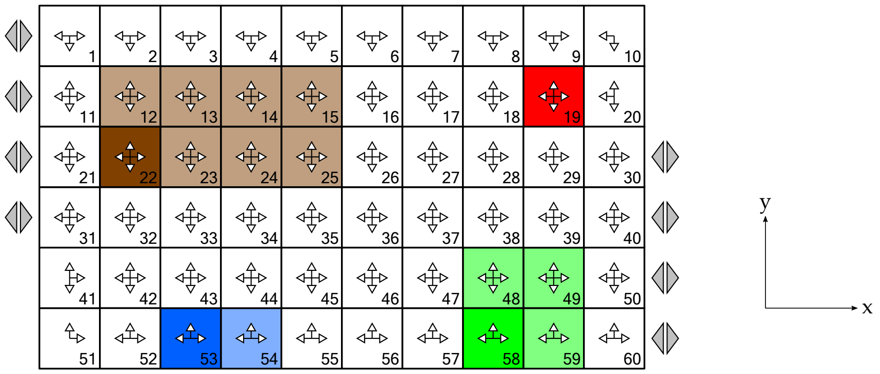


Figure 6: Logical representation of a section of the π-conveyor.

Such a model is represented by means of the coloured Petri net illustrated in Figure 7. Each place represents a cell of the π-conveyor and a token in a place means that a π-container has its π-core over the cell. It is obvious that, depending on the type (size) of the π-container, other adjacent cells are occupied by the π-container, even if the corresponding places have no token. As an example, the brown π-container in Figure 5 has its π-core over the cell #22 but it occupies also cells #12÷15 and #23÷25; in the CPN, a token with colour 422 is inside place p_{22} but also places p_{12}÷p_{15} and p_{23}÷p_{25} are "virtually marked" in the sense that no token (representing a different π-container) can enter such places. This is ruled by the guard functions associated with the transitions of the CPN. Each transition models the movement of the π-core of a π-container to one of the four adjacent cells (less than four in the border cells), that is, towards east, north, west, south. The token game models the movements of π-containers over the π-conveyor.

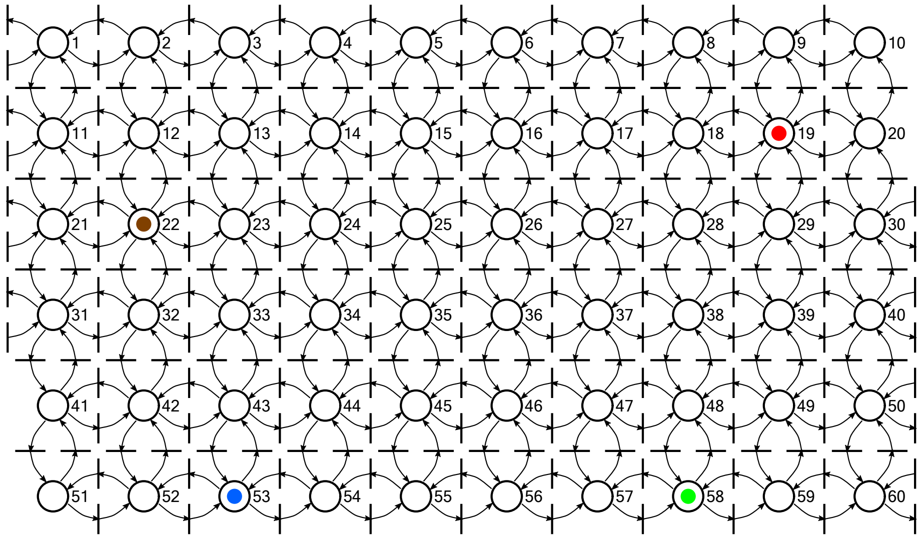


Figure 7: CPN representing the section of the π-conveyor.

The colour set functions, the set of typed variables, the arc expressions, and the guard functions are reported in the following.

$$\mathcal{C}(p_h) = \mathrm{BSIZE}\,, \forall h = 1, \dots, 60 \tag{5}$$

$$\mathcal{V} = \{b_h\text{:BSIZE}; h = 1, \dots, 60\} \tag{6}$$

$$\mathrm{E}(p_h, t_{h-k}) = 1'b_h\,, \forall h, k = 1, \dots, 60 \tag{7}$$

$$\mathrm{E}(t_{h-k}, p_k) = 1'b_h\,, \forall h, k = 1, \dots, 60 \tag{8}$$

$$\begin{aligned}\mathrm{G}(t_{h-k}) = {} & [(b_h = 111)\wedge(\mathrm{C}_{h-k-111})]\vee[(b_h = 211)\wedge(\mathrm{C}_{h-k-211})]\vee[(b_h = \\ & 121)\wedge(\mathrm{C}_{h-k-121})]\vee[(b_h = 221)\wedge(\mathrm{C}_{h-k-221})]\vee[(b_h = 411)\wedge(\mathrm{C}_{h-k-411})]\vee[(b_h = \\ & 141)\wedge(\mathrm{C}_{h-k-141})]\vee[(b_h = 222)\wedge(\mathrm{C}_{h-k-222})]\vee[(b_h = 422)\wedge(\mathrm{C}_{h-k-422})]\vee[(b_h = \\ & 242)\wedge(\mathrm{C}_{h-k-242})]\,, \forall h, k = 1, \dots, 60\end{aligned} \tag{9}$$

The guard function defined in (9) shows that the firing of a transition depends on the colour of the token in the corresponding input place. In fact, it is evident that the possibility of moving a π-container whose π-core is over a certain cell changes with the size of the π-container itself. As an example, the brown π-container with the π-core in cell #22 can move eastbound if cells #16 and #26 are free and can move southbound if cells #32, #33, #34, and #35 are free; instead, in the case that the π-container with the π-core in cell #22 is blue (with size 211), then it can move eastbound if cell #24 is free and can move southbound if cells #32 and #33 are free. In this connection, C_{h-k-s} is the Boolean condition to make transition t_{h-k} fireable when a token of colour s is within place p_h.

(a) (b)

Figure 8: Detail of the CPN representing the section of the π-conveyor: movement from cell #22 to cells #23 (eastbound) and #32 (southbound).

In the following, some of these Boolean conditions are reported. They are relative to the places p_{22}, p_{23}, p_{32} and transitions t_{22-23}, t_{22-32}, as illustrated in Figure 8(a) and 8(b) where, for the sake of brevity only two colours (sizes) are considered: 422 (brown π-container) and 211 (blue π-container). The condition $\mathrm{C}_{22-23-422}$ take into consideration all the cases in which cells #16 and #26 are free, that is, all the cases in which places p_{16} and p_{26} are neither marked nor "virtually marked". $\mathrm{C}_{22-32-422}$ is relative to the move towards south and then it considers all the cases in which places p_{32}, p_{33}, p_{34}, and p_{35} are neither marked nor "virtually marked". Conditions $\mathrm{C}_{22-23-211}$ and $\mathrm{C}_{22-32-211}$ report the cases in which p_{24}, and p_{32}, p_{33}, respectively, are neither marked nor "virtually marked".

$$\mathrm{C}_{22-23-422} = [(\mathrm{b}_{16} \neq 111)\vee(\mathrm{b}_{16} \neq 121)\vee(\mathrm{b}_{16} \neq 211)\vee(\mathrm{b}_{16} \neq 221)\vee(\mathrm{b}_{16} \neq 411)\vee(\mathrm{b}_{16} \neq 222)\vee(\mathrm{b}_{16} \neq 422)]\wedge[(\mathrm{b}_{26} \neq 111)\vee(\mathrm{b}_{26} \neq 121)\vee(\mathrm{b}_{26} \neq 211)\vee(\mathrm{b}_{26} \neq 221)\vee(\mathrm{b}_{26} \neq 411)\vee(\mathrm{b}_{26} \neq 222)\vee(\mathrm{b}_{26} \neq 422)]\wedge[(\mathrm{b}_{36} \neq 121)\vee(\mathrm{b}_{36} \neq 221)\vee(\mathrm{b}_{36} \neq 141)\vee(\mathrm{b}_{36} \neq 222)\vee(\mathrm{b}_{36} \neq 422)\vee(\mathrm{b}_{36} \neq 242)]\wedge[(\mathrm{b}_{46} \neq 141)\vee(\mathrm{b}_{46} \neq 242)]\wedge[(\mathrm{b}_{56} \neq 141)\vee(\mathrm{b}_{56} \neq 242)] \tag{10}$$

$$\mathrm{C}_{22-32-422} = [(\mathrm{b}_{31} \neq 211)\vee(\mathrm{b}_{31} \neq 411)]\wedge[(\mathrm{b}_{32} \neq 111)\vee(\mathrm{b}_{32} \neq 211)\vee(\mathrm{b}_{32} \neq 411)]\wedge[(\mathrm{b}_{33} \neq 111)\vee(\mathrm{b}_{33} \neq 211)\vee(\mathrm{b}_{33} \neq 411)]\wedge[(\mathrm{b}_{34} \neq 111)\vee(\mathrm{b}_{34} \neq 211)\vee(\mathrm{b}_{34} \neq 411)]\wedge[(\mathrm{b}_{35} \neq 111)\vee(\mathrm{b}_{35} \neq 211)\vee(\mathrm{b}_{35} \neq 411)]\wedge[(\mathrm{b}_{41} \neq 221)\vee(\mathrm{b}_{41} \neq 222)\vee(\mathrm{b}_{41} \neq 422)]\wedge[(\mathrm{b}_{42} \neq 121)\vee(\mathrm{b}_{42} \neq 221)\vee(\mathrm{b}_{42} \neq 222)\vee(\mathrm{b}_{42} \neq 422)]\wedge[(\mathrm{b}_{43} \neq 121)\vee(\mathrm{b}_{43} \neq 221)\vee(\mathrm{b}_{43} \neq 222)\vee(\mathrm{b}_{43} \neq 422)]\wedge[(\mathrm{b}_{44} \neq 121)\vee(\mathrm{b}_{44} \neq 221)\vee(\mathrm{b}_{44} \neq 222)\vee(\mathrm{b}_{44} \neq 422)]\wedge[(\mathrm{b}_{45} \neq 121)\vee(\mathrm{b}_{45} \neq 221)\vee(\mathrm{b}_{45} \neq 222)\vee(\mathrm{b}_{45} \neq 422)] \tag{11}$$

$$\mathrm{C}_{22-23-211} = [(\mathrm{b}_{24} \neq 111)\vee(\mathrm{b}_{24} \neq 121)\vee(\mathrm{b}_{24} \neq 211)\vee(\mathrm{b}_{24} \neq 221)\vee(\mathrm{b}_{24} \neq 411)\vee(\mathrm{b}_{24} \neq 222)\vee(\mathrm{b}_{24} \neq 422)]\wedge[(\mathrm{b}_{34} \neq 121)\vee(\mathrm{b}_{34} \neq 221)\vee(\mathrm{b}_{34} \neq 141)\vee(\mathrm{b}_{34} \neq 222)\vee(\mathrm{b}_{34} \neq 422)\vee(\mathrm{b}_{34} \neq 242)]\wedge[(\mathrm{b}_{44} \neq 141)\vee(\mathrm{b}_{44} \neq 242)]\wedge[(\mathrm{b}_{54} \neq 141)\vee(\mathrm{b}_{54} \neq 242)] \tag{12}$$

$$\mathrm{C}_{22-32-211} = [(\mathrm{b}_{31} \neq 211)\vee(\mathrm{b}_{31} \neq 411)]\wedge[(\mathrm{b}_{32} \neq 111)\vee(\mathrm{b}_{32} \neq 211)\vee(\mathrm{b}_{32} \neq 411)]\wedge[(\mathrm{b}_{33} \neq 111)\vee(\mathrm{b}_{33} \neq 211)\vee(\mathrm{b}_{33} \neq 411)]\wedge[(\mathrm{b}_{41} \neq 221)\vee(\mathrm{b}_{41} \neq 222)\vee(\mathrm{b}_{41} \neq 422)]\wedge[(\mathrm{b}_{42} \neq 121)\vee(\mathrm{b}_{42} \neq 221)\vee(\mathrm{b}_{42} \neq 222)\vee(\mathrm{b}_{42} \neq 422)]\wedge[(\mathrm{b}_{43} \neq 121)\vee(\mathrm{b}_{43} \neq 221)\vee(\mathrm{b}_{43} \neq 222)\vee(\mathrm{b}_{43} \neq 422)] \tag{13}$$

It is worth finally noting that C_{h-k-s} is set to "false" (or, equivalently, $\mathrm{C}_{h-k-s} = 0$) when a π-container of size s cannot be in correspondence of the h-th cell; for example, in the cell #22 it is not possible to have π-containers of size 141 and 242, and then $\mathrm{C}_{22-k-141} = 0$ and $\mathrm{C}_{22-k-242} = 0$ for any $k = 12{,}21{,}23{,}32$.

With the considered guard functions, all possible physical conflicts between π-containers are prevented, and thus the movements of coloured tokens within the CPN actually correspond to feasible movements of π-containers over the π-conveyor.

3.2 π-sorter/π-composer

The material handling system for the composition of containers of standard size to be delivered by road with trucks is here considered and modelled with a coloured Petri net. The structure illustrated in Figure 9 is taken into consideration: it consists of a π-sorter which handles π-containers and puts them in the correct position at the correct time in order to load them into one of the two π-composers (A and B) that are at opposite sides of the π-sorter[2]. The π-containers are loaded by following a strict order (loading sequence), and the π-container to be loaded can start its loading operation only when it has its π-core over the right cell. As an example, the seven π-containers that are included in Figure 9 have to be composed by the π-composer B (the one on the right side) to form the structure illustrated in Figure 4(c); this can be done by following the loading sequence reported in Table 1.

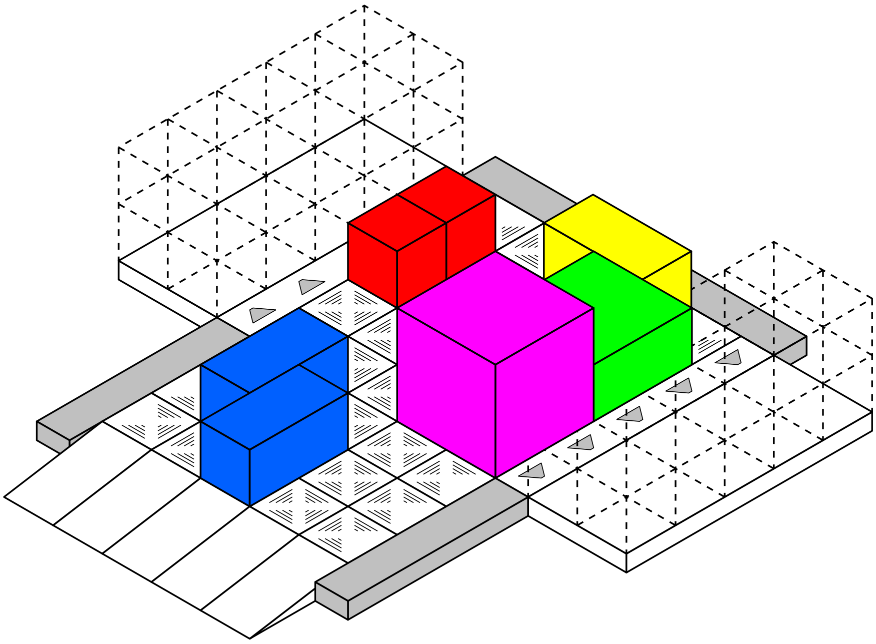


Figure 9: Physical model of a π-sorter with two π-composers.

Table 1: Loading sequence of the π-containers in Figure 9.

Sequence	π-container	π-core at start (cell #)	π-core at end (cell #)
1st	222 (magenta)	36	B6
2nd	221 (green)	38	B8
3rd	121 (yellow)	40	B10
4th	111 (red)	38	B18
5th	111 (red)	38	B13
6th	211 (blue)	39	B19
7th	211 (blue)	39	B14

---

[2] The problem of lifting the π-containers to the upper level of the π-composer is not addressed here, being out of the scope of this paper; as a matter of fact, it is here assumed that suitable handling systems exist and are able to move π-containers to any position of the π-composer.

In the loading sequence, also the destination cell for the π-core of the π-container which is loaded is reported in Table 1; letter B, obviously, refers to π-composer B, whereas the number correspond to the 3-dimensional cell structure defined in Figures 4(a) and 4(b). The final state of the material handling system π-sorter/π-composers is given in Figure 10.

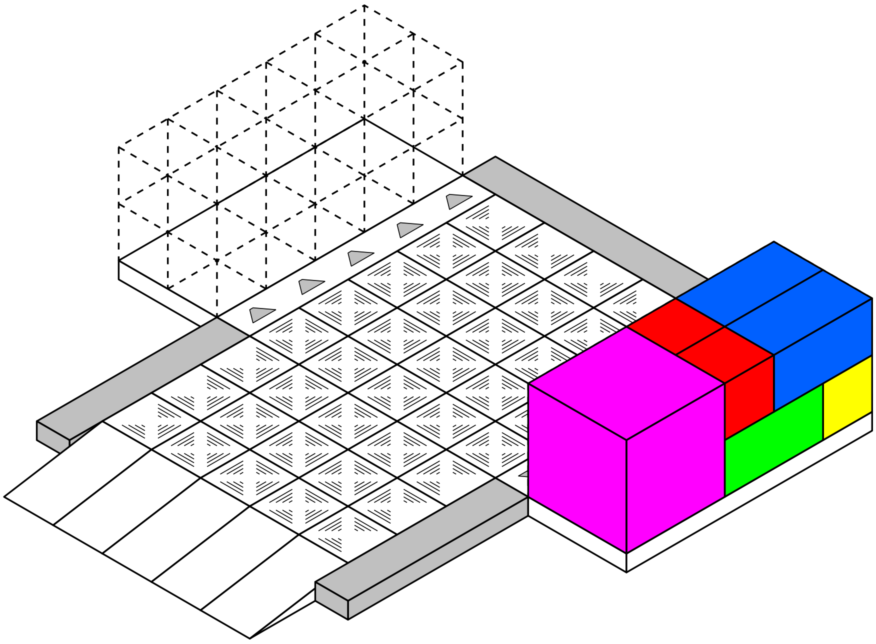


Figure 10: π-sorter/π-composer after the composition of a container.

Such a model is represented by means of the coloured Petri net illustrated in Figure 11. Places from p_1 to p_{40} represent the cells of the π-sorter and the transitions between these places model the movements of the π-core of π-containers from one cell to another; as a matter of fact, this part of the CPN has a mode of operation which is analogous to that of the CPN representing the π-conveyor.

The composition of a container is modelled with places from p_{41} to p_{60} and p_A (for the π-composer A) and from p_{61} to p_{60} and p_B (π-composer B). Places p_{41}÷p_{60} and p_{61}÷p_{80} contain coloured tokens that represents single π-containers placed in the 3-dimensional structure illustrated in Figures 4(a), 9 and 10. As illustrated in Figure 11, such places receive tokens from places p_4÷p_8 and p_{36}÷p_{40}, respectively, in accordance with some firing rules which are derived from the loading sequence of the container to be composed. Instead places p_A and p_B contain tokens whose colour is a structure defining the way a container is composed; such tokens are created by firing transitions t_A and t_B, respectively, which remove all tokens from places p_{41}÷p_{60} and p_{61}÷p_{80}; such firings are ruled by suitable guard functions which prevent the firing in the case the container is not composed appropriately.

The colour set functions, the set of typed variables, the arc expressions, and the guard functions are reported in the following. In equations (27)÷(30), f_{LS} and g_{LS} are two functions which express the fact that the guard functions associated with the transitions included in the part of the CPN relevant to π-composers A and B are defined in accordance with the loading sequences of the containers to be composed (an example of such functions is provided later).

$$\mathcal{C}(p_h) = \text{BSIZE}\,, \forall h = 1, \dots, 80 \tag{14}$$

$$\mathcal{C}(p_l) = \text{STRUCT}\,, \forall l = \text{A,B} \tag{15}$$

$$\mathcal{V} = \{b_h\text{:BSIZE}; h = 1, \dots, 80\} \tag{16}$$

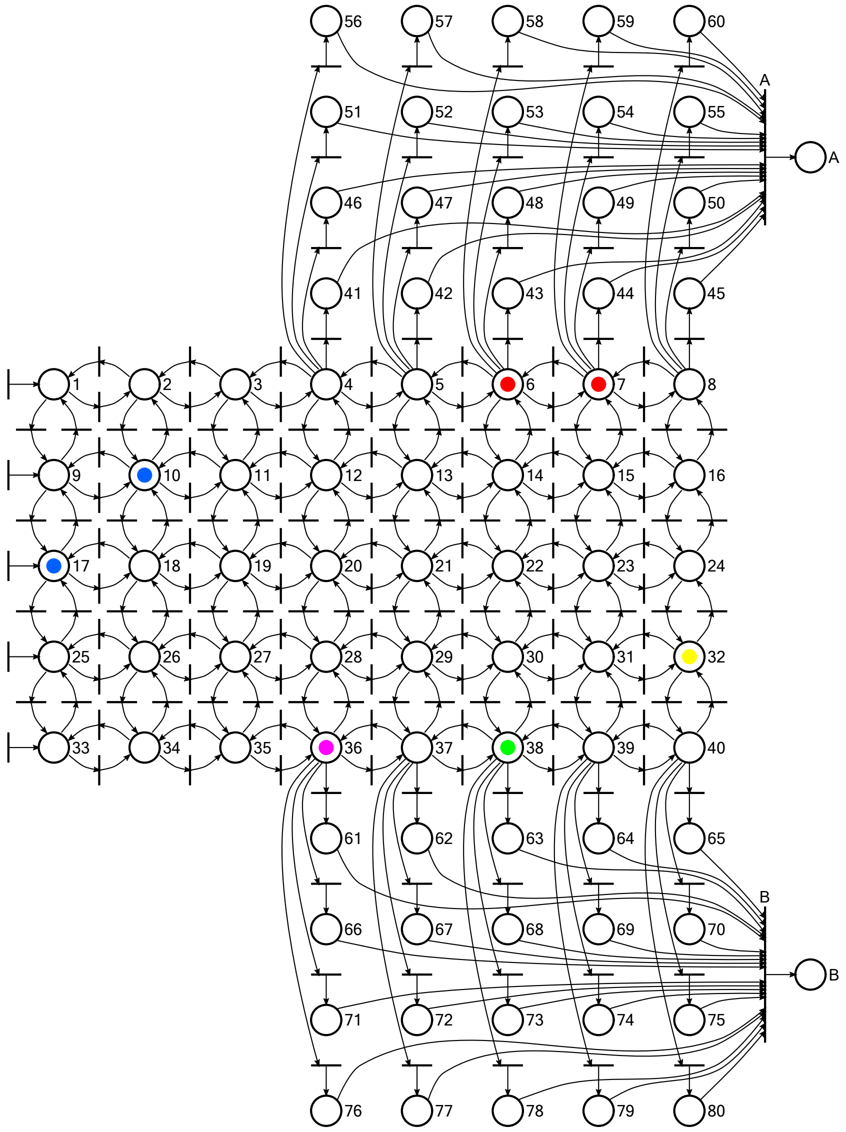


Figure 11: CPN representing the π-sorter with two π-composers.

$$\mathrm{E}(p_h, t_{h-k}) = 1'b_h\,, \forall h, k = 1, \dots, 40 \tag{17}$$

$$\mathrm{E}(t_{h-k}, p_k) = 1'b_h\,, \forall h, k = 1, \dots, 40 \tag{18}$$

$$\mathrm{E}(p_h, t_{\mathrm{A}k}) = 1'b_h\,, \forall h, k\colon (p_h, t_{\mathrm{A}k}) \in \mathcal{A}\,, h \in \{4, \dots, 8\}\,, k \in \{41, \dots, 60\} \tag{19}$$

$$\mathrm{E}(t_{\mathrm{A}k}, p_k) = 1'b_h\,, \forall h, k\colon (p_h, t_{\mathrm{A}k}) \in \mathcal{A}\,, h \in \{4, \dots, 8\}\,, k \in \{41, \dots, 60\} \tag{20}$$

$$\mathrm{E}(p_h, t_{\mathrm{B}k}) = 1'b_h\,, \forall h, k\colon (p_h, t_{\mathrm{B}k}) \in \mathcal{A}\,, h \in \{36, \dots, 40\}\,, k \in \{61, \dots, 80\} \tag{21}$$

$$\mathrm{E}(t_{\mathrm{B}k}, p_k) = 1'b_h\,, \forall h, k\colon (p_h, t_{\mathrm{B}k}) \in \mathcal{A}\,, h \in \{36, \dots, 40\}\,, k \in \{61, \dots, 80\} \tag{22}$$

$$\mathrm{E}(p_h, t_l) = 1'b_h\,, \forall h = 41, \dots, 60 \text{ when } l = \mathrm{A}\,, \forall h = 61, \dots, 80 \text{ when } l = \mathrm{B} \tag{23}$$

$$\mathrm{E}(t_{\mathrm{A}}, p_{\mathrm{A}}) = 1'(b_{41}, \dots, b_{60}) \tag{24}$$

$$\mathrm{E}(t_{\mathrm{B}}, p_{\mathrm{B}}) = 1'(b_{61}, \dots, b_{80}) \tag{25}$$

$$\mathrm{G}(t_{h-k}) = [(b_h = 111) \wedge (\mathrm{C}_{h-k-111})] \vee [(b_h = 211) \wedge (\mathrm{C}_{h-k-211})] \vee [(b_h = 121) \wedge (\mathrm{C}_{h-k-121})] \vee [(b_h = 221) \wedge (\mathrm{C}_{h-k-221})] \vee [(b_h = 411) \wedge (\mathrm{C}_{h-k-411})] \vee [(b_h = 141) \wedge (\mathrm{C}_{h-k-141})] \vee [(b_h = 222) \wedge (\mathrm{C}_{h-k-222})] \vee [(b_h = 422) \wedge (\mathrm{C}_{h-k-422})] \vee [(b_h = 242) \wedge (\mathrm{C}_{h-k-242})]\,, \forall h, k = 1, \dots, 60 \tag{26}$$

$$\mathrm{G}(t_{\mathrm{A}k}) = f_{\mathrm{LS}}(b_4, \dots, b_8, b_{41}, \dots, b_{60}) \quad (27)$$

$$\mathrm{G}(t_{\mathrm{B}k}) = f_{\mathrm{LS}}(b_{36}, \dots, b_{40}, b_{61}, \dots, b_{80}) \quad (28)$$

$$\mathrm{G}(t_{\mathrm{A}}) = g_{\mathrm{LS}}(b_{41}, \dots, b_{60}) \quad (29)$$

$$\mathrm{G}(t_{\mathrm{B}}) = g_{\mathrm{LS}}(b_{61}, \dots, b_{80}) \quad (30)$$

Consider now the part of the CPN representing the π-sorter/π-composers which is relative to the π-composer B (it is illustrated in Figure 12), and assume that the container to be composed has the structure illustrated in Figure 4(c). The marking to be reached, starting from the one in Figures 11 and 12(a), is the marking illustrated in Figure 12(b) which correspond to the Petri net representation of the vector (0,0,0,0,0,222,0,221,0,121,0,0,111,211,0,0,0,111,211,0) that is adopted to describe the composed container.

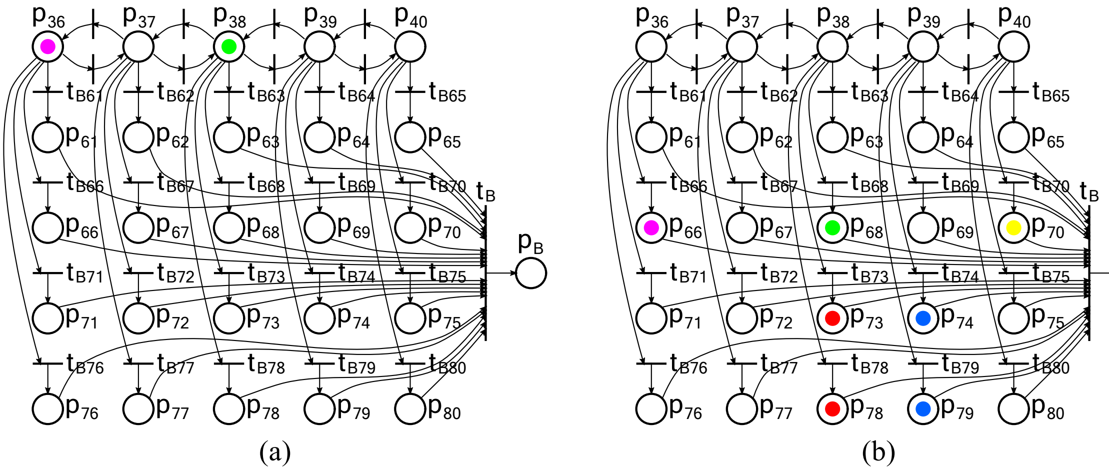


Figure 12: Detail of the CPN representing the π-sorter with two π-composers: (a) start of composition on π-composer B, and (b) end of composition on π-composer B (final marking).

To reach the final marking in Figure 12(b), coloured tokens representing the seven π-containers of sizes 222, 221, 121, 111, and 211, must reach places p_{36} (the one of size 222), p_{38} (the one of size 221 and the two of size 111), p_{39} (the two of size 211), and p_{40} (the one of size 121) through some moving operations on the π-sorter. From such places tokens are inserted into places p_{66}, p_{68}, p_{70}, p_{73}, p_{74}, p_{78}, p_{79} by firing transitions $t_{\mathrm{B}66}$, $t_{\mathrm{B}68}$, $t_{\mathrm{B}70}$, $t_{\mathrm{B}73}$, $t_{\mathrm{B}74}$, $t_{\mathrm{B}78}$, $t_{\mathrm{B}79}$, respectively. However, such firings must follow a strict order corresponding to the loading sequence reported in Table 1. Then, transitions must fire with the sequence $t_{\mathrm{B}66}$, $t_{\mathrm{B}68}$, $t_{\mathrm{B}70}$, $t_{\mathrm{B}78}$, $t_{\mathrm{B}73}$, $t_{\mathrm{B}79}$, $t_{\mathrm{B}74}$, and this is actualized by means of the following guard functions (which also check the presence of the right π-container in places p_{36}÷p_{40}).

$$\mathrm{G}(t_{\mathrm{B}66}) = (b_{36} = 222) \quad (31)$$

$$\mathrm{G}(t_{\mathrm{B}68}) = (b_{38} = 221) \wedge (b_{66} = 222) \quad (32)$$

$$\mathrm{G}(t_{\mathrm{B}70}) = (b_{40} = 121) \wedge (b_{68} = 221) \quad (33)$$

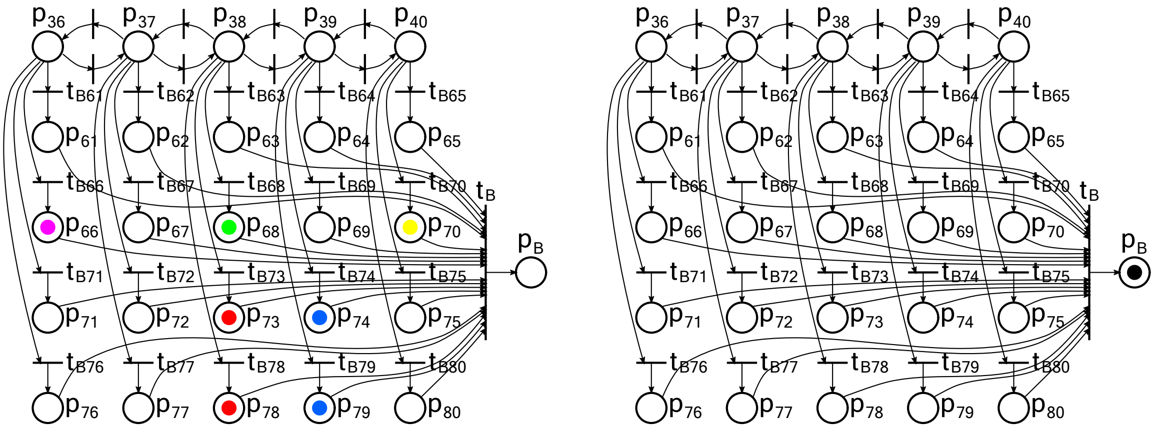
$$\mathrm{G}(t_{\mathrm{B}78}) = (b_{38} = 111) \wedge (b_{70} = 121) \quad (34)$$

$$\mathrm{G}(t_{\mathrm{B}73}) = (b_{38} = 111) \wedge (b_{78} = 111) \quad (35)$$

$$\mathrm{G}(t_{\mathrm{B}79}) = (b_{39} = 211) \wedge (b_{73} = 111) \quad (36)$$

$$\mathrm{G}(t_{\mathrm{B}74}) = (b_{39} = 211) \wedge (b_{79} = 211) \quad (37)$$

$$\mathrm{G}(t_{\mathrm{B}k}) = 0\,,\; k = 61,62,63,64,65,67,69,71,72,75,76,77,80 \quad (38)$$



(a) (b)

Figure 13: Detail of the CPN representing the π-sorter with two π-composers: (a) end of composition on π-composer B (final marking), and (b) consolidation of the composed container.

Once reached the final marking for what concerns places $p_{61}÷p_{80}$, it is possible to consolidate the composed container by firing transition t_B (see Figure 13), which is now enabled in accordance with the logical condition defined by the guard function (39).

$$\mathrm{G}(t_{\mathrm{B}}) = (b_{61} = 0)\wedge(b_{62} = 0)\wedge(b_{63} = 0)\wedge(b_{64} = 0)\wedge(b_{65} = 0)\wedge(b_{66} = 222)\wedge(b_{67} = 0)\wedge(b_{68} = 221)\wedge(b_{69} = 0)\wedge(b_{70} = 121)\wedge(b_{71} = 0)\wedge(b_{72} = 0)\wedge(b_{73} = 111)\wedge(b_{74} = 211)\wedge(b_{75} = 0)\wedge(b_{76} = 0)\wedge(b_{77} = 0)\wedge(b_{78} = 111)\wedge(b_{79} = 211)\wedge(b_{80} = 0) \qquad (39)$$

The firing of t_B puts a token in p_B (see Figure 13(b)), whose colour is the vector defining the structure of the composed container, as previously discussed.

4 Conclusions and further research directions

The use of coloured Petri nets to represent logistics facilities and material handling systems in a multimodal hub compatible with the Physical Internet paradigm has been addressed in the paper. Petri nets are very suitable for modelling the activities that are carried out by the various π-resources when handling π-containers: from the simple tasks for moving goods within the hub to the complex processes that are actualized when a composed container has to leave the multimodal hub by road. Besides, the applicability of the Petri net formalism is not limited to the representation of a multimodal hub; they can be effectively adopted also to represent logistics networks with the aim of modelling and controlling the flows of π-containers through the various nodes of a network. In fact, one of the promised benefit to assess consists of a better exploitation of the transport capacity, as some mode might be filled with disaggregated π-containers but not with standard container. To do that with CPNs, further colour sets can be adopted in order to associate more detailed information (e.g., the destination of each π-container, the status of them, etc.) to the token representing the aggregations of π-containers travelling on the logistic networks.

In this connection, the current activities on this research topic are: to define and test the CPN model for the whole multimodal hub, and to propose a CPN model for a PI-compatible logistics network at interregional level. A further research direction is relevant to definition of specific simulation models, based on the CPN representation of both the multimodal hub and the logistics network, to carry out a structural and performance analysis and to optimize some parameters of the considered class of systems.

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Towards Hyperconnected Resource Requirements Planning

Raphaël OGER[1,2], Matthieu LAURAS[1], Benoit MONTREUIL[2],
Frédérick BÉNABEN[1] and Nicolas SALATGE[1]

1. Industrial Engineering Center, IMT Mines Albi-Carmaux, Toulouse University,
Albi, 81000, France
2. Physical Internet Center, ISYE School, Georgia Institute of Technology,
Atlanta, GA 30332-0205, U.S.A

Corresponding author: raphael.oger@mines-albi.fr

Abstract: *This paper focuses on Resource Requirements Planning (RRP) for hyperconnected supply chain. The objective is to enable Physical Internet (PI) Logistics Web actors to plan their resources effectively to be able to fulfill the demand in the forthcoming years. We first identify a lack of research literature about RRP for hyperconnected supply chains. We conclude from our literature review that the research efforts done by the PI community are focused on enabling the PI to become operational. But the PI community has not yet shown any interest in PI strategic planning. So, we position our research regarding the MRP II system's RRP, focusing on the strategic planning processes for production and capacity control. Therefore, from the lack of research literature about RRP for hyperconnected supply chains, and from the MRP II strategic planning methodology structure, we demonstrate the significant need to adapt this MRP II system's RRP to fit the hyperconnected supply chains requirements and so the PI requirements. Finally, we introduce a Physical Internet Resource Requirement Planning (PI-RRP) methodology corresponding to our research agenda guidelines. The development of this methodology will drive our futures researches.*

Keywords: *Physical Internet, Logistics Web, Realization Web, Supply Chain, Strategic Planning, Resource Requirements Planning, Decision Support System, Information Systems.*

1 Introduction

Over recent years, the Physical Internet (PI) (Montreuil et al., 2010; Montreuil, 2011) gained significant attention from the academic and practitioner communities (Treiblmaier et al., 2016). This idea of designing and managing logistics flows (material, information and money) in a way inspired from the way the digital internet deals with data flows (Montreuil et al., 2012) appeals to both communities. The PI Foundations Framework introduced by Montreuil et al. (2013) proposes some guidelines to reach the PI ambitions. Through this framework, the PI is defined as "*an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols*" (Montreuil et al., 2013).

As expressed by Montreuil (2015), the PI aims to enable efficient and sustainable hyperconnected supply chains and logistics system, their components intensely interconnected on multiple layers, ultimately anytime, anywhere.

In this paper, we focus on Resource Requirements Planning (RRP) in such hyperconnected supply chains. For supply chain actors, the aim of the historical MRP II system's RRP is to plan their resources effectively so as to be able to fulfill demand in the forthcoming years (Arnold et al., 2008; Olhager et al., 2001).

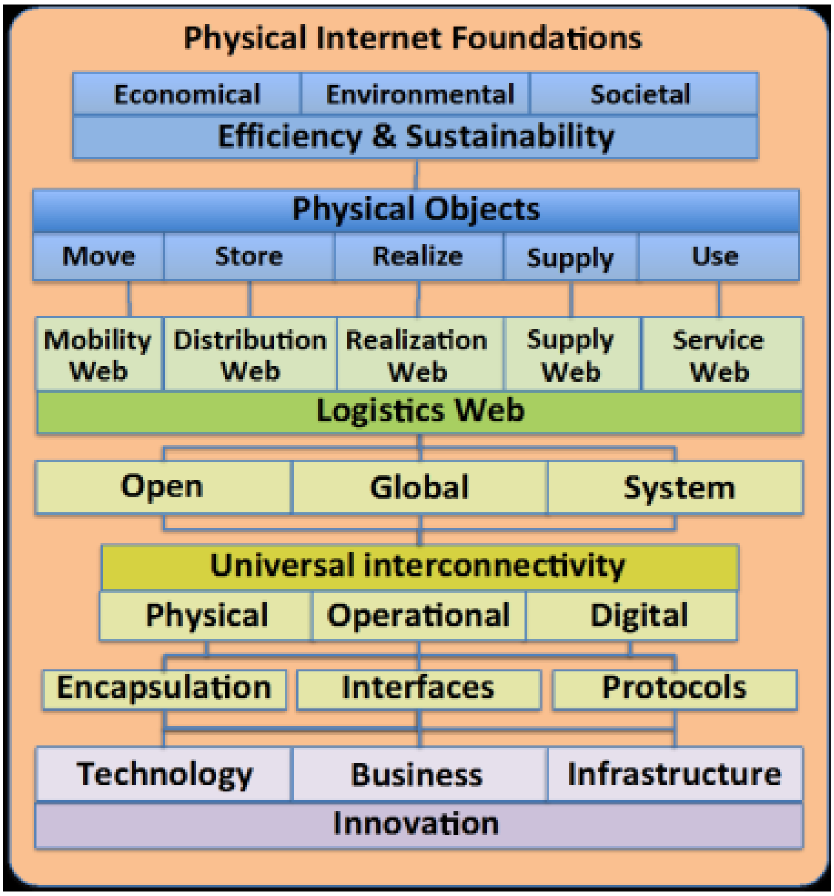

Figure 1: Physical Internet Foundation Framework (Montreuil et al., 2013)

After having further explained the lack of research literature about RRP for hyperconnected supply chains, we position our research regarding the MRP II system’s RRP. Then, we demonstrate the need to adapt this MRP II system’s RRP to fit the hyperconnected supply chains requirements. Finally, we introduce a Physical Internet Resource Requirement Planning (PI-RRP) methodology corresponding to our research agenda guidelines. To address this PI-RRP challenge and to design the PI-RRP methodology, we take advantage of the IO-Suite project aiming to support interoperability of collaborative networks (Benaben et al., 2014), as well as the PI foundation framework (Montreuil et al., 2013).

2 Background and research statement

2.1 Background

2.1.1 Physical Internet background regarding Resource Requirements Planning

In our journey to design a RRP for hyperconnected supply chains, we show a major interest in the literature about the PI strategic planning, considering the following elements in our literature review: strategic business planning, business planning, sales and operation planning, resource requirements planning, resource planning, strategic capacity planning, and capacity planning.

We started our literature review on these topics considering the literature review about the PI done by Treiblmaier et al. (2016). We choose to highlight three of their tables which synthetize some of their research results: “PI Components Reviewed by the Literature”, “Key Performance Indicators and Goals of the PI”, and “Problems and unanswered questions related to the PI”. We observe that the literature focuses on PI operational challenges. From Treiblmaier et al. (2016) results, neither the “PI Components Reviewed by the Literature” nor the "Key Performance Indicators and Goals of the PI" table contains research information about the considered PI strategic planning elements mentioned previously. From the "PI Components Reviewed by the Literature" table, Treiblmaier et al. say that "prior literature has invested considerable efforts in establishing the foundations of the PI components and further improving the same by working on practical solutions". The following PI components have been identified:

- Modular containers (transport containers, handling containers, packaging containers)
- Vehicle usage optimization
- Transit centers, hubs
- Seamless, secure and confidential data exchange
- Legal framework
- Cooperation models
- Business models

From the "Key Performance Indicators and Goals of the PI" table, Treiblmaier et al. say that "most of the literature focuses on the development of performance indicators addressing the main goals of the PI: logistics effectiveness, efficiency and sustainability". To summarize PI KPIs considered within the literature, we classified them within two categories:

- Transportation optimization and evaluation, from economic, environmental and societal perspectives.
- PI containers and PI infrastructure durability.

Finally, Treiblmaier et al. concluded their literature review by a synthesis of the PI related problems addressed by the literature, and a list of PI related unanswered questions they identified for additional research opportunities. The PI related challenges considered in the literature and the PI related unanswered questions might be summarize as the following questions:

- How to deal with the Physical Objects (designing PI containers, PI hubs, etc.)?
- How to design and manage the Logistics Web (transportation optimization, cooperation model, etc.)?
- How to manage the interconnectivity between all the Logistics Web components (Interconnectivity protocols, security, legality, openness, etc.)?

Within this literature review done by Treiblmaier et al. (2016), we did not found any papers about PI strategic planning. Therefore, in addition of the work done by Treiblmaier et al., we searched specifically for PI strategic planning researches considering the elements previously mentioned: strategic business planning, business planning, sales and operation planning, resource requirements planning, resource planning, strategic capacity planning, and capacity planning (all combined with Physical Internet). However we did not found either papers about PI strategic planning.

To conclude our literature review, the research efforts done by the PI community are focused on enabling the PI to become operational and making it efficient and sustainable. The PI community has not yet shown any interest in PI strategic planning, and mainly stay focused on the operational challenges. There is no research about the evaluation of the Logistics Web ability to fulfil the demand.

2.1.2 Research positioning regarding the MRP II system: Business Planning, Sales and Operation Planning, and Resource Requirements Planning

As the PI community has not yet shown any interest for PI strategic planning, we decided to use the historical MRP II system. Exploiting this MRP II system is one of the current dominant approaches in practice for performing Make To Stock manufacturing planning. MRP II is a method for the effective planning of all resources of a manufacturing company, driving the company manufacturing planning process from the business plan to the operational activities (Figure 2) (Arnold et al., 2008).

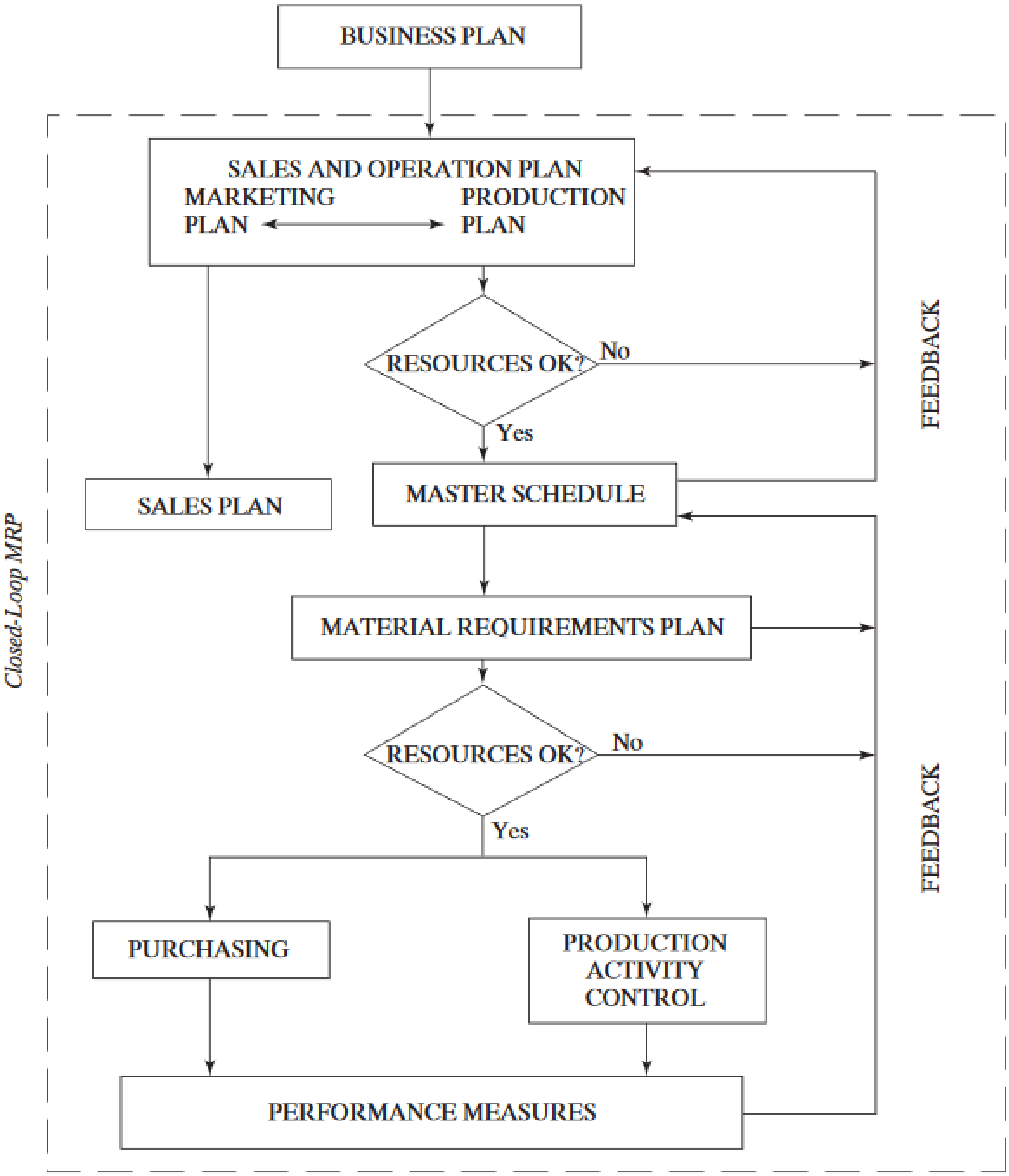

Figure 2: Manufacturing Resource Planning (MRP II) (Arnold et al., 2008)

In this paper, we are interested by the link between the strategic business plan and the Sales and Operation Plan that is illustrated by Figure 2 as well as Figure 3. To be more precise, we are mainly focusing on the link between the strategic business plan and the production plan. The reason is that we want to enable the actors of the PI's Logistics Web to plan their resources effectively to be able to fulfill demand in the forthcoming years.

As defined by Arnold et al. (2008), "the strategic business plan is a statement of the major goals and objectives the company expects to achieve over the next 2 to 10 years or more." It "provides direction and coordination among the marketing, production, financial, and engineering plans", and it is usually updated annually.

The Sales and Operation Planning (S&OP) is a process for continually revising the strategic business plan inputs (production, marketing, financial and engineering plans), usually at least updated monthly.

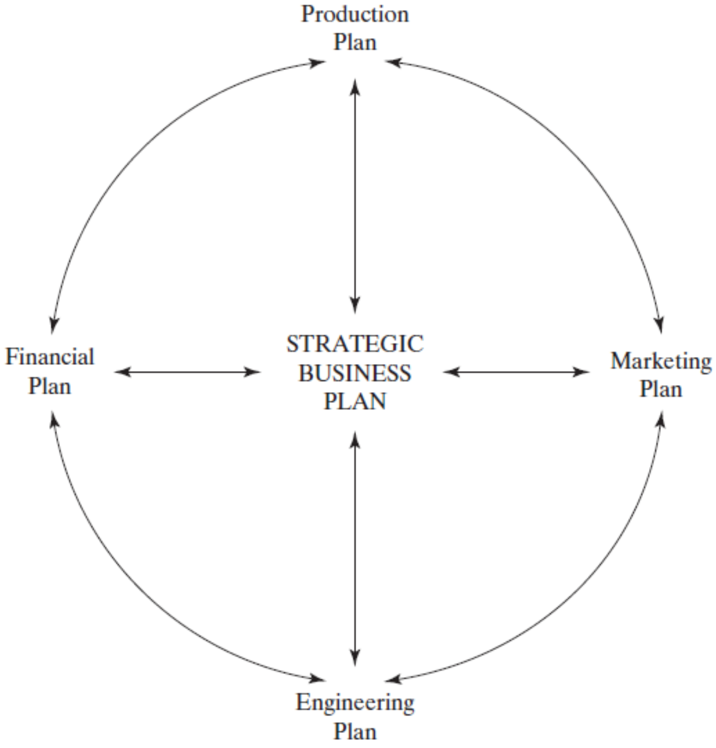

Figure 3: Strategic business plan (Arnold et al., 2008)

To ensure the feasibility of these company plans, the MRP II model organizes capacity control actions "at each level in the manufacturing planning and control system" (see Figure 2 and Figure 4), defining that "the priority plan must be tested against the available resources and capacity of the manufacturing system" (Arnold et al., 2008). Indeed, in our case, the Resource Requirements Planning corresponds to this capacity control action for the *production plan*, comparing the *production plan* to the existing resources of the company (*resource plan*).

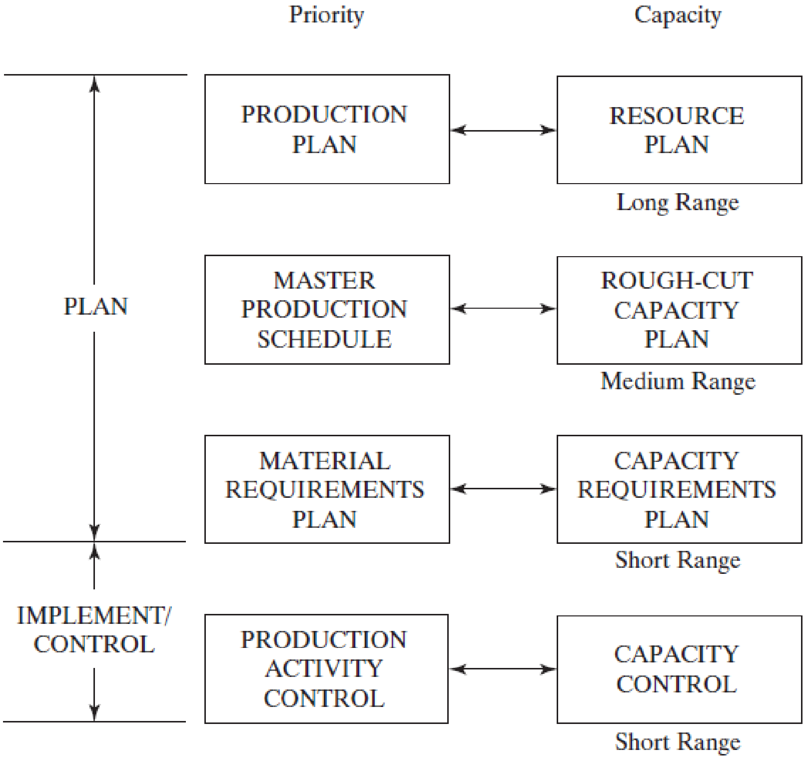

Figure 4: Production and capacity plans for each planning levels (Arnold et al., 2008)

Consequently, regarding the MRP II system, our research is focusing on the strategic planning processes for production and capacity control: Business Planning, Sales and Operation Planning, and Resource Requirements Planning. Our objective is to take advantage of these existing MRP II methodologies to enable the RRP for hyperconnected supply chains.

2.2 Research statement

To enable the RRP for hyperconnected supply chains, we will go more in depth into the MRP II S&OP and RRP processes to find out if either or not we might use these methodologies unchanged.

During their Strategic Business Planning process, every business needs to make decisions for a long-time range, often several years. This strategic Business Planning process relies on the outputs of the S&OP process: marketing plan and production plan (Figure 2 and Figure 3). Based on the marketing, production and resource plans (Figure 2, Figure 3 and Figure 4), the Resource Requirement Planning process consists in assessing if the critical resources of the company (resource plan) are well sized to respond to the global forecasted demand (from the marketing plan).

One major analysis of the S&OP process consists in identifying what is called “What-If” scenarios, corresponding to the different considered possible situations the business might have to cope with in the future (including the corresponding marketing, resource and production plans). So, these “What-If” scenarios need to be identified, calculated and analyzed in order to make good decisions.

To identify, calculate and analyze these “What-If” scenarios, businesses need first to gather their supply chain network information as well as their marketing environment information and their business potential strategic choices. Then, the following steps enable the business to establish a “What-If” scenario from the business perspective (process illustrated in Figure 5):

1. Marketing plans are deduced from the marketing environment information.
    a. A marketing plan is chosen for this scenario (including sales plan).
2. Production plans are deduced from the marketing plan.
    a. A production plan is chosen for this scenario.
3. Business resource plans are deduced from the business potential strategic choices.
    a. A resource plan is chosen for this scenario.
4. A set of supply chain network potential configurations is deduced from the supply chain network information.
    a. A supply chain network configuration (partners, production capacities, etc.) is chosen for this scenario.
5. Supply chain processes are deduced for each product that the business plans to produce according to the production plan, depending on the supply chain network configuration.
    a. A supply chain process is chosen for each product for this scenario.
6. A supply chain network production plan is deduced from the set of supply chain processes and the business production plan.

So, there is a scenario for each business marketing plan, each business production plan, each business resource plan, each supply chain network configuration, and each set of supply chain processes (with a supply chain process for each product of the production plan).

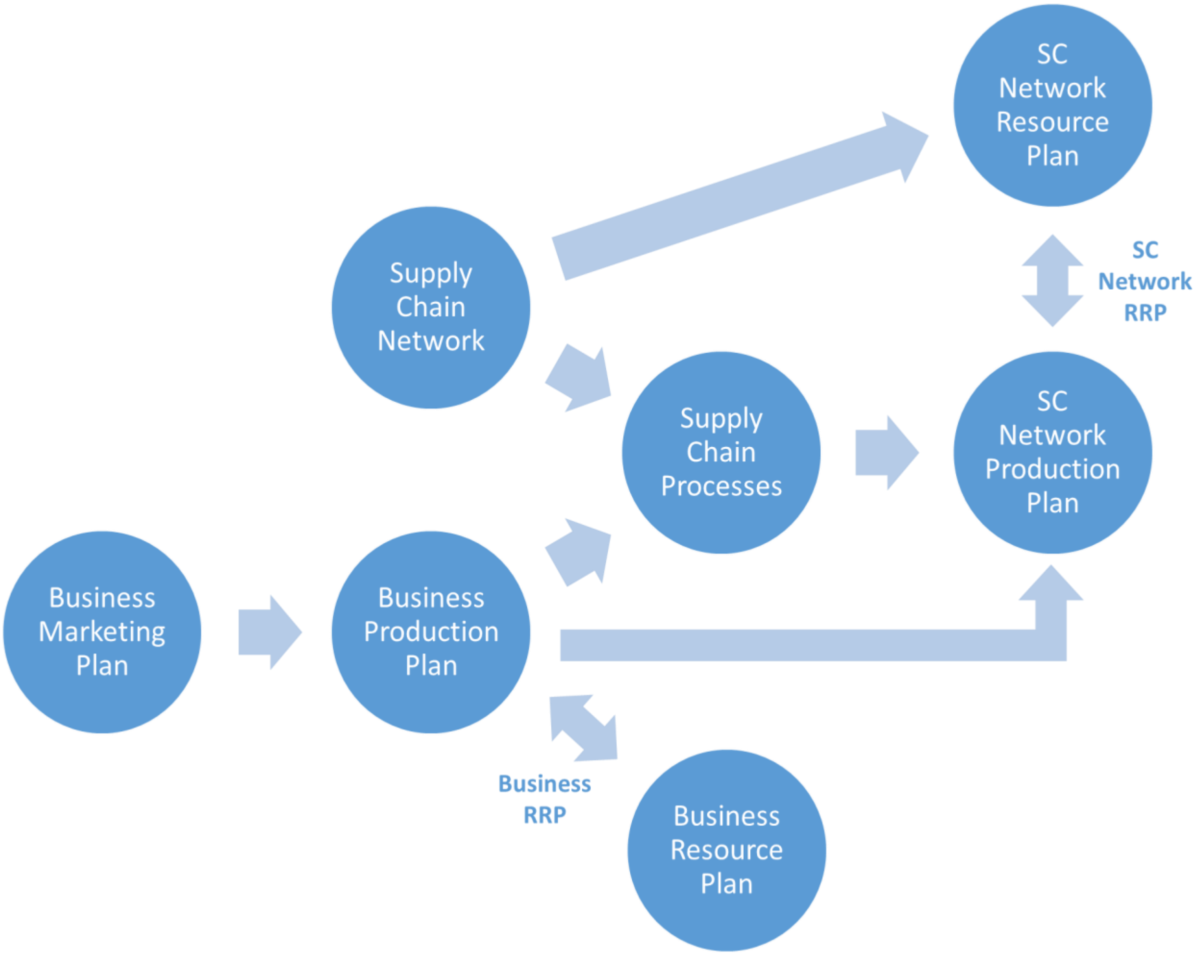

Figure 5: A process to establish S&OP “What-If” scenarios

At this point, the company identified the possible “What-If” scenarios and so can calculate and analyze them. One of the questions which can be answered from these “What-If” scenarios is: “does the business will be able to fulfil the demand in the circumstances of each scenario?” It is the RRP process which enable to answer this question using these “What-If” scenarios. Finally, having the “What-If” scenarios and their respective RRP process output will give decision makers the visibility on different possible futures with corresponding probabilities analysis, risks analysis, and even other analysis.

One of the issues identified is that this description of the S&OP is a daydreaming description. These tasks of the S&OP process are often manually achieved by supply chain engineers from the manufacturing team and by the marketing team, and can be quite complex and time consuming. Moreover, each time there is a modification in the supply chain network (new partner, new partner’s know-how, new product, etc.), the list of possible supply chain processes enabling the production of each type of product might undergo several changes. In addition, with the world globalization, businesses supply chain networks are evolving quicker and quicker, and so the needs for updates of the list of possible supply chain processes are more and more frequent. In this way, businesses face the difficulty to keep their list of possible supply chain processes up-to-date, with the additional risk of mistakes during the updates. They also face the difficulty to realize an important number of “What-If” scenarios. As a consequence, businesses face the difficulty to obtain reliable, up-to-date “What-If” scenarios and their respective analysis, and in a sufficient number. The difficulty to obtain reliable scenario is also explained by the lack of communication and transparency between businesses. Companies are often building their S&OP for themselves only without having a real collaboration with their supply chain partners when building their S&OP plans.

Additionally, the MRP II system was fit for the needs of deterministic pre-established supply chains (Arnold et al., 2008; Stadtler, 2005). An explanation is that supply networks were much less volatile few decades ago than they are nowadays. With the PI, the Logistics Web enables dynamic supply chain networks whose actors may opt from spot on-demand relationships to longer-term partnerships, expanding significantly their decision space when strategically planning resources. The Logistics Web is much more dynamic than a single business centric supply chain network. Therefore, unlike MRP II system-based RRP which is done at a low frequency (such as monthly or quarterly), RRP in the PI needs to be as dynamic as the Logistics Web. In addition, unlike MRP II system-based RRP which is business centric, RRP in the Physical Internet needs to be Logistics Web centric. So, the historical MRP II system's RRP does not fit the needs of the Physical Internet: needs for a very dynamic RRP and for a Logistics Web centric RRP.

The following Figure 6 synthetize the different reasons we mentioned explaining that businesses face difficulties to take good decisions to secure their supply chains and so to ensure their capacity to fulfil the demand for a long time horizon. This figure highlight the importance for businesses of being able to build a complete and reliable set of "What-If" scenarios to ensure their capacity to fulfil the demand in the forthcoming years. Because complete and reliable scenarios enable to have a good visibility on possible futures which enables the businesses to take good decisions to secure their supply chains, which finally enables the businesses to ensure their capacity to fulfil the demand in the forthcoming years.

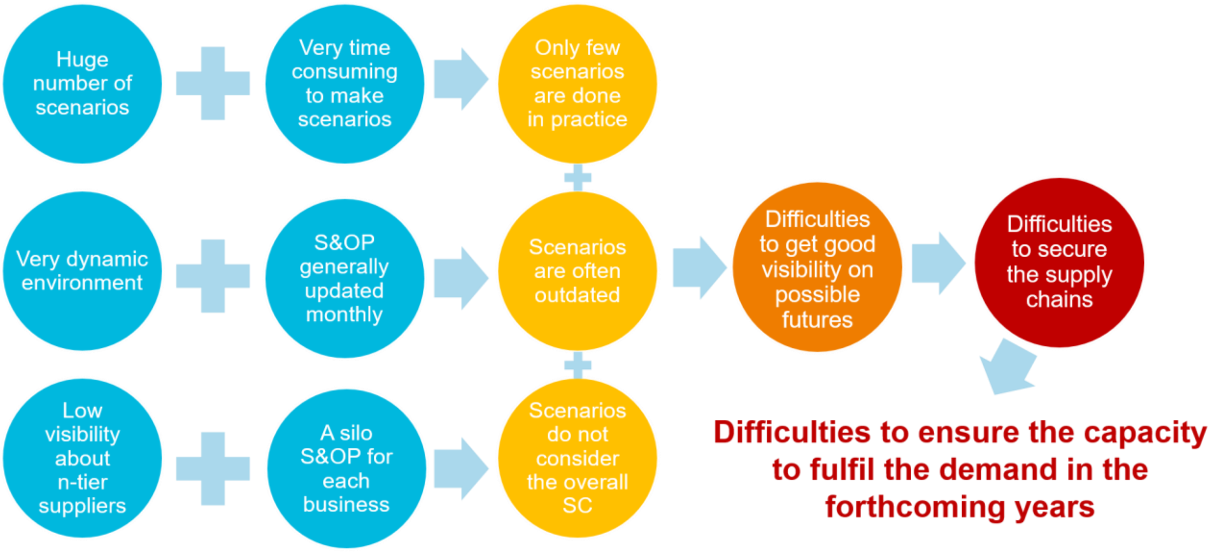

Figure 6: Some explanations of the difficulties businesses face to ensure their capacity to fulfil the demand for the forthcoming years

Consequently, there is a significant need for developing a RRP methodology adapted to hyperconnected supply chains exploiting the PI Logistics Web. As hereafter termed, PI-RRP aims to plan how the openly shared resources of Logistics Web actors are expected to dynamically support the stochastic and variable demand of the targeted supply chain in the forthcoming future. A RRP for hyperconnected supply chains to enable the actors of the PI Logistics Web to plan their resources effectively so as to be able to fulfill the demand in the forthcoming years.

3 Research agenda

We identified that the historical MRP II system's RRP does not fit the hyperconnected supply chains and so the PI Logistics Web. Therefore, to enable the actors of the PI Logistics Web to plan their resources effectively to be able to fulfill demand in the forthcoming years, we developed a Physical Internet Resource Requirements Planning (PI-RRP) methodology.

To address this PI-RRP challenge and to design the PI-RRP methodology, we take advantage of the following research works:

- IO-Suite project aiming to support interoperability of collaborative networks (Benaben et al., 2014);
- PI foundation framework (Montreuil et al., 2013);
- Methodology guidelines proposed by OGER et al. (2017) to enable supply chain agility and resilience improvement;
- MRP II methodology (Arnold et al., 2008).

The proposed PI-RRP methodology performs iteratively the following six steps:

1. Logistics Web data gathering;
2. Logistics Web modeling;
3. Available Supply Chain Processes deduction;
4. Logistics Web plan of experiments ("What-If" scenarios for load and capacity balance analysis, etc.);
5. Logistics Web risk analysis;
6. Logistics Web recommendation deduction.

Each of these steps should be designed to enable the complete automation of the methodology with the PI environment. Table 1 describes the objectives of each step of the proposed PI-RRP methodology.

Table 1: PI-RRP methodology steps and objectives

PI-RRP step	Objectives
Logistics Web data gathering	To gather information about the Logistics Web.
Logistics Web modeling	To build a model of the Logistics Web in order to enable the visualization of the situation as well as the automation of the next steps.
Available Supply Chain Processes deduction	To deduce the, hereafter defined, Available Supply Chain Processes (ASCP) on the base of the modeled Logistics Web. For each product the business plans to sell, we define the corresponding ASCP as the succession of all possible activities, enabled by the LN's partners' know-hows (abilities), which enable to produce the product. In other words, it corresponds to a unique supply chain process containing all the possible ways enabling the product production (OGER et al., 2017).
Logistics Web plan of experiments ("What-If" scenarios for load and capacity balance analysis, etc.)	To assess whether given the current set of decisions and options, the supply chain will be able to exploit the Logistics Web to have sufficient and effective production capacity to efficiently fulfil demand in the forthcoming future (load and capacity balance analysis), depending on the possible futures ("What-If" scenarios).
Logistics Web risk analysis	To evaluate the probability of each potential scenario and the corresponding risks.
Logistics Web recommendation deduction	To suggest recommendations to improve the Logistics Web, to plan the resources effectively to be able to fulfill demand in the forthcoming years.

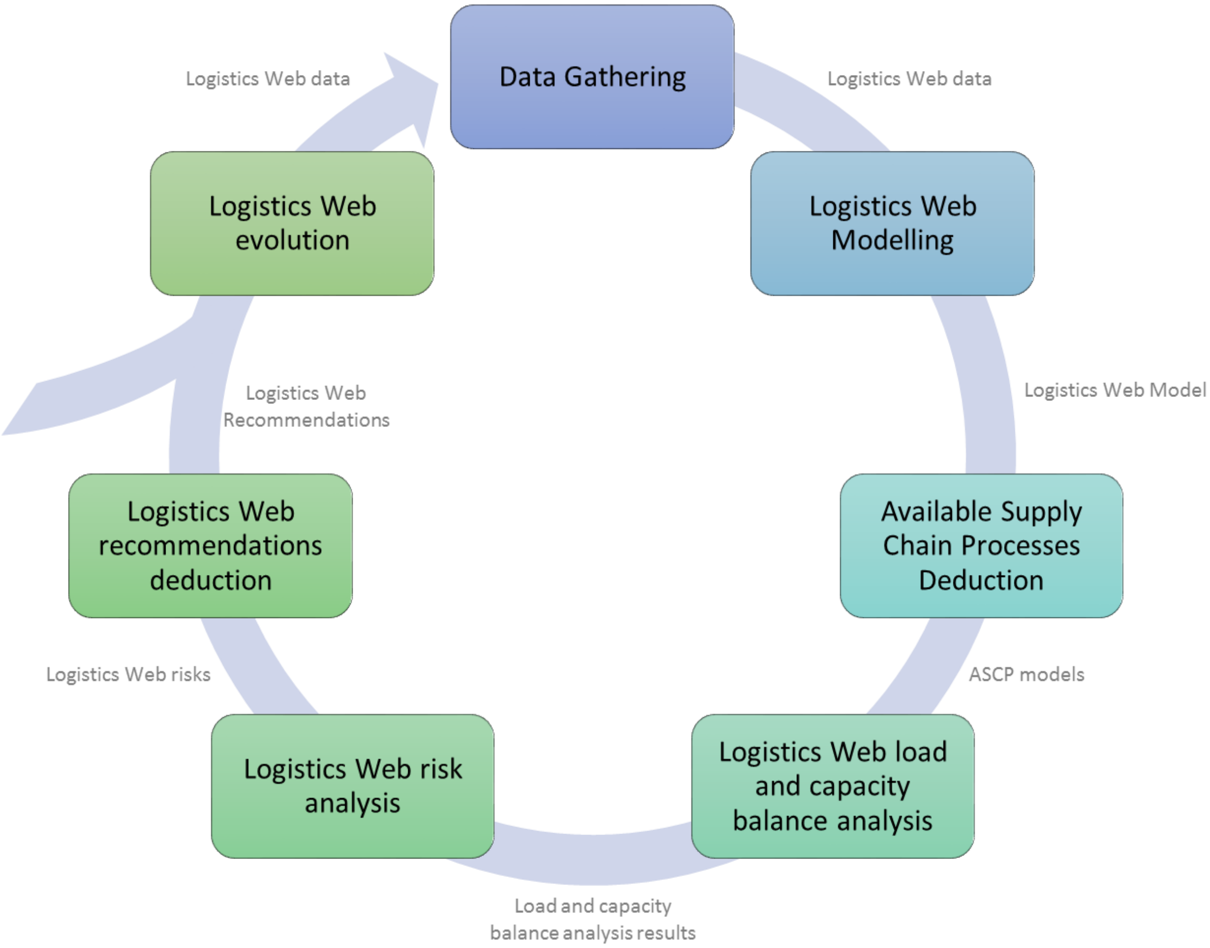

Figure 7: Physical Internet Resource Requirements Planning - Methodology proposal

4 Conclusion and perspectives

In this paper, we focused on Resource Requirements Planning (RRP) for hyperconnected supply chain, to enable PI Logistics Web actors to plan their resources effectively to be able to fulfill demand in the forthcoming years.

We explained the lack of research literature about RRP for hyperconnected supply chains. We also concluded from our literature review that the research efforts done by the PI community are focused on enabling the PI to become operational and making it efficient and sustainable, and that the PI community has not yet shown any interest in PI strategic planning.

Then, we positioned our research regarding the MRP II system's RRP, focusing on the strategic planning processes for production and capacity control: Business Planning, Sales and Operation Planning, and Resource Requirements Planning.

From the lack of research literature about RRP for hyperconnected supply chains, and the MRP II strategic planning methodology, we demonstrated the significant need to adapt this MRP II system's RRP to fit the hyperconnected supply chains requirements. A RRP for hyperconnected supply chains to enable the actors of the PI Logistics Web to plan their resources effectively so as to be able to fulfill the demand in the forthcoming years.

Finally, we introduce a Physical Internet Resource Requirement Planning (PI-RRP) methodology corresponding to our research agenda guidelines. The development of this methodology will drive our futures researches.

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Physical Internet
Efficient Sustainable Logistics

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Physical Internet and its impact on the emission calculation standardization of transport chains – are we there yet?

Verena Charlotte Ehrler [1]
1. DLR Institute of Transport Research, Rutherfordstr. 2, 12489 Berlin, Germany
Corresponding author: verena.ehrler@dlr.de

Abstract: *Expectations are high that the Physical Internet (PI) will contribute substantially to the improvement of transport chains' efficiency and therefore to a swift reduction of freight transport related emissions. However, the PI's ecological superiority still needs to be proven in reality. Moreover, in a synchro modal hyper-network, where routing management is decentralized, mechanisms need to be implemented that support emission minimization, both for individual flows as well as on a systems level. A standardized emission calculation tool for measuring emissions of freight transport chains ex-ante as well as ex-post is therefore necessary. Over the past decade, various approaches toward such a standard have been developed. This paper analyzes whether the currently existing approaches of emission calculation standardization are able to provide the necessary evaluations and whether they are equally able to support a successful steering of transport within the PI, so that lower emissions of freight transport can be realized compared to today's freight transport system. Based on an overview of the basic principles of the PI and on a summary of the status of transport chain emission standardization approaches, the paper analyzes how far these two developments are fully compatible already and which major gaps still need to be closed.*

Keywords: *Physical Internet, global logistics, transport, emission calculation, international standardization, sustainability, transport chains, greenhouse gas emissions*

1 Motivation and objective

The need to reduce emissions related to transport chains is pressing: annual global greenhouse gas (GHG) emissions have to peak by 2020 and then have to be reduced by 40% by 2040 (UNEP 2016; WRI 2017; IPCC 2014) (see Figure 1: Historical GHG emissions and projections until 2050) to ensure that we remain within the climate target of a maximum global warming of 2˚C. Therefore, the European Union (EU) aims for a reduction of greenhouse gas emissions of 20% by 2020 and of 40% by 2030 compared with 1990 levels (EU 2014), and the reduction of transport emissions plays an important role, as it is estimated that transport contributes with about 25% to CO_2 emissions, on a worldwide scale as well as on a European level. In 2004 roughly 21% of these transport related emissions derived from the domestic freight transport in the UK, which corresponds to 6% of total CO_2 emissions from all sectors (McKinnon 2010). Data for France indicates a 14% share of freight transport in greenhouse gas emissions (Duong, Savy 2008) and for Germany around 20% of all CO_2 emissions are related to road transport (Shell, DLR 2016).

As freight transport is expected to further increase over the coming years (e.g., for Germany an increase of freight transport of around 50% by 2040 is expected (Shell, DLR 2016)) and as global freight transport is currently based by a minimum of 95% on energy from fossil fuels, it is important, if not vital, to ensure that its greenhouse gas emissions remain within the climate goal target (IPCC 2014).

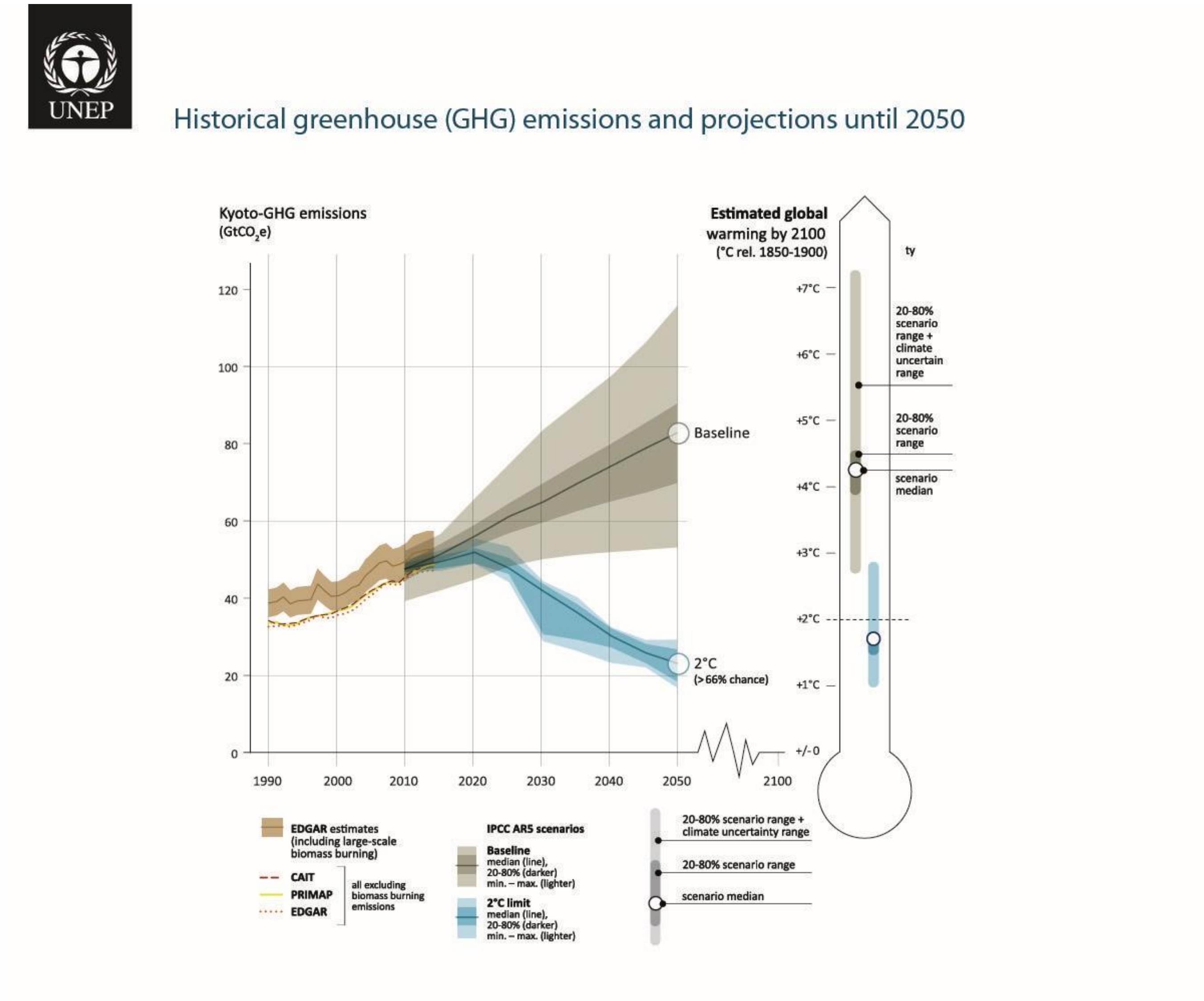

Figure 1: Historical Greenhouse (GHG) Emissions and Projections until 2050 (UNEP 2016)

In response to these challenges, innovative approaches and concepts to logistics and freight transportation are needed, developed and tested. They aim at decoupling the growth of freight traffic from economic growth.

One of these concepts is the Physical Internet, named in analogy to the Digital Internet. It is defined as “an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols” (Montreuil, Meller, Ballot 2012a). Despite the fact that it is still a new concept, the Physical Internet is anticipated to be a game changer in logistics and expectations are raised that it can and will contribute to the improvement of transport chain efficiency and therefore to the reduction of freight transport related emissions, both on a regional, as well as on a global level. Current targets envisaged by the Alliance for Logistics Innovation through Collaboration in Europe ALICE are a reduction of CO_2 emissions of 10% by 2020 (Phase 1 of the ALICE Roadmap), 25% by 2030 (Phase 2) and 40% by 2040 (Phase 3) compared to current levels. With the realization of these targets the Physical Internet would significantly contribute to the agreed emission targets for freight transport in Europe and on a worldwide scale (ALICE 2017).

If we really want to reach those targets though, we have to be able to measure emissions of freight transport (ex-post emission calculation) to compare different transport solutions. We also have to be able to steer transport so that it causes as little Greenhouse gas emissions as possible (ex-ante emission calculation). Furthermore, in a transport network with de-central routing decisions, mechanisms need to be integrated which take Greenhouse gas emissions into account. And the integration of these mechanisms has to extend up to the point where they provide the right signals to production and intra-logistics systems to encourage efficient and sustainable decisions for entire supply chains.

The purpose of this research is to analyze how far ongoing efforts for transport chain emission calculation standardization are able to support the evaluation of Greenhouse gas emissions of the PI, because if we want to reach the climate targets we need meaningful and transparent emission controlling now. At its core is the question, whether the characteristics of the Physical Internet are compatible with the currently developed approaches towards transport chain emission calculation standardization and whether, subsequently, these approaches are suitable and ready yet to measure the emissions of transport solutions of the Physical Internet.

First, this paper reflects upon how far the basic principles of the PI are further developments of existing logistics concepts or whether they are entirely new, requiring fundamental changes to the way logistics and transport are organized (section 3: The Physical Internet and a change of game). In a next step, the paper gives an overview on the current status of efforts for transport chain emission calculation standardizations on a global level (section 4: Emission calculation standardization – an overview on the current status of developments). The paper analyzes to which extent the current global standardization approaches support those aspects of the PI which have been identified as fundamental changes and innovations, and it is analyzed in how far these two developments are compatible already (section 5: Relation of basic principles of PI to current emission calculation standardizations – challenges and gaps). The paper closes with an outlook on the further developments of the PI and of emission calculation standardization needed to steer freight transport towards the established climate goal (section 6: Conclusion and outlook – are we there yet?).

2 The Physical Internet and a change of game

Transporting goods from shipper to consignee is per se a linear process, as it is the move of an object from one starting point to its final point of destination. In the past, freight documents travelled with "their" goods, and the routing of the freight was chosen prior to its departure, with price, transport mode and estimated time of arrival agreed between the involved partners. The introduction of electronic documentation for freight, so called e-freight, has enabled the separation of goods from their freight documentation. Freight related information can be processed in data network structures, whilst goods transported still move along a linear process (Ehrler 2011). With the introduction of the Physical Internet it is suggested that also this predefined linear process of goods' movements is changed into a network structure where goods' routings are decided ad hoc as they move through the network in smart containers.

Benoit Montreuil (2011) describes the basic principles of the Physical Internet, which is attributed with the potential of being a game changer in logistics. The following section investigates, whether these principles are a further development of existing characteristics of current logistics structures or whether they require a completely new way of thinking and organizing logistics and freight transport:

1. Encapsulating merchandise in world-standard smart green modular containers: Goods will be transported in modular, standardized containers, with all information relevant for routing decisions and handling processes included on the “packet header,” an electronic label of the container. These PI-containers (also called “π-containers”) are standardized worldwide and modularized, from small sizes up to current TEU container size and they are to be made of environment friendly materials with minimal tare weight. Standardized containers exist in various elements of the transport chain already (e.g., TEU containers, Euro-palettes or also standardized shapes and sizes for parcels sent by mail or couriers). Therefore, the development of a further modularized container system, here the PI container, is a logical next step of standardization of packaging and can be considered a further development of existing concepts.
2. Aiming toward universal interconnectivity: The PI is a network of transport networks, with operations and processes functionally standardized on a global scale. Logistics nodes of the PI are routing sites, accumulation sites, logistics’ services facilities and interface to players outside the Physical Internet at the same time. Aviation and sea transport, as well as road transport have realized this principle of interconnectivity and multi-purpose nodes to a large extent already, unlike rail systems. Developments of long-distance train connections such as Asia-Europe lines promote a better interconnectivity though.
3. Evolve from material to PI–container handling and storage systems: The standardized and modular format of PI-containers and their smart labelling in combination with dedicated PI-handling and storage systems build the basis for the optimization of efficiency of the PI. Therefore, the focus of system optimization is shifting from a material based focus of current transport systems to a container flow-oriented focus within the PI. Similar concepts are realized for handling of luggage in aviation, at transshipment centers and in warehousing concepts already. It is to be kept in mind though, that also in those systems and despite a standardized containerization, variations in handling are often required, e.g. for dangerous goods or due to weight issues when loading and unloading transport vehicles, such as vessels.
4. Exploit smart networked containers embedding smart objects: The use of smart labels enables a fully traceable and trackable self-routing of the standardized PI-containers through the interconnected transport networks. The seamless, ubiquitous introduction of electronic documentation and full e-freight coverage of the transport system is a prerequisite for a full exploitation of the introduction of smart labels. The concept of e-freight is introduced, a swift completion of the shift is necessary.
5. Evolve from point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport: Supported by web software, networks of all participating providers of transport and handling services are connected with one another. Containers chose ad-hoc and from node to node which transport mode, handling or network provider to use. Such a self-routing system requires an ex-ante calculation and comparison of costs, time and emissions of the next route element from node to node in order to establish which routing option is best. The decision of the routing is therefore not taken by those who pay for the transport any more. Instead, parameters have to be set according to the preferences of the customer and they have to be embedded on the smart label of the π-container, thus driving the decisions taken at each node en-route. This shift of decision-taking is considered a major change to current structures. It is expected to be one of the central aspects related to the issue of emission calculation of transport chains and shall be analyzed further within section 5 of this paper.

6. Embrace a unified multi-tier conceptual framework: Like fractals, the PI transport system is characterized by the same basic structures being reproduced on all of its scales: international, national, regional, urban. Such a concept is interesting and research is investigating the efficiency this approach supports especially for urban transport (Batty 2008). The granularity of emission calculations is related to the level of detail of the transport network planning and analysis. The structure being repeated on the various scales should simplify the approach, as the logical concept of one emission calculation approach can be transferred to the other levels, as long as the data for the calculation is available in the necessary granularity. This aspect therefore poses a data availability issue, rather than a conceptual challenge for the emission calculation.
7. Activate and exploit an Open Global Supply Web: This aspect of the Physical Internet might contain one of the more challenging implications and changes of game. The World Wide Web so far could be hindered from shifting to a differentiation in data transport speed, despite many providers pushing for it. In logistics and transport services though, the speed of delivery often is a USP (Unique Selling Proposition) and an aspect of high strategic relevance. Opening up its supply web could substantially weaken the competitive advantage of an organization, for producers or sellers of goods as well as for logistics providers. Therefore, logistics structures are well kept secrets and infrastructures usually are not openly available. Changing this structural element of commercial principles requires new business models (Montreuil et.al. 2012b) as well as a mind shift, a concept shift and most probably a paradigm shift in economics as well as a shift in international politics. Throughout the development of standardization approaches for the calculation of transport chain emissions, logistics providers have mentioned their concern on having to reveal more information than desirable on their transport structures, concepts and customers. An Open Global Supply Web might lead to further worries. Impacts related to the emission calculation standardization approach structures are further discussed in section 5.
8. Design products fitting containers with minimal space waste: Products that fit into predefined containers (i.e., function following form and perhaps even function following wrapping) is a principle already introduced by flat-pack product developers. This aspect would be brought to the next level if wrapping is standardized on a global scale.
9. Minimize physical moves and storages by digitally transmitting knowledge and materializing objects as locally as possible: In its full development, open distributed flexible production centers support local productions based on digitally transmitted information. This is, like aspect 7, an aspect requiring a change of game on the level of general principles of our economic system. At the moment it is most attractive for businesses to maximize their profit over their entire value chain. With low transport costs percentage in overall production costs combined with massive variations in salaries over the world, a maximization of profit is not necessarily realized when objects are materialized as locally as possible. This concept becomes attractive though where production processes are fully automated, e.g. in the form of 3d-printing. Such a shift therefore requires or a dramatic change in transport costs, a global assimilation of salaries or the complete replacement of human work force in production processes. General concepts of current approaches to emission calculation standardization are not related to this aspect.
10. Deploy open performance monitoring and capability certifications: Key performance indicators (KPI) of supply chain will provide for the necessary information for its further optimization. These KPIs need to support the monitoring of the transport chain,

including the transport time needed, quality, emissions, costs, services level, safety and security. Similarly to principle 5 this aspect has a direct interference to the topic of emission calculations of the transport chain and will be further investigated within section 5;

Looking at the basic principles of the Physical Internet, several aspects of it are already en route, whilst others require a change of game of business and economic principles, before the Physical Internet can become a game changer itself.

The following analysis will focus on those aspects of the PI which have been identified as being directly related to the calculation of emission calculation of transport chains: principle 5 ”Evolve from point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport,” 7 “Activate and exploit an Open Global Supply Web”, and principle 10: “Deploy open performance monitoring and capability certifications”.

The next section gives a short overview on the current status of emission calculation standardizations, before the changing requirements for emission monitoring implied by the Physical Internet on these standardization efforts are analyzed.

3 Emission calculation standardization - an overview on the current status of developments

“Businesses that measure their emissions have the opportunity to make informed decisions that lead to improved efficiency and reduced emissions” (LEARN 2017). This sentence introducing the project LEARN, Logistics Emissions Accounting and Reduction Network, summarises the core motivation of the transport industry and its related stakeholders for their ongoing efforts to develop a standard for measuring emissions of transport chains.

These players and stakeholders include logistics providers, governmental bodies, research organizations, consultancies, NGOs as well as combined consortia of these. Tools developed range from internationally applicable standards to transport mode specific methods, to data basis or calculation tools. An analysis carried out within the EU project COFRET, Carbon Footprint of Freight Transport, analyzed over 140 different tools in 2011 already (Kiel et.al.2014). More tools have been developed since. To be able to compare measured and calculated emissions of different transport solutions it is necessary though, to define unambiguous principles which can be applied to entire transport chains and on a global scale; the development of an internationally applicable standard for the calculation of transport chain emissions is needed.

Such a standard needs to include the calculation of emissions of logistics hubs. It needs to specify which data is to be used for the calculation and how the data used is to be sourced and communicated within the emission reporting scheme. As it is not always possible to track data over entire transport chains, default data should be used for emission calculation instead. Such default data needs to be tagged though and sourcing procedures of default data have to be standardized, too, if true transparency on the emission calculation is to be achieved.

International standards suitable as a basis for the calculation of transport are mainly ISO 14064 (Greenhouse Gases - Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals), ISO/TS14067 (Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication), the GHG Protocol Scope 3, the European Standard EN16258 and the Global Logistics Emission Council GLEC Framework for logistics emissions methodologies.

The ISO standard 14064, the ISO/TS 14067 as well as the GHG Protocol support the calculation of emissions for organizations (ISO 14064), products (ISO/TS 14067), and value chains (GHG Protocol Scope 3) (see also Table 1: Emission Calculation Standards for Transport Chains and their scope). They build an established and implemented framework for further developments of transport chain emission calculations; they do not provide transport chain specific guidelines though. An unambiguous comparison of transport chains including various transport modes is therefore not possible based on these standards only.

Table 1: Emission calculation standards for transport chains and their scope

Emission Transportation Standard	**Scope**
ISO 14064	methodology for the calculation and declaration of energy consumption and GHG emissions of transport services, freight and passengers
ISO/TS 14067	methodology for the calculation of carbon footprint of products
GHG Protocol Scope 3	methodology for the assessment the impact of emissions of companies entire value chains; no explicit focus on transportation
EN 16258	methodology for the calculation and declaration of energy consumption and greenhouse gas emissions of transport services,
GLEC Framework	framework combining existing standards and methodologies to calculate logistics emissions

The European Norm EN 16258 “Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)”, addresses transport chain related issues for both freight and passengers, as its title states. The standard does not provide guidance on how to calculate emissions from logistics nodes though. It is left up to the user of the standard to describe how they included nodes in their calculations. Different approaches, and subsequently different calculation results, are therefore allowed within the standard, rendering a comparison of calculations impossible. Also, the standard allows the use of different levels of data quality and accuracy for different levels of detail of calculation. Boundaries of vehicle operation systems (VOS) are not clearly defined and the standard allows the use of different units for the allocation of GHG emissions, weight or tonne-kilometers, putting the fairness of allocation in question (Ehrler et. al. 2016). Beyond these considerations and perceived issues, the EN 16258 is a European norm. It might prove difficult for a European norm to be accepted on a global scale.

To close the identified gaps and to lift the transport chain specific standardization efforts on a global scale, the Global Logistics Emission Council GLEC has developed the GLEC framework for logistics emissions methodologies, which was published in 2016 (Smart Freight Center 2016). Based on the Greenhouse Gas Protocol, the GLEC framework is in line with the EN 16258.

GLEC itself is “a group of companies, industry associations and programs that want to make carbon accounting work for industry; it is backed by leading experts, governments and other stakeholders.” (GLEC 2017) With this motivation and backing, the GLEC framework is providing simplicity and flexibility as necessary for being applicable by industry, balancing these characteristics with accuracy and transparency as requested and expected by research, governments, and other stakeholders (see Figure 2: Tenets of the GLEC Framework, adapted from Diekmann, COFRET).

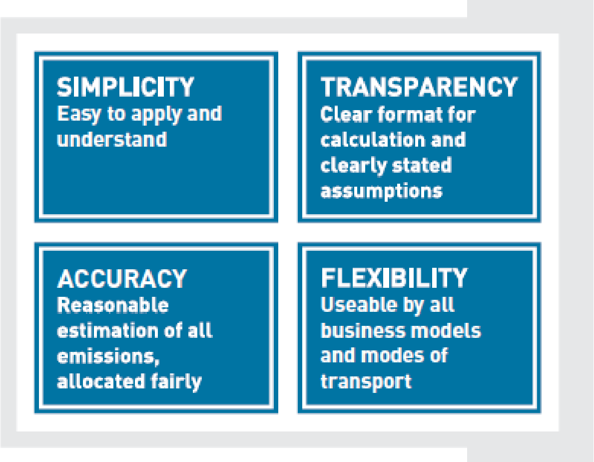

Figure 2: Tenets of the GLEC Framework, adapted from Diekmann COFRET (Smart Freight Center 2016)

It is covering all transport modes, is internationally applicable and provides clear guidance on the sourcing and use of data, both for trackable data as well as for default data. In its targeted scope the GLEC framework states that it aims to cover the full well-to-wheel approach for the fuel life cycle and the inclusion of the following Greenhouse gas emissions: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3. Furthermore, the inclusion of short-lived climate pollutants like Black Carbon and fugitive GHG emissions like methane slip and HFC leakages as well as air pollutants, such as NOx and particulate matter is aimed for with a future version of the GLEC framework.

The document describes its gaps, which are to be covered in future editions, as the following:

- Inclusion of black carbon into GLEC (part of 2016-2017 planned activities)
- Refining modal default factors, organized by TSC (Transport Supply Chains) and geographic region
- Improved accounting of scope 3 emissions
- Identifying sources of uncertainty and quantifying the degree of uncertainty within default and primary data in order to better understand the accuracy of emissions estimates
- Challenges in data collection by SMEs and in developing countries
- Transshipment center methodology, including application of TSCs in large and small businesses
- Development of default dataset of transshipment center TSCs
- Further research into weight of contents of containerized loads
- Harmonization of approach to allocation between passengers and freight in instances of shared transport
- Consistent accounting for leakage of gaseous fuels and refrigerants
- Translation into other languages

Taking these gaps into consideration, the GLEC framework meets the requirements mentioned for a globally applicable standard for the calculation of emission of a transport chain.

In the next section it is discussed whether the current status of a standard as developed with the GLEC framework is also able to cover the requirements of emission calculation and monitoring within the PI, taking into consideration its basic principles.

4 Relation of basic principles of PI to current emission calculation standardizations – challenges and gaps

Following the reflection on the basic principles characterizing the PI (see section 3), it is mainly three aspects that are directly related to the calculation of transport chain emissions: characteristic 5 (the evolution from a point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport) characteristic 7 (the activation and exploitation of an Open Global Supply Web), and characteristic 10 (the deployment of open performance monitoring and capability certifications).

Emission calculations approaches distinguish between three different levels of calculation (IWA 16:2015):

1) Level of operation of transport chain element (TCE), where a TCE is a logistics operation; the sum of all TCEs builds the transport chain (see Figure 3: Transport Chain and TCEs)

2) Level of network including company level

3) Level of cargo.

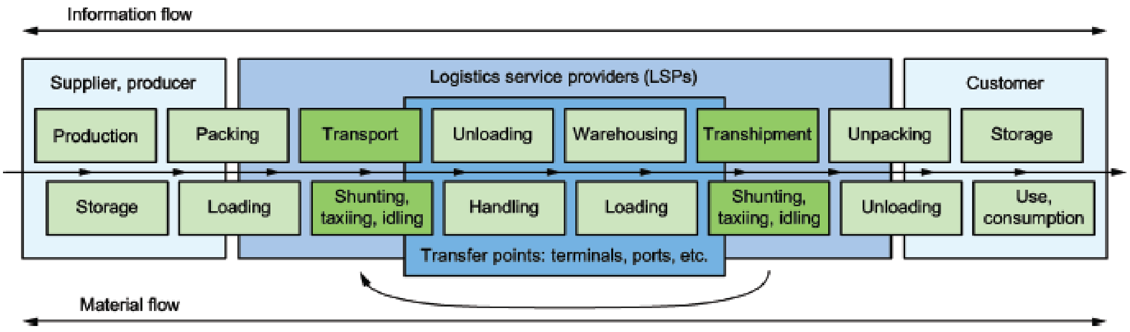

Figure 3: Transport Chain and TCEs (IWA 16:2015)

In the following these levels shall be considered separately in relation to the mentioned characteristics of the Physical Internet relevant for emission calculation. Emission calculations need to be based on measured energy consumption, in order to be meaningful. Measured data of completed transport can be used to evaluate existing transport structures and to identify best practice (ex-post emission calculation). To steer transport in a PI in a way that it causes as little greenhouse gas emissions as possible it will be necessary to evaluate expected emissions at each node (ex-ante emission calculation) and to integrate mechanisms which take Greenhouse gas emissions into account when they provide signals to production and intra-logistics systems so efficient and sustainable decisions for entire supply chains are taken. Therefore, the impact of the PI principles on ex-ante and ex-post emission calculations will be considered separately.

Level of operation of transport chain element

The concept of TCEs is compatible with the node-to-node concept of the Physical Internet. It is therefore to be expected, that the impact of a shift from current structures to the PI has no major impact on the requirements for a calculation of emissions for transport chains, neither ex-ante nor ex-post.

Level of network including company level

Calculation of emissions of transport chains on a network level are at the heart of current standardization efforts. Currently, decision makers of logistics are customers, shippers or consignees, who usually decide on the transport mode, and logistics providers, who organize their network and steer its utilization. A shift to PI results in a shift of decision maker: customers of transport will set parameters for the shipment. According to the basic principles of the PI though, decisions on routing details will then be taken at each node automatically. These decisions on routings, taken at each node will have to take into account the energy consumption and emissions expected for the next leg of a shipment's routing. Choices will be made ad hoc on the basis of ex-ante calculations for each of the possible legs. A direct steering and active contribution of the transport network provider toward minimization of network emissions is not possible anymore.

The ex-post tracking of emission will be easier as far as following the moves of a shipment is concerned, since the smart π-container provides information on its "live and historical performance" (Montreuil 2011). Capturing energy consumption of a specific transport vehicle with the transport of a shipment will have to be supported by software which is able to align specific vehicles with specific shipments. Otherwise, default data for emission calculation will have to be allocated to a shipment for the emission calculation.

Level of cargo

Decisions on the transport of a container from one node to the next can be taken with different levels of autonomy in the aimed for distributed multi-segment intermodal transport network. During the shift from the current point-to-point system to the full Physical Internet all degrees of decentralization are thinkable. In the ideal PI of an open supply web with a high percentage of distribution and production centers available to many clients, shippers would define the final destination, the requested time of arrival as well as the monetary budget at disposition for the shipment (Montreuil 2011). Furthermore, for ensuring an optimized energy efficiency of the shipment's transportation, parameters defining an "emission budget", have to be programmed prior to the shipment's departure. Based on these parameters for the budgets of money, time and emissions, ex-ante estimations have to be carried out at every node before it is decided, which route the shipment takes. The challenge is though, that the estimation for one node-to-node connection is not a sufficient basis for the identification of the optimized solution for the shipments entire route. With the sum of emissions being the total of the emissions of the legs constituting the entire journey of a shipment, the full amount of emissions is only available once all elements of the transport chain are known.

$$\begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ \vdots \\ v_n \end{pmatrix} \rightarrow \boxed{\begin{matrix} n \\ \sum (v_i) \\ i=1 \end{matrix}}$$

with v_n= CO_2e per TCE

Decisions which seem best for the instant pending next leg might result in restricting later legs to poor solution. The identification of the next best leg cannot be separated from the analysis of emissions of the entire transport chain. At each node it would therefore be necessary to anticipate options and their probability of the nodes following throughout the remaining network through which a shipment is travelling on the way to its final destination, similar to the calculations of a chess computer. The complexity for such a program will be challenging.

Summarizing, the following aspects currently pose the central challenges regarding emission calculation in the PI:

- ex-ante calculation of emissions in an ad-hoc network as basis for identification of overall lowest emission transport choice,
- optimization of transport networks which require the steering of usage of the network by its provider, and
- linking information of a shipment to information on the transport device it was carried with on every leg of its journey.

These are important aspects though for the optimization of the efficiency of freight transport and its emission reduction.

5 Conclusion and outlook – are we there yet?

To reach the agreed climate targets, it is necessary to decouple growth of economy from growth of transport demand by improving freight transports efficiency. PI is expected to support this improved efficiency, thus contributing to the realization of the emission reduction. The precise emission reduction that can and is realized by a change in transport chain concepts and structures has to be measured though. The currently existing transport chain emission calculation standardization efforts provide for a good basis for such a measuring.

Still though, important gaps need to be closed, both related to the PI as well as to the emission calculation standardization. Beyond the list of developments that are targeted for a future version of the GLEC framework, the gaps that we need to address are mainly the following:

- Empty containers need to be included in the emission calculation standard based on an analysis of their routing within the PI;
- Categories of goods suitable for the PI need to be identified, their transport requirements specified, their volume estimated and their transport routing established in order to estimate the potential maximum impact of the PI on the freight transport system's efficiency;
- The impact of PI on sustainability including environmental, economic and social aspects needs to be established;
- The paradigm shift in economics and business which is needed for a successful introduction of the PI if overall efficiency of transport is to be maximized needs to be discussed and considered;

2020, the targeted and needed point in time for Greenhouse gas emission peak, is in three years. It is important to improve the efficiency of freight transport quickly, without such an efficiency improvement resulting in more transport capacity offered. Measuring the effect of changes to transport chain concepts, such as the introduction of the PI, needs to go beyond the evaluation of transport only. Instead, it has to include the entire supply system.

We are not there yet.

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INNOVATION PAPER

Collaborative City Logistics in hyperconnected delivery networks

Roland Frindik[1] and Max Prudon[2]
MARLO Consultants GmbH, Karlsruhe, Germany
Binnenstadservice Nederland B.V., Nijmegen/Maastricht, Netherlands
Corresponding author: roland.frindik@marlo.no

Abstract: *Supply chains with rather small volumes in a disperse network are rather fragmented. City logistics is an example, where Physical Internet is a real game changer in this type of business. Binnenstadservice Nederland B.V. is an advanced operator of a network of city hubs in the Netherlands. What has been missing is an IT tool which enables collaboration between involved stakeholders. Therefor the SaaS MixMoveMatch from MARLO has been implemented in 2016 to proceed fast planning of consolidation of shipments in the city hubs as well as the routing and delivery in the city distribution. MixMoveMatch also controls the various processes in the cross docking. Through easy to install standard interfaces data can be imported from the various suppliers and carriers who feed cargo into the hub. The operation in the hub and at the last mile can be done with only one solution and its device substituting the confusing variety of systems to be handled previously. Existing TMS and WMS can remain which keeps new investments to an absolute minimum. This approach enables in an economically feasible way a level of visibility and high quality distribution which hardly existed until now for small volumes of parcel shipments.*

Keywords: *city logistics, collaboration, last mile, consolidation, parcel delivery, return logistics*

1 Introduction

Nowadays 40% of the transport costs are in the last miles. City logistics is 30% of the freight volume, but causes 70% of the traffic congestions in the cities. A drastic growth of delivery addresses and much higher frequency of smaller deliveries is to be foreseen by the expanding e-commerce business. Changes in distribution channels in the direction of platforms and portals lead to small scale logistics services that are individualized for customers. [Kersten et al.]. Consequently, the impact of delivery vehicles will increase, notable their emissions and omnipresence all over the day. Technical measures as electric vehicles are not sufficient to solve the problem. The solution must start at the root cause, the organisation of the supply chain. Digitalization of business processes and transparency in the supply chain are the most important trends [Kersten et al.]. Also an enabler for collaboration is needed.

This innovation paper presents an approach which has been developed by Binnenstadservice Nederland and MARLO to improve the impact of city logistics in a much more competitive and sustainable way.

The implementation has gone even a step further beyond the city hubs as all stakeholders from shipper, long distance hub and carrier as well as city logistics hubs and last mile delivery could be involved in the same application. At the first time, each stakeholder is now able to check only his relevant data at any time. Notably the shipper gains an overview on the distribution of his products throughout the network of all city hubs until proof of delivery at shops and customers. Usage of capacities at long distance and at the last mile are increased as the systems works on parcel rather than pallet level. Short-term changes due to ad-hoc demand or incidents can be made through an update of the planning. Increase of volume and additional stakeholders can be covered due to the modular scalability of the solution. Urban logistics hubs and consolidated distribution becomes much more attractive as they can much better be integrated both in a synchronised physical and information flow throughout their network. Delivery to multiple cities becomes transparent.

2 Objectives

The overall objective is to optimise the inefficient small-volume flows of goods in cities. This is done by neutral smart city hubs that coordinate and consolidate the flows. Nevertheless, the existing smart city hubs are struggling with the same challenge: how to get more volume to make a significant impact in cities and at the same time make their business economically more sustainable? If this efficiency improvements can be achieved the likelihood of the establishment of further smart city hubs in much more cities all over Europe will be increased substantially.

3 New approach to city logistics

The ‘Triple X and Triple P’ solution is a novel integrated approach to make Smart City Hubs work for the cities and create the impact that is needed. The approach is working in parallel both on the private and on the public side. At the same time, it works in parallel both upstream and downstream in the supply chain. This new approach is born out of experience in city logistics. New smart city hubs will be involved by simultaneously working on involving new shippers, connecting the local governments and connecting the hubs to the IT platform.

3.1 Structure of Triple X

Every city above 100.000 inhabitants needs a local independent smart city hub of at least 1000 m². Smaller cities may bundle their volume in common smart city hub of which delivery tours cover one or several of these small cities. The three main pillars of the value proposition concern the physical, financial and IT level of coordination and connectivity at a smart city hub implemented by the private service provider.

3.1.1 Physical cross-dock

The physical cross-dock is an integrated network of innovative smart city hubs. These hubs consist on the one hand of the physical infrastructure as warehouses and hub buildings as well as devices required to handle and move the shipments (sorting facility, forklift truck, scanner, rack storage etc.). All hubs should be connected in the Smart City Hubs Europe network not only for the purpose of cooperation in marketing and sales but also to provide a uniform service in distribution and value added logistics which improve their competitiveness significantly.

3.1.2 Financial cross-dock

The financial cross-dock is an attractive financial value proposition for all stakeholders involved in the city logistics supply chain. It ensures that all stakeholders profit from a win-win situation. The possibilities for bundling of deliveries creates lower price per delivery stop. End receivers should be able to ask for a city logistic Incoterm, creating a better fit with their demands.

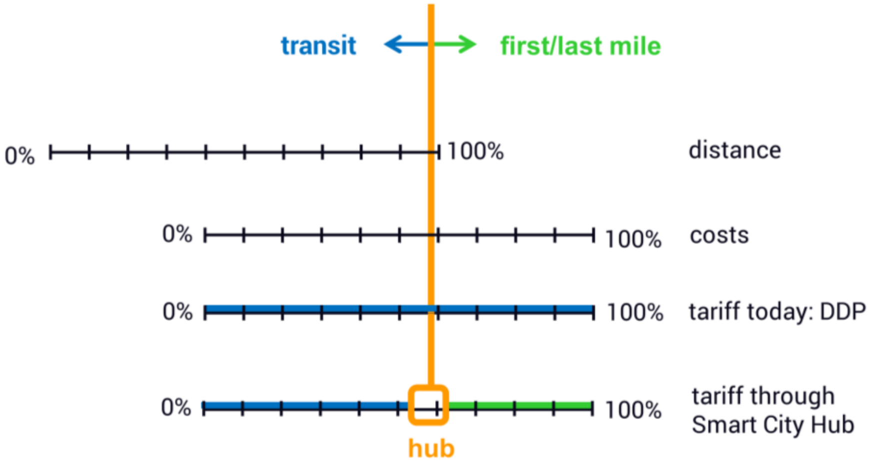

Figure 1: costs and tariff today and with Smart City Hub

3.1.3 *IT cross-dock*

The IT cross-dock is a software services to ensure seamless and integrated processes across the network supply chain. The leading IT platform which provides the required features is MixMoveMatch.com. This solution provided a layer of collaborative intelligence over the supply chain that would take decisions in real-time to optimise cost and performance.

3.2 Structure of Triple P

The governments have to create the trigger for the industry stakeholders to change their logistic behavior, ‘the triple P for municipalities’. The three main pillars of the complementary supportive activities on the public administration and policy side are policy on sustainable logistics, procurement and promotion level.

3.2.1 *Policy on sustainable logistics*

The municipal council can make a significant contribution by shaping an adequate framework in terms of an explicit sustainable urban logistics policy. A main driver are the ambitions towards a reduction of the impact of logistics activities on inhabitants. This can be achieved by zero-emission logistics regarding noise and exhaust. Furthermore, the duration of the presence as well as the frequency of delivery trucks in sensitive city areas (residential or pedestrian areas) can be reduced significantly.

3.2.2 *Public procurement*

City governments can use their purchase-power to make their own supplies zero emission and energy neutral. The benchmark for the evaluation is not only the lowest price which counts, but especially environmental impact due to the applicable sustainable urban logistics policy is highly relevant. Tenderers who make use of environmentally sustainable goods and supply are evaluated higher.

3.2.3 *Promotion and publicity*

City governments can promote the solution while at the same time maintaining the level playing field that is needed to balance interests. The alderman can play her/his symbolic role by providing opening acts and doing presentations at conferences. The local government can use social media to seek publicity for the solution thru various channels (e.g. twitter, Instagram, apply for awards etc.). The city government already knows the local logistics community very well and by being a neutral public body itself it is easy for them to approach and convince potential partners. City government may also give the floor to the solution on conferences, and workshops. Finally, the city government may also coordinate on a national or even better on an international level through city associations working as a coordinator and multiplicator. The city government already experienced with their city logistics approach can inform and convince other city governments about their solution. The cities can support city logistics solutions significantly by coordinating between each other so that their solutions provide similar service or in the best-case act together at the market.

4 Best practice case Netherlands

Binnenstadservice had started its operations in 2008 in Nijmegen and s´Hertogenbosch with start financing by the Dutch state. Since than more and more small and big retailers are served so that operations could grow gradually and into profitability. The ambition is to create 24 hubs serving 40 cities in the Netherlands. To achiev this goal, it became obvious that further measures needed to be undertaken to make the operations more efficient and the usage for the customers and stakeholders much easier. That is why MARLO get involved in 2016 to improve planning, information management and exchange significantly by applying its cloud-based supply chain management software MixMoveMatch.

4.1 Network configuration

The 9 smart city hubs branded Goederenhub in the Netherland, initially at Nijmegen and Maastricht, do work as consolidation centers for various shippers, logistics service providers and couriers. Previously they all deliver their shipments into the city hubs avoiding their own time consuming and therefor costly delivery tour within the city. Doing so they can increase the efficiency of their line hauls. For the consignees, mainly retailers, value added services as buffering or return logistics can be offered by the city hub operator. Therefore, commercial contracts have been signed between Binnenstadservice Nederland and the consignees.

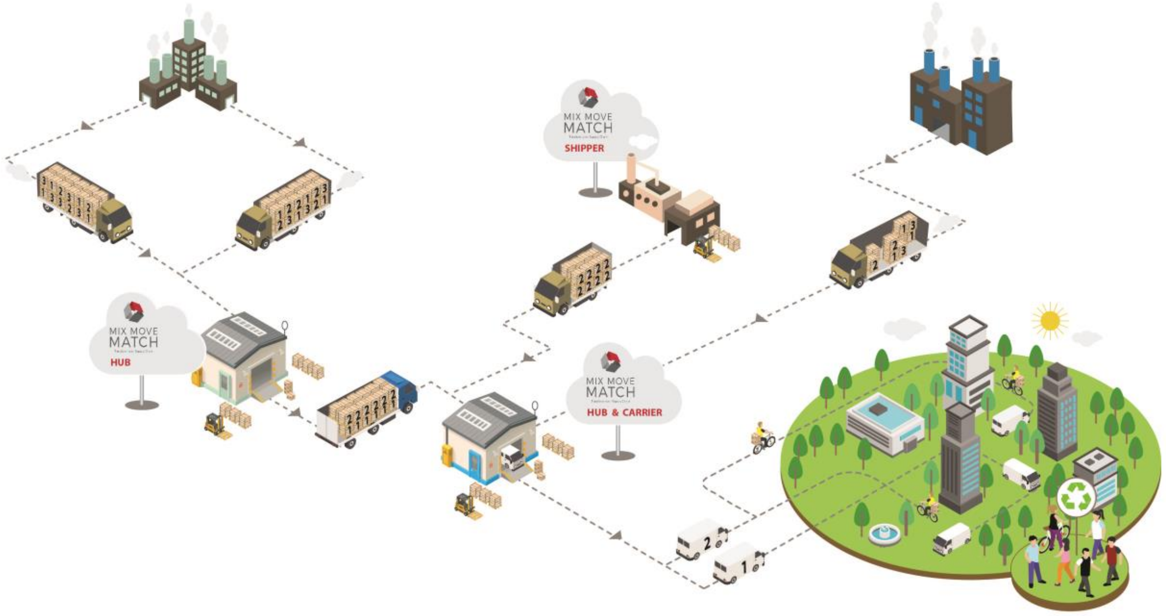

Figure 2: Full smart city hub distribution network

4.2 IT solution MixMoveMatch

MixMoveMatch.com provided a layer of network collaboration that filled in the integration and collaboration gaps. It enables a seamless integration with all kind of services along the supply chain. At the same time full control and visibility over the handling and delivery process can be gained. MixMoveMatch is based on a holistic approach for supply chain management on parcel level, even so it does consist of three portals dedicated to shippers, hubs and carriers to provide the toolset appropriate to their specific needs. MixMoveMatch.com was appointed by the European Commission as best innovation in Europe in the category of Information and Communication Technologies for Society. It has enabled 3M to reduce emissions related to line haul logistics in Europe by 50% and related logistics cost by 35%. For further details on the hub features of MixMoveMatch please check the presentation 29 at IPIC 2017 [Pedersen, J.T. et al.].

In May 2017, MixMoveMatch has been implemented and is operational in more than 30 locations in 18 European countries handling more than 2 million items per month. Binnenstadservice Nederland became the first user who applied MixMoveMatch in the city logistics business in 2016. The highest benefits of the holistic supply chain managament solution for all stakeholders, but notably for shippers, can be achieved if suppliers, carriers and hubs are covered throughout the supply chain from supplier to consignee (see central flow in *Figure 2*). If mainly the optimisation the usage of vehicle capacity should be achieved the involvement od the various hubs in a supply chain is sufficient (left flow in *Figure 2*).

Another city logistics implementation could be done at the cargo bicycle carrier Camisola Amarela in Lisbon, who aquired a new customer instandly after implementing the IT-solution MixMoveMatch due to its capability to exchange data using standardised interfaces.

4.3 Benefits observed and experiences made

Completing the triple X and triple P model by involving MixMoveMatch Binnestadservice nederland gained the following benefits and made the following experiences with the approach taken:

- added value for shippers, carriers and consignee are highly relevant
- it is profitable notably for smaller retailer and companies
- start financing is necessary in most cases – operation needs to be profitable on long term
- reduction of frequency of unloading/loading activities and presence of delivery trucks on city roads could be achieved [van Rooijen]
- there is little effect on air quality due to dominance of other emitting vehicles [van Rooijen]
- the software offers higher flexibility while at the same time reducing administrative effort
- the software enables consolidation of increasingly smaller shipments
- the software makes city logistics more attractive due to a much easier embedding in the supply chain from shipper to consignee
- with an increasing number of participating cities, the benefits increase disproportionately
- finally, it is a best practice case for other cities, even the smaller one

5 Benefits for all stakeholders

The combination of neutral acting urban logistics hubs and cloud-based management offer the following benefits to the advantage of all stakeholders in the supply chain:

- free choice of each single logistics service provider in each part of the logistics chain by the shipper

- bundling even of the smallest volume to reduce delivery tours within the city
- flexible integration of delivery tours in the city centre on the physical and IT level
- continuous visibility of the supply chain in all cities served for all stakeholders regarding the data allocated to them,
- guarantied confidentiality of the data by a neutral IT service provider
- demand specific scalability of the performance criteria in cross-docking und on the delivery tour
- short-term responsiveness on changes and deviations due to a fast IT-based planning
- short cycle time from shipper to consignee due to short-term dispatching of ad-hoc orders
- low initial threshold even for small volumes by applying user-dependent pricing
- integration of further service provider due to standardised interfaces
- applicable even for smallest volumes for delivery to retailers and customers (B2C, B2B)
- enable shippers to postpone and trigger the customization of their load (goods to be delivered) close to their receivers (customers).

6 Conclusion

The implementation of a fully collaborative network of city logistics hubs and services is at its very beginning. The long-term vision is to implement a network of smart city hubs all over Europe. A step forward has been done by convincing Rome and Gothenburg to test the approach notably regarding the IT solution in their local environment. City logistics hub will only succeed if they are acting together with one face to the customers.

There are ambitions on the way to create the right governance structure of the group of Smart City Hubs. The approach is to develop a constructive and effective collaboration between the individual local Smart City Hub companies. Regarding the ambition to create a European organisation based on good governance principles a method will be developed for steering this organisation by providing valuable ‘open’ construction principles and procedures that can be used for designing and running this wide range of organisations.

Furthermore, there are several incentives from the sharing economy. An increasing fragmented and volatile demand for logistics service requires an increased flexibility on the supply side. An example is the share of warehouse space or delivery vehicle transport space [Gesing]. IT-solutions are the enabler to be able to manage such complex and fast acting processes in competitive and environmentally sustainable way.

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Modular Solutions for Mobile Hospitals

Stephen Spulick[1], Grainne Lynch[2], and Changliang Liu[3]
1. US Army Medical Materiel Agency, Maryland, United States of America
2. Chartered Institute of Logistics and Transport and Lynchpin Innovation, Cork, Ireland
3. CILT(London), CIRRELT and McGili, Montreal, Canada
Corresponding author: stephen.spulick@gmail.com, grainne@lynchpin.ie, liuchangliang.mcgili@gmail.com

Keywords: *rapid deployment, medical systems, modular hospitals, mobile hospitals, military hospitals*

1 Abstract

The requirement for rapidly deployable medical capabilities, such as mobile hospitals, has been recognized from the time of the US Civil war to more recent occasions (Hoyle, 2004, Mohr et al, 2005) for military and non-military requirements. Hoyle (2004) describes the conversion of a semi-trailer to support readiness outside of Cincinnati, Ohio in the 1960s and Mohr et al., (2005, p. 91) describe a more modern and robust MED-1 which "is the nation’s first fully equipped mobile surgical hospital and consists of two 53-foot tractor trailers, one of which stores equipment and the other a fully functional patient care facility. The facility center morphs into a 1,000-square-foot workspace featuring a two-bed shock–resuscitation and surgical unit and a 12-bed critical and emergency care unit. MED-1 also includes materials for a climate-controlled tented area holding 130 additional beds".

While effective in local and regional circumstances due to mounting on tractor trailers, they are currently less mobile if desired to support non-contiguous requirements, for instance during the recent Haiti earthquake, which required mobile military hospitals to be utilized (Pape et al., 2010, Kreiss et al., 2010). The ability to rapidly move a standardized and scalable medical package, capable of rapid expansion and replenishment is critical. Potential barriers to adoption by Military-civilian and Humanitarian organizations are discussed. Future research opportunities are identified.

2 Introduction

Hospitals are a vital part of healthcare provision to a population. Hospitals may be either fixed facilities, used regularly by a population at risk, or hospital capabilities can be mobile. These mobile capabilities can be used to provide a higher level of care in a regularly underserved population, such as many rural areas, or they may be used in contingency operations. The latter is the main focus of this research, as those facilities must often move rapidly and efficiently in a constrained logistics environment.

Often, the requirement for a hospital in a given location is unknown until a short time before the requirement (Kovacs and Spens, 2009). In some cases, such as hurricane Sandy along the East Coast of the United States in 2011, onshore destruction was highly anticipated within a span of approximately 7 days. The unknown however was the extent of the damage in the location at which the damage would occur. Likewise, the severe destruction caused by hurricane Katrina in the New Orleans, Louisiana area of the United States stopped services entirely at many fixed facility hospitals. Earthquakes in Pakistan, tsunamis in Japan, and other threats to life occur regularly. Often, help is requested from outside organizations, and some responders, such as a military organization, are uniquely equipped to respond.

Research by the Fritz Institute (Thomas, 2003) has identified several key challenges to humanitarian organization response to disasters. Likewise, military responses are often guided by the political realities within their government, or overarching homeland requirements.

3 Unplanned Hospital Employment

3.1 Humanitarian

The goal of a humanitarian operation is to bring relief to those who are suffering. The suffering can be caused through environmental changes or through civil or military unrest. Often, the result is a reduction or destruction of critical infrastructure performance. The provision of healthcare is a critical part of most infrastructure designs. Some events can be forecast. These may result from environmental effects that have long cycles or civil and military unrest that has occurred for greater than a short period of time.

Often, the permission of a government must be obtained or a request received from the government in order to move humanitarian aid to support an effected population. The required permission is a complication for those tasked with providing logistics to support the move of a hospital. Affected infrastructure may include roads, airports, and seaports as well as warehousing and cross docking facilities. Therefore, shipments with the smallest weight and most efficient use of cube will take the most advantage of limited and constrained resources.

3.2 Contingency

Contingency use in this paper will refer to the short-term requirement of a military force to deploy hospital medical assets. Militaries of various countries around the world maintain different postures based on requirements of their government and ability to provide appropriate material. To this end, some countries have small defensive forces which are designed to remain within the political boundaries of their home nation. Other countries have forces which may be considered more expeditionary and nature (Pettit and Beresford, 2005).

Expeditionary forces may be used to project military capabilities over great distances. These may be within a region, within a hemisphere, or globally. Countries that have the capability to project a military force globally often also have the required C and airlift to move those assets. There may be limitations and bottlenecks based on force requirements and the situation to which the military force is responding. Additional constraints may include available funding for the operation as well as country clearances and force availability.

3.3 Preparedness

Requirements for hospitals to support preparedness in the context of this paper, include a mobile hospital facility that resides in storage to support an unplanned or planned closure or repair of a facility or to maintain the civil capability to respond rapidly in the event of an outage of critical local infrastructure. Additionally, hospital systems may purchase, store, and maintain the capability to deploy in the event one of its facilities has degraded capabilities. This use is generally outside the scope of this research at this time.

4 Hospital History

4.1 US Civil War

Early healthcare systems provided rudimentary care to patients who presented themselves to personnel working as doctors. During the pre-Civil War time, there was little standardized care provided. The United States Civil War (1863 to 1865) was witness to terrible carnage inflicted by both sides of the conflict. The surgeon general of the northern forces, Surgeon General Hammond, was frustrated by the lack of capability to remove the wounded from the battlefield and it eventually comes to medical care. The result of this frustration was the formation of a standard Ambulance Corps, developed by Letterman.

Letterman's Ambulance Corps was seen as a very successful innovation to battlefield care. One of the most remarkable demonstrations of the capabilities of a trained, staffed, and equal force occurred during the battle of Antietam. Antietam is the bloodiest single day of fighting in United States military history. Over 22,000 soldiers were casualties that day. Of the approximately 17,000 who were injured, it is estimated that one in seven would die from their wounds. The Ambulance Corps evacuated over 9,400 wounded from the battlefield in one day. Figure 1 illustrates the 57th New York Ambulance Corps removing wounded from the battlefield after the Battle of Fredericksburg in December of 1862.

Figure 1: 57th NY Ambulance Corps removes wounded from the battlefield 1862

4.2 World War II

Some of the most challenging terrain in which to conduct healthcare occurred across the Pacific theater. For the United States, the large fixed hospitals that were capable of seeing hundreds of patients at a single time or impractical to move, set up, and sustained across the vast reaches of the Pacific Ocean. To solve this problem, US Army Col. Percy J. Carol developed a concept of modularity, which effectively shrank the capabilities, size, and manning requirements. His development contained 25 beds, 29 staff, was able to be carried entirely by the staff and could conduct basic procedures. Its size restricted its capability to operate as a fully functional hospital Greenwood, 2009). This concept remains in use in modern day with specialized surgical facilities far forward on a contemporary battlefield.

4.3 The 1950s

Although designed to pick up and move patients from the point of injury to the point of care, prior to the 1950s ambulances served no further purpose. Innovation occurred, as is often the case, following a disaster. Healthcare providers realized that more lives could have been saved with the provision of en-route care to those who were wounded. The particular incident is referred to as the

Harrow and Wealdstone train disaster, which occurred in 1952 in the United Kingdom (BBC, 2005). Following this event, more hospital like capabilities were introduced onto the ambulance platform which was previously sparse, as depicted in Figure 2. This mobile healthcare capability, combined with emergency medical treatment training, remains in effect currently.

Figure 2: Typical 1950s British Ambulance

4.4 Modern Day

The ability of technology, combined with the skills of a physician at a remote location using standardized telecommunications devices and protocols enabled the first remote-controlled toy surgery in 2001. The patient, who required their gallbladder to be operated on, was in Strasbourg, France. The surgeons, were in New York city. This operation, popularly referred to as "the Lindbergh operation", named after the famed solo Atlantic flyer, provided proof that the technological advances could yield great benefits. This technique of telemedicine has stretched to more efficient use of time, leveraging of capabilities in different time zones, as well as efficient reach back capability for specialized diagnoses and conferencing.

Hyperconnected telecommunications are available in most any region through the use of sophisticated equipment and a robust infrastructure (Howden, 2009). The challenge is to effectively move the hospital facility where needed efficiently and in enough time to treat the wounded.

5 Speed/Material Velocity

Research conducted by the Fritz Institute (Thomas, 2003) “whose mission is to strengthen the infrastructures of humanitarian relief organizations by mobilizing logistics and technology expertise and resources”. This mobilization of resources to move to the affected area, may occur as soon as 2-3 days after the event and last the duration of the mobilization as shown in Figure 3. The 1952 UK incident emphasizes the importance of rapid movement to the wounded. Likewise, military contingencies are closely tied to prior planning for a certain area of the world where armed conflict may erupt.

Once the order is given, rapid, efficient and effective movement of much materiel begins to flow. Synchronization and deconfliction with other materiel, humanitarian aid providers and transportation is under constant assessment. This operation serves as the essential bridge between Readiness and Response and requires extensive pre-planning to be successful. While a military may be properly staffed to plan and uses a common language to communicate, HROs often lack the requisite skill sets and experience to optomize operations.

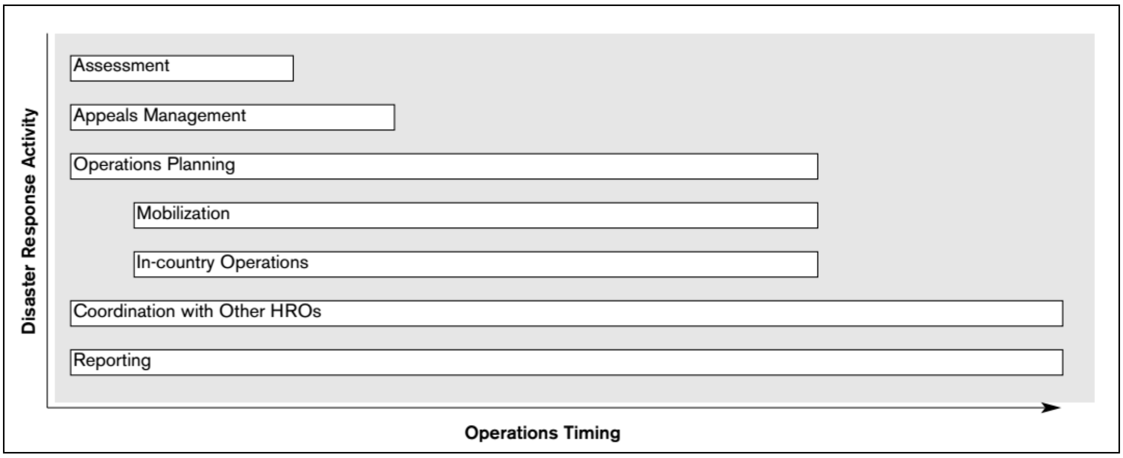

Figure 3: Major Activities within a Disaster Response Operation

6 Pain Points

Five Pain Points were identified by Fritz researchers (Thomas, 2003) as impacting a Humanitarian Relief Organizations' ability to respond effectively. 1) Donor scrutiny of funding flow emphasizes direct aid to the affected, not systems and preparedness, 2) Organizational culture and turnover such as a mismatch between roles in logistics and actual logistics experience, leading to eventual short tenures, 3) Lack of institutional learning driven by turnover rates as high as 80% in some organizations, 4) Little pre-event coordination which leads to inefficient redundancies, no coordinated efforts or standardized practices and 5) Ineffective technology leverage which is caused by funding restrictions and culture barriers such as the available ERPs lacks flexibility for material donations and rapid non-standard data inclusion.

7 Challenges

A hospital consists of over ten thousand unique items of varying sizes. The number of manufacturers involved in supplying this equipment can be several hundred, depending on the size and specialty of the hospital. There is no current incentive for manufacturers to change the design and engineering of products to improve handling.

There is very little cross-talk within the HRO community about methods to best store, organize and ship hospital capability to affected regions. When considering military and civil requirements, there is virtually no interconnectivity and cross-talk. Lack of technology innovation hampers the ability to effectively design and structure PI configured loads.

The nature of the logistics requirement to deliver healthcare assets to a area with potentially compromised infrastructure under sub-optimal conditions seems to support PI principle implementation to drive improvements.

8 Conclusion

Capabilities to deliver healthcare on a large scale to impacted populations has greatly improved since the earliest Ambulance Corps use. However, current delivery methods for mobile and modular hospitals remain inconsistent among hospital users. Military, civilian and NGOs spend little time in discussion about how to configure their equipment for shipment. Recent reports emphasize the military availability of hospitals (Rand, 2010), but assume adequate lift will be made available to move the material to a required location with little regard to ultimate efficiencies within the shipping container.

Continued research is warranted in the areas of personel capability and knowledge, qualitative research with key enablers to better and more fully understand the scope of the current challenges across key disaster and contingency mobile hospital providers, to include manufacturers identified in other PI research. Leverage use of technology to identify and explain the benefits of PI principle usage to stakeholders to encourage change.

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Physical Internet
Efficient Sustainable Logistics

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Hyper-connected Modular Renewable Energy Production

Changliang Liu1 , Suzanne Marcotte2 , Grainne Lynch3, Stephen Spulick4
1. CILT (London), CIRRELT, and McGili, Montreal, Canada
2. Department of Management & Technology, UQAM and CIRRELT, Canada
3. Enterprise Systems Partners (ESP), Cork, Ireland
4. U.S. Army Medical Materiel Agency, Maryland, United States of America
Corresponding author: liuchangliang.mcgili@gmail.com, marcotte.suzanne@uqam.ca,
grainne@lynchpin.ie, stephen.spulick@gmail.com

Abstract: *To develop and pilot the concept of hyper-connected modular and decentralized production, we should rethink Edison's vision of producing electricity on one's own. In other words, a PI-enabled Realization Web will be designed with self-supplied PI-facilities (nodes), which could form the micro-energy network with self-production, supply and utilization. This is a decentralized and hyper-connected renewable energy production network. This counters Westinghouse's idea to provide centralized electricity to nodes via transmission lines, which leads to the current conditions of electricity production using fossil fuels and hydro power. Although it is a better systemic outlook, it also leads to economic dilemma, environmental pollution and social problems.*

With the increasing demand for a sustainable lifestyle among the millennial generation, we believe that supplying electricity in a decentralized way will return gradually to the vision of its pioneer Edison. One of renewable energy's value propositions is its large reliance on decentralized operations, installation and distribution, which highly aligns with the Physical Internet founding principles. In this innovation paper, we have identified the decentralized solar energy production gap, adding on the modular and mobile micro-energy production to satisfy the needs of prosumers (producer & consumer) in the 21st century.

Keywords: *Physical Internet (PI), Modular Production, Assembly Process, Realization Web, Feasibility, Solar Energy Industry, Energy Internet.*

1 Introduction

During the evolution of human society, energy has played the most fundamental role for the survival and reproduction of human beings. The sun is the ultimate source of energy. Conventional energies are formed by solar energy that has been captured over extremely long geological periods. In Early Times, the sources of energy mainly came from the renewable ones, such as directly from photovoltaic (PV), indirectly from wind and water etc. The very first milestone of mankind's utilization of energy was the mastery of fire, for cooking and heating, using biomass as fuel. Then the next milestone for mankind was the Agricultural Revolution, which increased the world population in a substantial way. Finally, the Industrial Revolution based on the fossil fuel has been dominating the world energy landscape until today (Bithas and Kalimeri, 2016).

The world is dynamically shifting back from a centralized energy network to a decentralized renewable energy infrastructure, in a future where the consumers can support their daily energy usage. By making electricity themselves, such as system based on solar for example, they can share the remaining energy via micro-grid among the micro-community. Solar is now cost competitive compared with conventional energy sources in many regions of the world. Tenders are currently being won at less than $30/MWh. This will continue to fall by an estimated 10% per year for the next 10 years (Rifkin, 2015).

A better future aligning with the Physical Internet (Realization Web) is the mega & microenergy network featuring a large number of small power sources located near the end-users, rather than a small number of large sources located far away (Montreuil, 2011). At first glance, this shift toward micro-power may seem like a return to electricity's roots over a century ago. Thomas Edison's original vision was to place many small power plants close to consumers. The grid will be transformed into a digital network capable of handling complex, multi-directional flows of power (Edison, 1883). Mega-power and micro-power systems will then work together. Therefore, diversifying the energy mix will be crucial in the evolving Energy Internet Era.

The objective of this research is to identify the gap between the academic and industry perspectives in the field of clean energy industry, to envisage and design the integrated renewable energy network from the whole system perspective, and finally to introduce the proposed solutions for the potential market in an effective and efficient way. The remainder of this paper is structured as follow. Section 2 presents the background while section 3 presents the problem addressed and the objectives of this research. Section 4 then presents an analysis and provides insights and solutions. Finally, section 5 introduces the next steps that we propose for future research.

2 Background

2.1 Supply chain process perspective

A renewable energy service supply chain is critical in modern life, from its generation, transmission and distribution up to its consumption and storage. Assessing the renewable energy flow from the supply chain perspective is described in Figure 1 below:

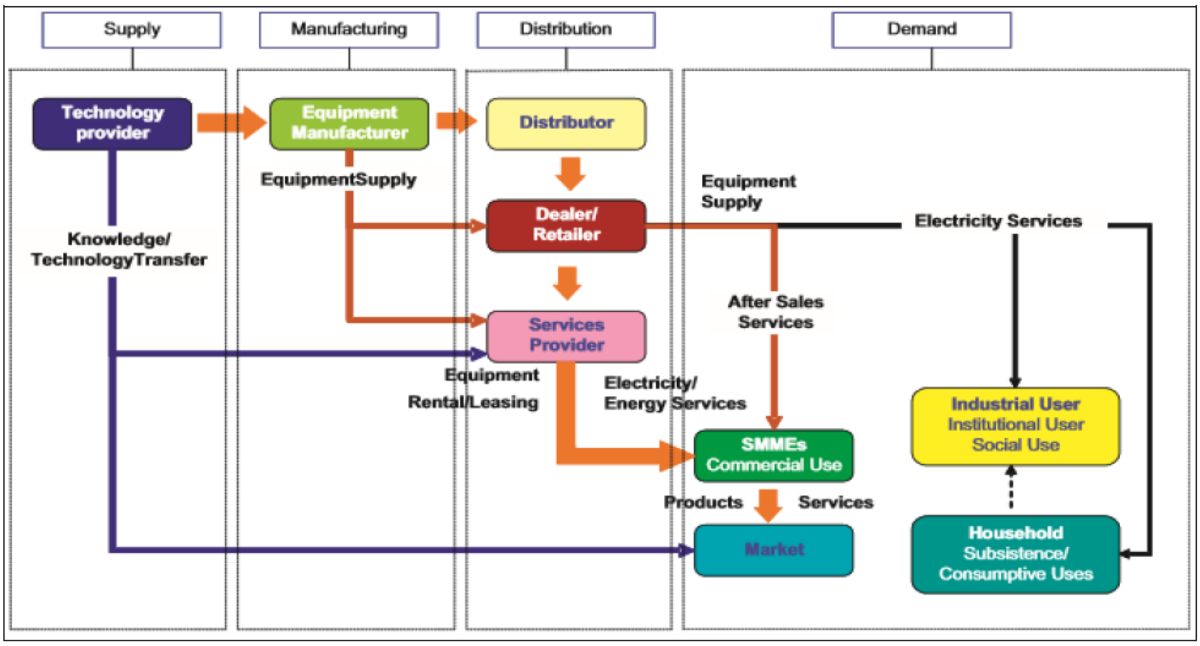


Figure 1: Renewable energy (RE) supply chain process, adapted from Wee and Yang (2012).

If we look at the investment statistics of RE in 2016, more for less (more RE installations with less capital invested) phenomenon happens, major reasons why installations increased even though dollars invested fell was a sharp reduction in capital costs for solar PV, onshore and offshore wind. Renewable energy (excluding large hydro) accounted for 53.3% of the new electricity generating capacity added worldwide in 2016, the highest proportion in any year to date.

Transforming today's centralized power grid into something closer to a smart, distributed network will be necessary to provide a reliable power supply---and to make possible innovative new energy services, such as the Brooklyn Microgrid (BMG) in New York City and Demand Energy Enel in Germany (2017). The technology exists to enable a radical overhaul of the way in which energy is generated, distributed and consumed, an overhaul whose impact on the energy industry could match the internet's impact on communications.

The distributed network will bring direct impact on the renewable energy production and storage, in terms of their locations, energy management analytics and related optimization techniques, and also will bring indirect social impacts, for example, it will give consumers more choices to select as energy sources.

The structure of the electricity market continues to be a challenge not just for renewable energy developers but also for energy ministries around the world. There is the issue of how to reward flexible generation and storage, so that the system is always able to respond when wind and solar production drops. The other challenge is the political regulation; different regulations limit the research and massive renewable energy project's scale development in the solar and wind industry. Unless regulators restore the economic incentives for investment, the future looks bleak. Apart from that, Crypto-currencies like Bitcoin could enable a truly independent peer-to-peer and global collaborative commons by providing a decentralized means to directly exchange verifiable value. Solar energy has now reached its singularity, a tipping point beyond which a technology grows exponentially. Energy transformation has never before been this fast. Similar to mobile phones and cars, solar and wind will follow an S curve of growth. We are just at the start of an energy revolution driven not only by climate change but by simple economics.

2.2 Centralized Network

From the long history of the energy evolution, there are significant disadvantages in the capacity market (which means the centralized energy network), which cause the current conventional energy dilemma. Here are some of the main disadvantages. Dirty energy generation exceeds consumption in a greatly imbalanced way. The weather and human errors frequently led to blackout. Overall, the end-consumers had no choice but rely heavily on the monopoly of power companies; the delayed maintenance response and huge cost from macrogrid network are not sustainable in the long term. Therefore, a new style of energy demand is needed: provide cheap, clean, reliable power in the face of new technologies, new types of user behaviors and an all-encompassing need to address climate change.

2.3 Decentralized Network

In the Integrated Grid Network, the core components are the micro-grid (wind and solar power in the smart house, apartment and hospital), energy storage technology and macro-grid. Our focus in this research is the micro-grid, to try to bridge the gap between the academic and real implementation in practice. According to Bloomberg New Energy Finance (BNEF), renewable energy sources are set to represent almost three quarters of the $10.2 trillion the world will invest in new power generating technology until 2040, as rapidly falling costs for solar and wind power, and a growing role for batteries, including electric vehicle batteries, in balancing supply and demand (BNEF, 2017).

Towards a demand-led energy system, the key components include the control centre, energy storage and micro-grid, complementing with the macro-grid as shown in Figure 2. Many owners of photovoltaic (PV) plants make use of the battery storage solutions to harness the energy of the sun even when it is not shining. This allows them to cover much of their own energy needs with green solar power. Higher-capacity battery storage facilities are also available these days. Not only does the utility distribution network need an upgrade to support the influx of renewable energy generation to the grid system, it must also consider that without local energy storage, the network is seriously inefficient. Energy storage is crucial to protect the vulnerability of the grid and to more effectively manage supply with demand.

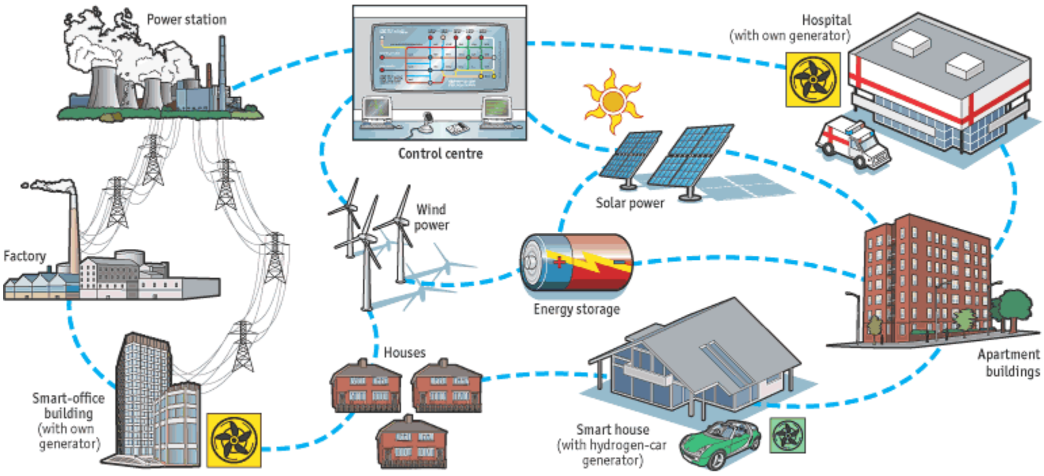


Figure 2: Integrated Grid in a distributed energy network, adjusted from Economist (2004)

For TESLA as an example, energy storage has the potential to represent a $12 billion market in the following five years. The ability to provide the network infrastructure to support energy storage and local distribution with EV recharging stations provides TESLA with a competitive advantage. The combination of the new highly efficient panels, the volume of product coming out of a new factory, and a simplified manufacturing process (automation and customization) is a big reason why the TESLA (SolarCity) expects its costs for residential solar to fall well below $2.5 per watt by the end of 2017, when the Buffalo facility reaches full production. At that point, the solar panels coming out of the Giga-factory (TESLA's massive plants in the solar industry) may seem as conventional as commodity panels produced in China today. It is, however, SolarCity's willingness to take on such risks that makes the Buffalo facility so ambitious. Over the last 10 years, the Silicon Valley company has made residential solar a popular choice for many consumers through smart marketing and attractive financing. Now it wants to transform solar manufacturing. Whether SolarCity succeeds or fails, it is once again pushing the possibilities of solar power.

Efficiency matters because the panels themselves represent only 15 to 20 percent of the cost of the full installation. Much of the rest comes in what's known as balance-of-system costs: inverters to connect to the grid, materials to house the array, nuts and bolts to attach it to the roof, the labor to install it, and so on. SolarCity's installation will require one-third fewer panels to produce the same amount of electricity as conventional installations. "Fewer panels means fewer bits and pieces, less wire, less days on the roof to install." (Francis, 2017)

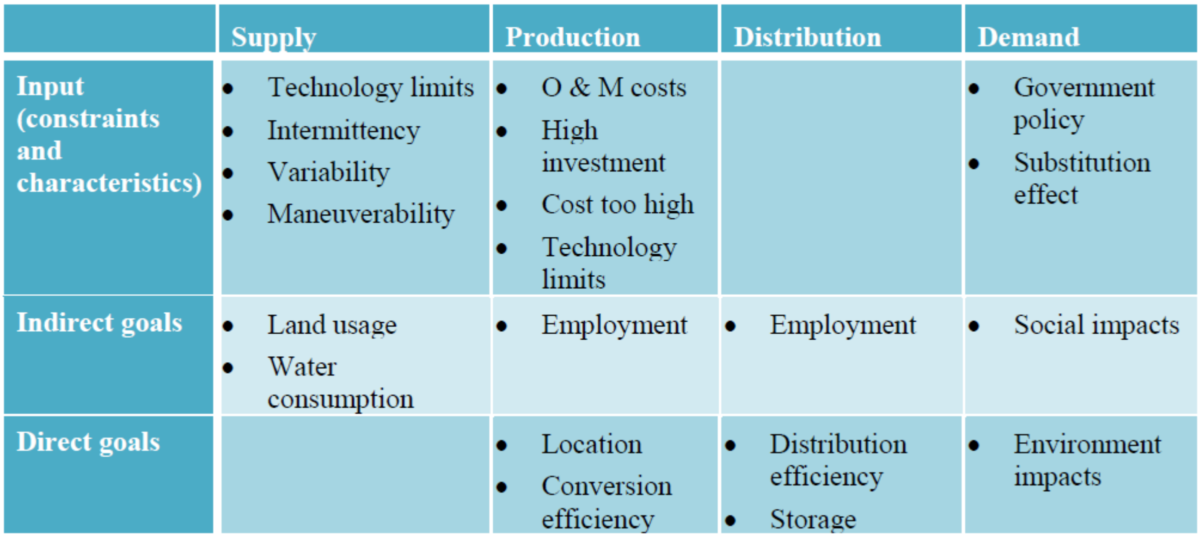
3 Problem and objectives

One of the reasons why we focus on micro-grid is that it will play a great role in a demand-led energy system. The power markets are very complex, and the supply has to meet demand, everywhere in the system, at every moment. However, its complexity can be broken down into sub-problems and we just need to focus on the fundamental issue across the renewable energy generation flows. The second key design principle of the power market of the future is suitably matching supply and demand, to a large extent, placed on power retailers, as they are near the end-consumers, they hold customers' consumption and transaction data, which are more valuable than the one owned by generators, transmission, distribution system operators, and also regulations or policy-makers (Michael, 2017).

In terms of the micro-grid performance and its sustainability goals, we need more research on them. In this innovation paper, we will focus on the micro-grid, through analyzing identified case studies, comparing and contrasting the two different business models in the power industry: Tesla (2017) and Brookyln Microgrid (BMG) in U.S.A, Himin and Global Energy Interconnection Development and Cooperation Organization (GEIDCO) in China (2017). The goal is to conduct a research initiative and investigate on the renewable energy production in a decentralized way, and have extended research based on the hyper-connected modular and mobile production (Marcotte and Montreuil, 2016), to set up the link between Physical Internet and Energy Internet towards a hyper-connected Physical Internet era.

With the expansion of sustainable renewable energy, it is gradually shifting its position as an alternative choice into the main stream energy sources, and the requirements for an intelligent, flexible power grid are increasing. The climate-friendly production of electricity will only fully pay off if the grid is able to handle all of the electricity that is generated. This requires the role of the distribution system operator to change from a reactive to a proactive one. The 'Proactive Distribution Grid' needs to assess how exactly that proactive, formative role will look. Table 1 illustrates the main constraints across the renewable energy service supply chain, from perspectives of input, goals (indirect and direct), to give clear direction for research and development. We have identified as direct goals the ones pursued in our research, while the indirect goals are expected to be indirect improvements achieved through the direct goals.

Table 1: The key identified constraints across the RE service supply chain, adjusted from Wee and Yang (2012).



	Supply	**Production**	**Distribution**	**Demand**
Input (constraints and characteristics)	• Technology limits • Intermittency • Variability • Maneuverability	• O & M costs • High investment • Cost too high • Technology limits		• Government policy • Substitution effect
Indirect goals	• Land usage • Water consumption	• Employment	• Employment	• Social impacts
Direct goals		• Location • Conversion efficiency	• Distribution efficiency • Storage	• Environment impacts

The main objective is to make grid operation flexible. A key principle in this context is the 'traffic light concept' for describing the interaction between market and grid. Therefore, ideas for optimally fleshing out the traffic light concept in terms of the technology and organization need to be developed. Network optimization will be important to dynamically design and flow the value in an efficient and effective way.

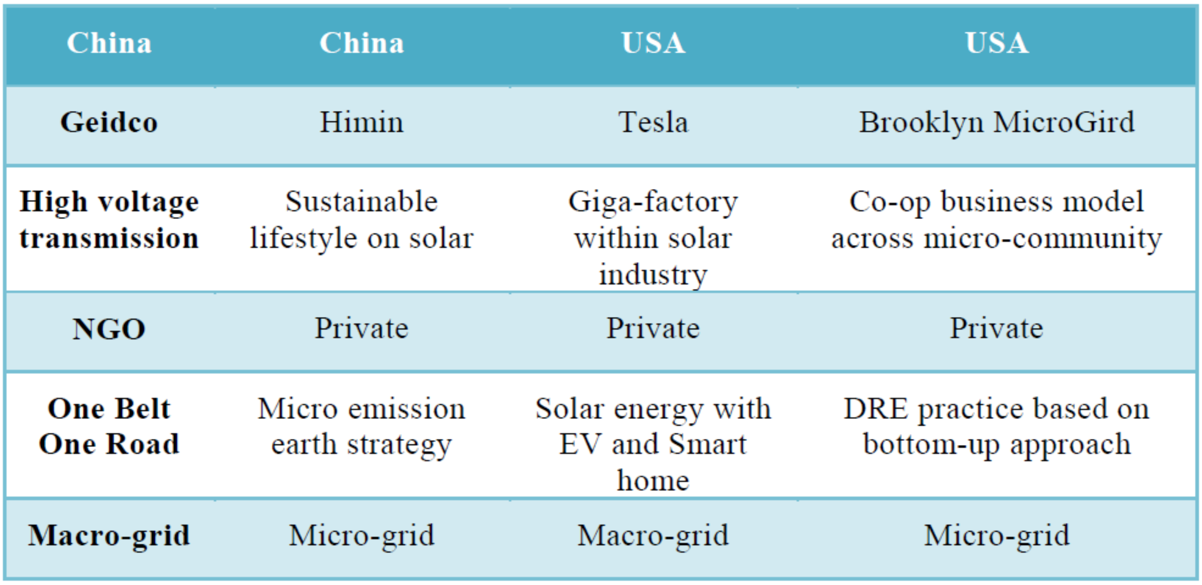
4 Analysis and solutions

4.1 Analysis

In this innovation paper, the concept of "supplying electricity in a decentralized way" has already attracted ample attention from the academic and industrial stakeholders. We are now at the singularity in the self-sustained energy disruption times. More impressive disruptions taking place in energy storage, electrical vehicles (EVs), digitalization and smart energy demand, will facilitate and accelerate the self-sustained disruptive nature of solar.

Since solar and wind power are energy technologies, not energy resources, their growth offers increasing opportunities, not challenges, when compared to conventional resources. But we should be mindfully optimistic about its future when rethinking the renewable energies (RE) manufacturing process and their respective value propositions in this particular energy market, to have the decentralized energy network with a large pool of prosumers (producers & consumers). We will compare and contrast the macro and micro grid projects between China and U.S., with specific measurements in terms of its performance and carbon emissions; than we propose a future that energy mix will be a way out for the sustainable lifestyle. Table 2 shows a preliminary comparison between the actual proposed projects.

Table 2: E-macro vs E-micro vs E-mix



China	China	USA	USA
Geidco	Himin	Tesla	Brooklyn MicroGird
High voltage transmission	Sustainable lifestyle on solar	Giga-factory within solar industry	Co-op business model across micro-community
NGO	Private	Private	Private
One Belt One Road	Micro emission earth strategy	Solar energy with EV and Smart home	DRE practice based on bottom-up approach
Macro-grid	Micro-grid	Macro-grid	Micro-grid

4.2 Proposed solution

Microgrid Prosumers Dashboard (MPD)

In the demand-led RE landscape, prosumers can identify the core data from their own dashboard, which give them a clear and transparent view on the energy generation, consumption and transaction flows.

As micro-grid gives prosumers more free choices concerning energy self-usage or trade in the micro-community, they can monitor the dashboard to make decisions on the quantity that they will sell and to whom, this is in the case that the prosumers produce sufficient energy in their own RE sources. On the opposite case, if it works as well, the Microgrid Dashboard can decide how much will be used and which neighbor to send his/her excess energy to.

The Dashboard also allow prosumers to store power in their own batteries to provide energy when the sun does not shine and the wind does not blow, as well as to set the interface to sell the excess energy to the existing major transmission and distribution network in case of extra energy. Figure 3 gives a view on an example of a dashboard.

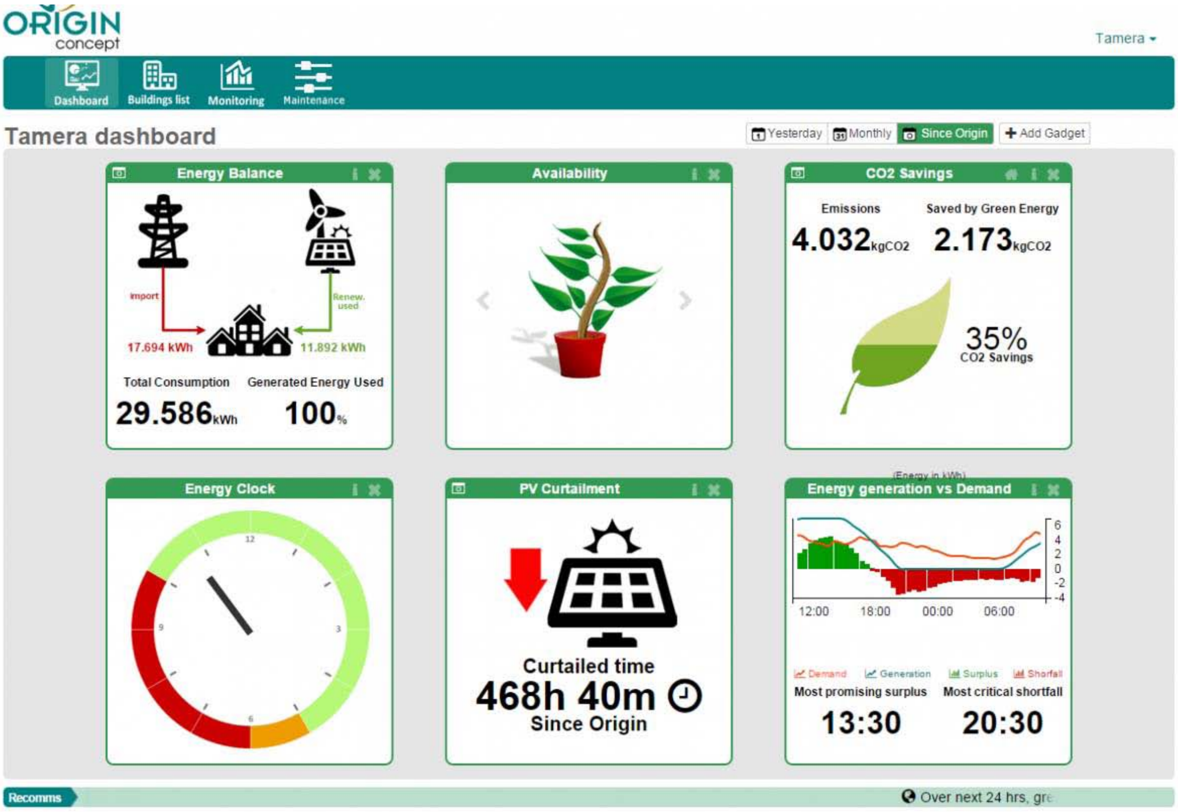


Figure 5: Dashboard, adjusted from Origin concept, adjusted from Peacock et al. (2017)

5 Next steps

5.1 Artificial Intelligence

The challenges remain in the following three aspects: Firstly, the mindset shift from the ownership to access in the coming zero marginal society, the emerging Realization Web and Supply Web will be the first enablers during the critical transformation; Secondly, Artificial Intelligence Management (AIM) in the energy service supply chain, for organizations in traditional energy industry, the question is no longer whether they should consider adopting AI in their business and strategy processes, the question is what their AI strategy should be and how to implement that strategy. For example, the solar panel system, battery storage and artificial intelligence tool can be integrated as a service for residential and industrial use, which will be transparent and cost-effective in the coming decades. Last but not least, as mentioned in the context above, the upgraded energy policy will be critical when the technology innovation is moving faster than regulations in the 21st century. It will have significant impact on the redefined market and enabling collaborative commons mindset.

5.2 Co-optimization & Mobile and Modular Logistics Unit Innovation

In the foreseeable future, with the introduction of cutting edge analytics, smart meters and software solutions, the prosumers will be more productive, as they have the potential tools to combine and process energy usage, on-site rooftop generation, thermal and electric storage, and even electric vehicle charging. They analytics can help aggregate the demand requests from the different layers and respond in an intelligent and cost-effective way. They will be able to co-optimize all resources against forecast weather conditions, basic usage demand, market reliability information and capacity market prices, in order to help them minimize the impact of reliability events and leverage excess capacity.

"Mobility as a service" is emerging in the open and sharing transportation market, with the Physical Internet prototype containers also emerging, the potential integration between PI trailer (equipped with mobile) PI-box and solar PV on the top is appearing as a further research avenue.

6 Conclusion

One of the biggest utility trends is the migration from centralized distribution to a distributed grid where more generation is pushed to the network edge. To effectively interface with the electric grid, energy storage and visibility into generation and demand are required. Strategically, the integrated and distributed grid is the foundation of the global economy for both service and manufacturing industries. The distributed grid is also required to improve national security from intrusion and manipulation of the grid. Building decentralized manufacturing networks, empowered by Industry 4.0 and technological enablers such as 3D printing, that could collaborate (vertically and horizontally) in order to increase efficiency of transport, could support this process and provide the hub with a higher role in the whole network, the modular renewable energy production unit will be the challenges related to the realization web, which opens the ample space for research and development for academics and industry stakeholders.

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A Collective Intelligence Approach for the Composite PI-Containers Management

Nicolas Krommenacker, Patrick Charpentier and Jean-Yves Bron
Université de Lorraine, CRAN CNRS UMR 7039, Campus Sciences, BP 70239
Vandoeuvre-lès-Nancy Cedex, 54506, France
Corresponding author: nicolas.krommenacker@univ-lorraine.fr

Abstract: *Standardized, smart and modular PI-Containers are key elements for an open global logistic system. The modularity provides composition capabilities to build composite PI-containers which allow efficient and easier handling or transport. In the same way, embedded technologies confer intelligence to each PI container. They become individual intelligent objects which can not only identify themselves, but can also sense and measure their environment, and communicate with others objects. From the collaboration of individual intelligences emerges the collective intelligence. This research paper proposes a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. The cognitive abilities of each PI-container, associated to a cooperative information aggregation mechanism, are used to generate a virtual object of the composite PI container. The latter makes possible to provision new services in accordance with the users/stakeholders' requirements. A guidance information service for automated PI-container picking illustrates the proposed approach.*

Keywords: *Physical Internet, PI-Containers, Collective Intelligence*

1 Introduction - Collective Intelligence

The term collective intelligence is a combination of two words where *intelligence* is "the ability of an individual to adapt its behavior to meet its goals in a range of environments" (Fogel, 1995), and the adjective *collective* meaning "shared or done by a number of people acting as a group". The MIT Center for Collective Intelligence defined very broadly collective intelligence as *"Groups of individuals doing things collectively that seem intelligent"* (Malone, 2009). This definition, at first glance, may seem very confusing. However, it reminds us two important factors of collective intelligence:

- It makes possible new actions, competences and developments resulting from interaction within the group;
- It is not simply the addition and juxtaposition of individual intelligences, although the collective intelligence relies upon this ability of each individual. It stems from their communication ability and their relationships to the environment.

The well-known example of collective intelligence comes from the American entomologist William Morton Wheeler, and its observation of ants, not as individuals, but as one single unit working in a colony which created a superorganism due to collective efforts (Wheeler, 1965). These very simple animals, with very few competencies and limited intelligence, are able to find the shortest way from one point to another, carry heavy loads or build ant-hills. They produce highly sophisticated results through collective behaviour and communication (by the means of pheromones). Another example is the online encyclopaedia Wikipedia where anyone can create a new page of information or indeed add information to an existing page. It promotes the distribution of knowledge between users, but also gives the opportunity to change or amend information that other users have uploaded. This crowdsourcing system is not a platform aggregating anonymously produced quantifiable data, but a social media arising from collective intelligence (Detlef, 2013), in which crowd contributors/consumers, volunteer content curators and social curators play a key role.

Collective Intelligence is not something new, and a large and growing literature appears in computer networks, business, political science, sociobiology, and many other domains. However, all of these experiences demonstrate that the combinations of cognitive and cooperative mechanisms are needed to achieve a collective intelligence level (Brosnan, 2010). The basic cognitive processes such as acquisition, memory or representation … are used by each individual in order to perceive its environment and develop its own knowledge. The cooperation specifies how the individuals interact between them to solve collective problem. Mechanisms such as information sharing, confidence or feedback/control can be used to develop the synergy so that a collective decision-making emerges. If the cooperation should implicitly include an aspect of coordination between individuals, the evolution and stability of this cooperation is also strongly linked to the cognitive abilities. So, there are several enablers and disablers of a collective intelligence. In the Wisdom of Crowds, (Surowiecki, 2004) provides a framework illustrated Figure 1 where the main features (diversity, decentralization and independence) in cognitive abilities are associated to a cooperative information aggregation mechanism to achieve collective performance. The diversity and decentralization ensure that each individual of the group hold a variety of opinions that draw on their own specialized or localized knowledge. Thanks to their independence, they are able express them without being unduly influenced by others.

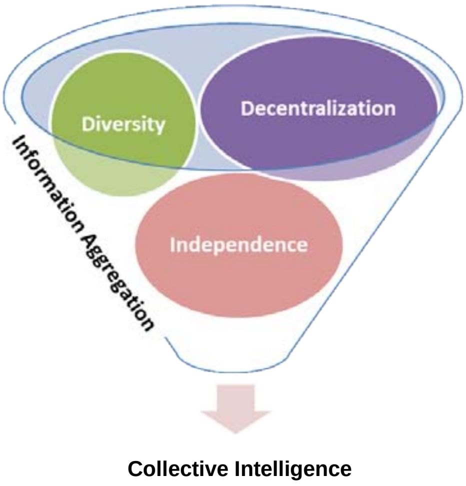

Figure 1: Surowiecki's framework

This article discusses collective intelligence in the light of smart products and how that could bring solutions to develop an efficient Physical Internet. The section 2 focuses on the collective intelligence concept apply to intelligent products/objects, also called Collective Intelligence of Things (CIoT). A collective intelligence approach for the management of composite PI-containers is proposed in section 3 and some scenarios are described in section 4. Finally, section 5 concludes the paper.

2 Collective Intelligence of Things (CIoT)

Micro-Electro-Mechanical Systems (MEMS) play a significant role in the development of intelligent products/objects. Driven by Moore and more than Moore's laws, the physical product can be easily equipped with sensors, processors, computational capability and data communication ability, in order to collect, process data and produce useful information. The major development of the Internet of Things (IoT) community in the last years is a good example (Atzori, 2010) with an increasing number of products showing more or less intelligence features. One of the most important of IoT is definitely to satisfy and to increase the users comfort (Horvath 2012), contributing to the daily rise in the quantity of new intelligent consumer products. The deployment of the product intelligence in industrial systems is also well studied since the earlier of 2000. A review of intelligent industrial product and applications in industrial domains such as manufacturing, logistics and industrial services, is detailed in (McFarlane, 2013). However, in both cases, one of the most important key elements for intelligent products is that the intelligence is a matter of degree. That’s means more the product embed electronics (sensors, memory, computational power and data transmission), more it aims at revealing the product individual behavior … in order to extract “embedded” intelligence about the individual and its environment.

Meyer et al. (2009) proposed a three-dimensional classification model, illustrated Figure 2, which can be used to classify the intelligent products in comparison to their individual intelligence degree. The classification is based on three axes: the level of intelligence, the location of the intelligence and the aggregation level of intelligence.

- *Level of intelligence.* This axis is divided into three categories to discern a product able to manage its own information (information handling) with a product more intelligent able to notify a problem to the owner (problem notification). The last degree represents the most intelligent product able to take some decisions without any external intervention (Decision making);
- *Location of intelligence.* Two situations are considered. The intelligence is external (e.g. a server running a dedicated agent for the product) and the physical product uses it through communication interface (intelligence through network). A second solution is to consider intelligence at the physical product itself (intelligence at object);
- *Aggregation level of intelligence.* This axis allows us to consider an intelligent product composed from parts. When the intelligence is distributed inside each component (intelligent container), the product can manage information, notification and/or decisions about itself and from each part. Otherwise the product is regarded as an intelligent item.

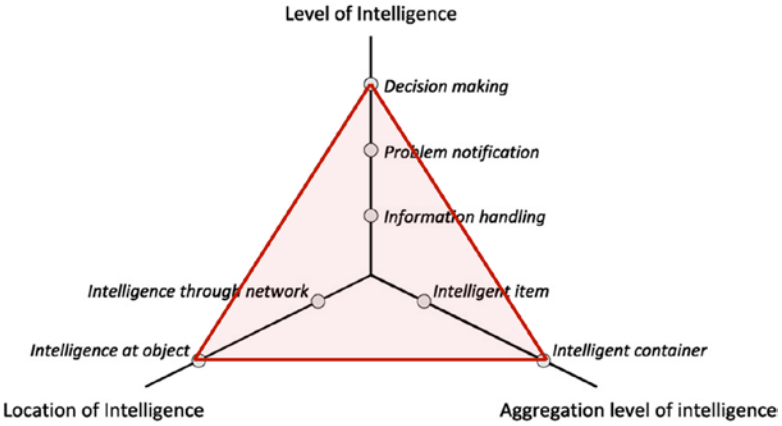

Fig. 2: Individual intelligence levels

The sum of the intelligence embedded within several individual devices, if efficiently and effectively communicated between network nodes and applications, can produce benefits above and beyond those provided by the individual pieces of equipment. In (Schreiber, 2012), the author shows that all intelligent systems (any information processing system made up of simpler devices that collaborate) have a collective intelligence potential if they can be described as a *Surowiecki machine* (Surowiecki, 2004) based on four principles:

- The devices contribute their input to the machine's aggregation mechanism, which then computes the machine's output;
- The contributions are diverse because each device is processing information in different ways (specialization), or because each device is processing different information (localization), or both;
- Each device carries out its processing mostly independently of the others, and sends its output directly to the machine's aggregation mechanism with no interference from other devices;
- The output of the machine may or may not loop back as input to the component devices.

Hence, cross-fertilize knowledge can help to address problems that occur out, but also, promote the creation of new individualized customer-services. We propose in the next section a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. The cognitive abilities of each PI-container, associated to a cooperative information aggregation mechanism, are used to generate a virtual object of the composite PI container on which new services will be conceptualized.

3 Management framework for composite PI-containers

This section describes the proposed management framework based on a virtual representation of the composite PI-container obtained from a collective intelligence approach.

3.1 Framework overview

A virtual object is a virtual representation of a real object enriched with context information. The benefits of virtual view are to enable multi-party multi-use of objects in a way that is acceptable to all parties involved. A Virtual Object (VO) has multiple views, including for instance:

- business view, to serve all parties to generate a positive business;
- security view which can increase mutual trust and confidence between stakeholders;
- operational view which can contribute to optimize and accelerate processes;

In this direction, the approach proposed in this paper aims to provide the means to realize the virtual representation of the composite PI-containers. This type of real-world object is obtained from a set of stacked PI-containers. Thus, basic VOs can be composed in a more sophisticated way by forming a Composite VOs (CVOs). The advantage of this approach is that CVOs are virtual objects created dynamically in an autonomous manner. A CVO reflects the real composition of the composite PI-container and can provide services in accordance with the user/stakeholder requirements.

Based on the Physical Internet foundations (Montreuil, 2011), the Figure 3 illustrates our approach with real objects that are unitary PI-containers with Information and Communication Technologies (ICT) capabilities. They include low cost sensors and communication devices to be able to sense and measure their environment, and communicate with other PI-containers. Each VO is associated to a VO registry that includes information about the unitary PI-container, like unique identifier, the dimensions or sensors values. Information are available at the information level.

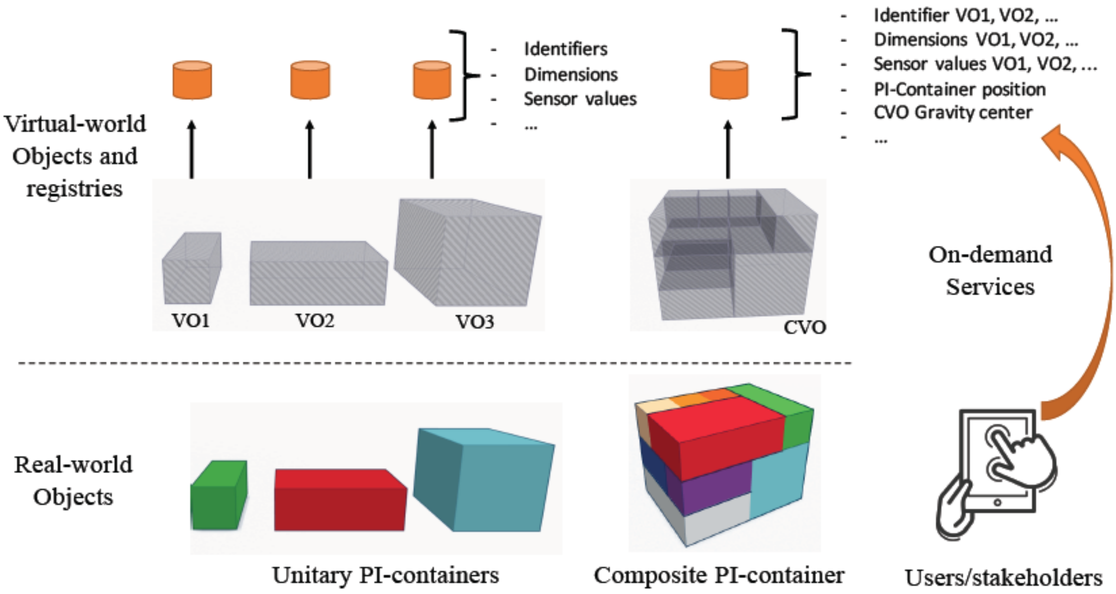

Fig. 3: CVO registry - cooperative information aggregation to achieve collective performance

Similarly, the CVO registry contains information regarding the components of the composite PI-containers, but also information emerging from the collective intelligence and the cooperative information aggregation mechanism. This information can be exploited on demand by users/stakeholders to take some decisions during the different management processes of the composite PI-container, or to develop new services. For instance, the exact position of each PI-container or the gravity center can be stored in the CVO registry and exploited during the composition/decomposition processes of the PI-container.

3.2 Framework implementation

In previous works (Tran-Dang, 2015)(Tran-Dang, 2017), the collective intelligence framework has been implemented to retrieve the exact position of stacked PI-container within a composite PI-container. This approach is based on key functional specifications of π-containers (Montreuil 2011) where each PI-container is a smart object equipped with low cost sensors and communication devices to be able to sense and measure its environment, and communicate with other smart containers. From these individual intelligence, cognitive processes associated to cooperative information aggregation mechanism were developed at the composite PI-containers level to:

- Identify of the number of unitary PI-container that composed the composite π-container;
- Detect and identify the PI-containers in their neighbourhood;
- Collect and forward data throughout the network to aggregate information.

Like a *Surowiecki machine* described in section 2, each device (unitary PI-container) shares its knowledge (dimensions, identifiers) and perceive its environment (neighbors). Contributions are diverse and independent due to their different localization. From these inputs and the machine's aggregation mechanisms, a Constraint Satisfaction Problem has been developed, as the output of the machine, to compute and determine the CVO with its registry values. The Figure 4 illustrates the collective intelligence framework implemented.

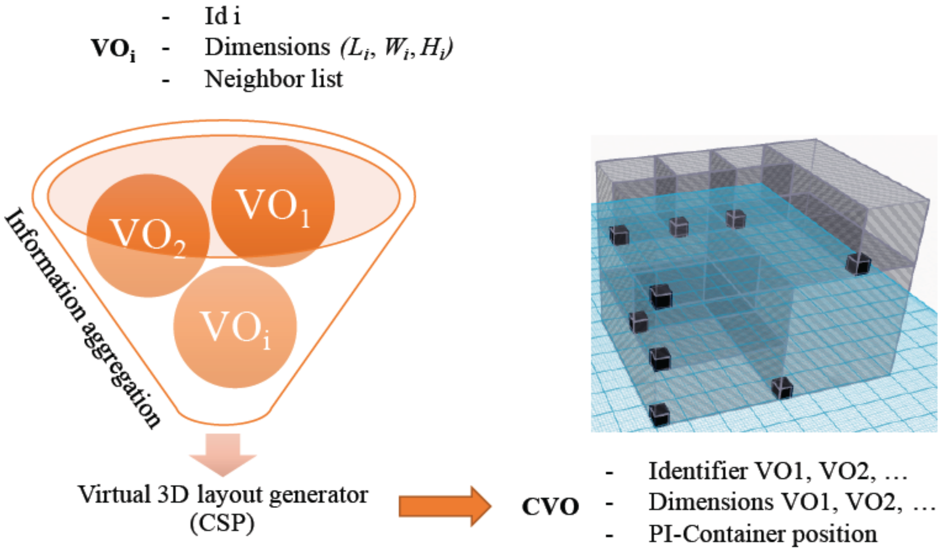

Fig. 4: Collective Intelligence framework

Based on the proposed framework in section 3, the 3D layout of a composite PI-container can be obtained from cross-fertilize knowledge. This model can help to address problems that occur out, but also, promote the creation of new individualized customer-services. We propose to illustrate in the next section several scenarios that can contribute to the development of the Physical Internet.

4 New individualized customer-services

The virtual view of the composite PI-container can be exploited on-demand by users/stakeholders, at any time of its life cycle. It can serve to take some decisions at different level - business, security or operational - during the different management processes of the composite PI-container, or to develop new services. This section presents two indicative scenarios where the collective intelligence framework is used to facilitate human-human, human-agent and agent-agent interacting in a Physical Internet.

- *The physical and informational integrity of composite PI containers*

The CVO can be obtained on-demand at each point of the logistic processes (transportation, storage and delivery of goods). Hence, knowledge based dematerialization of the composite PI-container can serve as a tool for permanent checking and inventory. Figure 5 illustrates a scenario where the CVO is used to facilitate trucker - logistic assistant interactions during daily operations at the PI-hub level. For instance, the composite PI-container can be checked in terms of goods conformity, transportation condition or opening tentative. This can help to strengthen mutual trust between all stakeholders in open global logistic infrastructure.

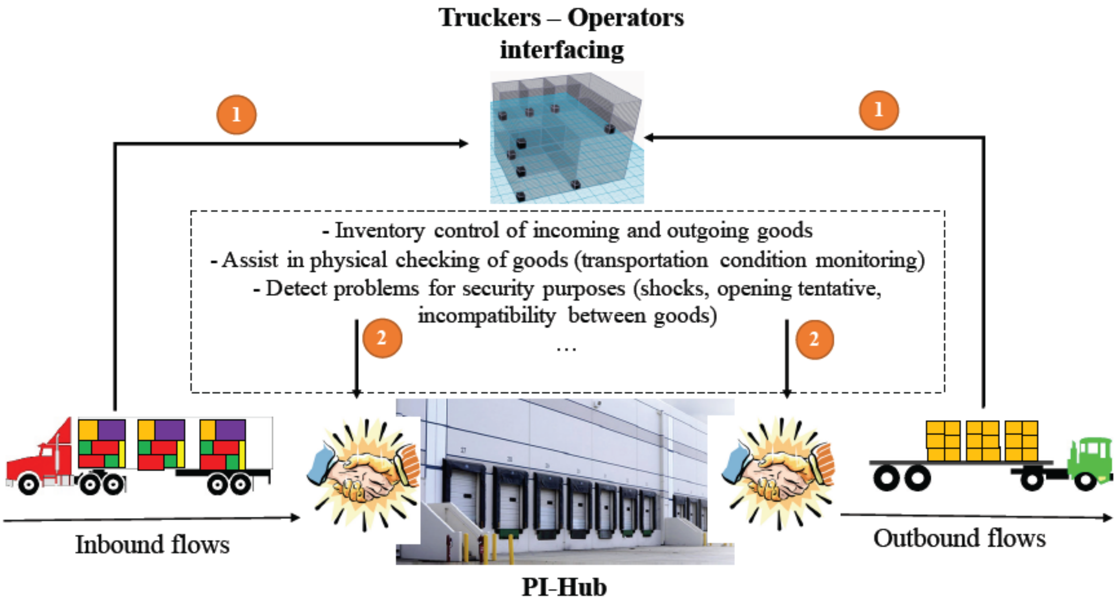

Fig. 5: Physical and informational integrity

- *Fully automated palletizing/depalletizing handling systems*

New value-added services such as guidance information for loading/unloading systems can be derived. For instance, the CVO could be used to detect and localize objects in automated palletizing/depalletizing systems that use traditionally vision sensors. From this, picking sequence and guidance information can be generated to partially unload or decompose the composite PI-container. The Figure 6 illustrates the simulation of a fully automated robotic cell where the loading/unloading motion execution are derived from the position of each PIcontainer.

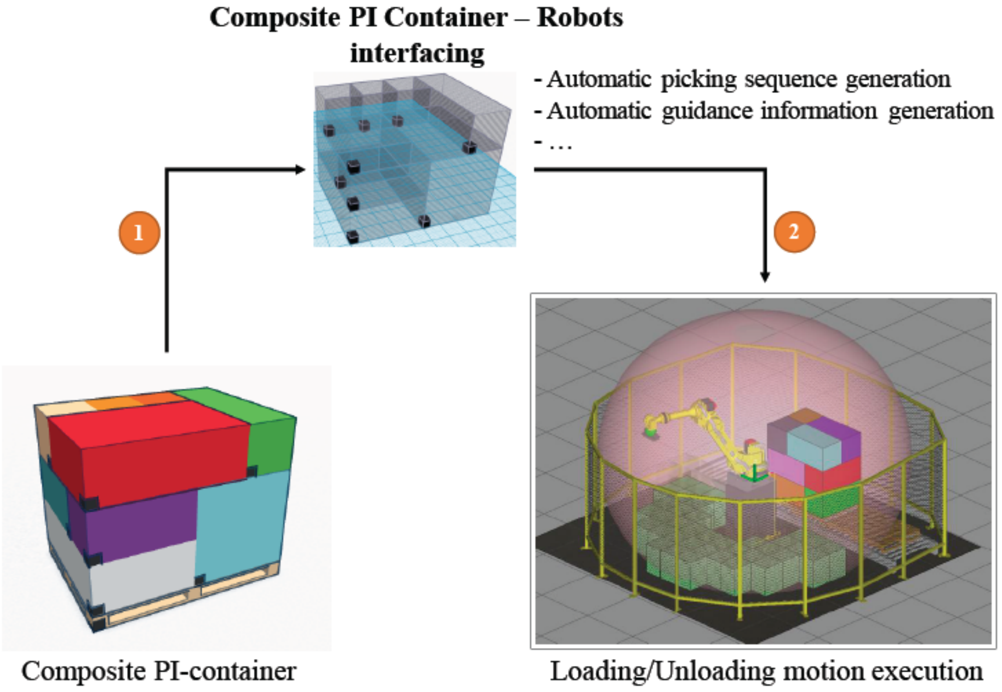

Fig. 6: Fully automated palletizing/depalletizing handling systems

5 Conclusion

In this paper, general definition and concepts of collective intelligence have been presented. From the collaboration of individual intelligences emerges the collective intelligence, and we developed a collective intelligence approach for the management of composite PI-containers in key facilities such as PI-Hubs. This approach relies on the cognitive abilities of each PIcontainer, associated to a cooperative information aggregation mechanism, which are used to generate a virtual object of the composite PI container. To illustrate the proposition, two indicative scenarios are given in a Physical Internet context.

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Wearable solutions for efficient manual logistics processes – RFID Wristband and Smart-Glasses

Olaf Poenicke[1], Martin Kirch[1], Klaus Richter[1], Falko Schmid[2] and Péter Telek[3]
1. Fraunhofer IFF, Magdeburg, Germany
2. Ubimax GmbH, Bremen, Germany
3. University of Miskolc – Institute of Logistics, Miskolc, Hungary
Corresponding author: olaf.poenicke@iff.fraunhofer.de

Abstract: *In logistics processes with increasing complexity and flexibility the use of wearable solutions can help to increase the efficiency and reliability of manual operation like order picking. With the proof of improving such processes by using wearables like Smart Glasses or a RFID Wristband at hand, the project AR-LEAN focusses on integrating these devices in a flexible wearable assistance solution. Supporting manual processes with such solutions will still be relevant in Physical Internet based environments, as manual handling will remain crucial in processes handling small PI containers. Besides describing the wearable solutions and their development, the paper discusses the relevance of such technologies in relation to smart PI containers.*

Keywords: *RFID Wristband, Smart Glasses, Wearables, Augmented Reality, Picking and Placing, Process Reliability, Process Efficiency, Assistance Solutions for Physical Internet*

1 Introduction

Within current global supply chains warehousing operation make up about 20 percent of the overall logistics costs (De Koster et al., 2017). Manual handling processes like picking and placing cause the major share of these costs – they make up roughly 60 percent of the warehouses' operational costs (Baumann, 2013). Even with ongoing steps towards standardization of load carrier units like PI containers of the Physical Internet Initiative and further developments in the field of logistics automation, operations like picking and placing will remain as manual processes when it comes to handling actual single items.

To enable error-free order picking, assistance solutions for the manual processes are of growing importance. Within this paper, applications for Head-Mounted Displays (HMDs) or Head-Up Displays (HUD), assisting manual order picking processes are describes and discussed in section 2. These Wearable based applications on Smart Glasses are used to display job orders and other process relevant information for the worker within the process environment. The Ubimax GmbH as a leading developer and provider for HMD based assistance solutions, carried out studies with different industry partners to measure the increase of productivity using the Smart Glasses in productive processes.

Most of the picking assistance solutions mainly guide the manual operation. Other technical solutions are required to control and confirm the actual manual processes – such as barcode or RFID scanning. For the process-integrated RFID scanning of tagged objects (like e.g. load carriers), the Fraunhofer IFF developed a mobile RFID Reader as a wearable device as it was described by Kirch et al., 2014. With this so-called RFID Wristband RFID-tagged objects are automatically identified within manual processes like picking or placing. This enables a process-integrated control and verification of job orders – saving process time as also increasing the process reliability. This solution is described and discussed in section 3.

In the ongoing R&D project AR-LEAN both wearable solutions are integrated into a completely mobile assistance solution for information (processing and visualization by Smart Glasses) and control (identification by RFID Wristband). The paper describes the current state of the project developments in section 4.

Section 5 examines the relation between the approaches of the Physical Internet and the requirements for manual processes like order picking. Furthermore the described Wearable solutions can be seen in other assistance solutions based on using smart PI containers. In this context, current approaches as also productive use cases of smart load carriers and the integrated wearable assistance solution are discussed in relation to the Physical Internet.

The paper concludes with a short summary and an outlook on further relevant research and development, for a seamless use of smart containers and process integrated assistance with wearable devices.

2 Wearable assistance using Head-Up Displays

As a developer for industrial assistance applications using wearable devices the Ubimax GmbH in Bremen has taken a leading role in the use of HMDs. Using market available HMDs like Google Glass or devices from Vuzix, Ubimax focusses on developing and rolling out mobile applications for user guidance. This includes typical order picking processes but also applications for assembly or inspection tasks.

2.1 System overview

The Ubimax Enterprise Wearable Computing Suite (UEWCS) is a solution platform for industrial wearable assistance systems. Although it has a focus on HMDs as primary devices, it is designed to develop implementations consisting of many different wearables, such as smart glasses, mobile barcode scanners, smartwatches, or RFID readers. The platform is designed in a device-agnostic manner, thus most available wearable devices can be integrated for specific solutions.

UEWCS consists of two layers: the solution layer and wearable computing layer (see Figure 1). The wearable computing layer defines device agnostic implementations of wearables and their sensors to ensure that many wearables can be integrated in specific solutions. The available solutions of the solution layer are organized along segments of the industrial value chain where manual processes are predominant: logistics, production, service and maintenance, and remote support.

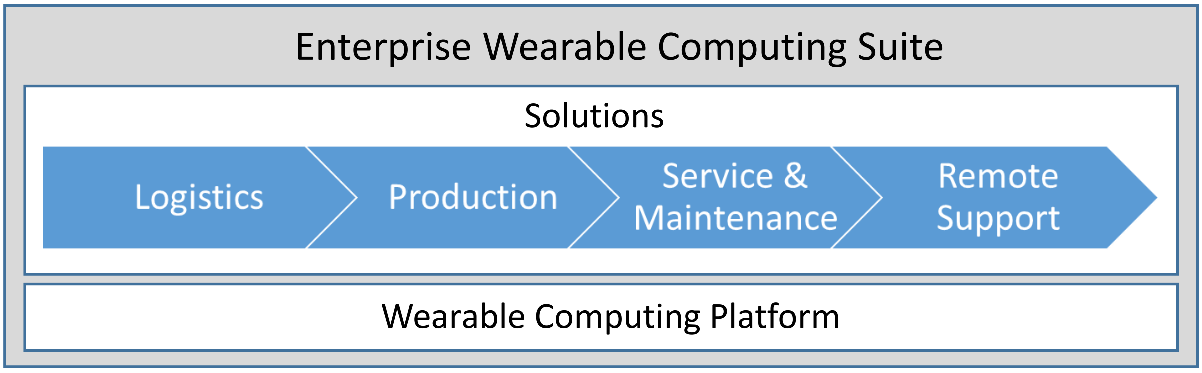

Figure 1: Architecture of the Ubimax Enterprise Wearable Computing Suite (source: Ubimax)

A typical implementation is based on a client-server deployment consisting of a wearable worker assistance system involving one or more wearables (see Figure 2). The wearable ecosystem is communicating to and fed by a server managing all aspects of the application at hand: user and device management, process and workflow management, and implements all communication with and transactions from/to the involved backend landscape.

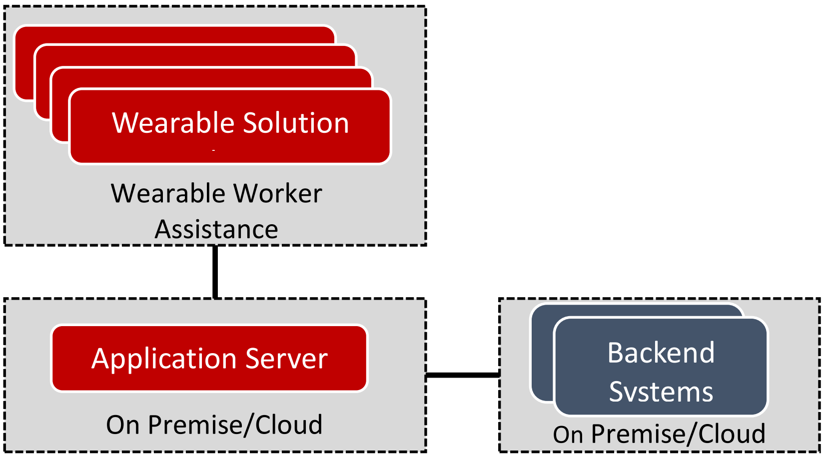

Figure 1: Typical implementation of a UEWCS deployment (source: Ubimax)

In a picking case, a client usually consists of a Smart Glass HMD which can be connected to other wearable devices. The HMD serves as the local process and ecosystem integrator and displays process information to the picker. The visual information supports context-specific information, thus only the information required to complete the (sub-)task at hand.

2.2 Use Cases

A White Paper by Intel, 2017 describes a typical use case of the HMD assisted order picking in a warehouse. In comparison with the current use of barcode handhelds for guiding the workers and scanning the storage locations, the use of HMDs together with a barcode ring scanner showed an improvement of 29 percent time savings. In another use case study, carried out by Ubimax with DHL, the use of HMDs showed a gain in process efficiency of 25 percent (Logistik Heute, 2015).

Figure 3: User view of a HMD assisted Ubimax application (source: DPDHL)

As shown in Figure 3 the HMD information are permanently visualized in the visual field of the user. In that specific example of the DHL use case, the picking tasks are displayed on the left side (aisle number, location, quantity and next pick location) and the information where to put the picked item on the trolley are shown on the right side with a schematic representation of the trolley.

These industrial use cases only can give rough measures on time savings or reduced error rates, as the different assistance solutions are not compared in a controlled environment. Still these measures are almost similar to measures of scientific studies.

2.3 Improvement potential

Such studies are showing that solutions like Pick-by-Light, Pick-by-Vision or Pick-by-CMD (Car-Mounted Display) are able to reduce the operation time and the error rate in order picking processes significantly compared to the basic pick-by-paper list. In such comparative studies, the use of HMDs showed the highest potential to ensure efficient and reliable picks (Guo et al., 2015; Baumann, 2013).

Nevertheless, there is several potential for further improvements. One field for improvements can be seen in combining the HMDs as a guidance solution with other devices for controlling and verifying the actual manual processes. As barcode scanning of the actual picking location is often cumbersome, RFID scanning is a promising approach. Also integrating other wearable device for picking quantity verification is an important point for improving the assistance solutions, as these wrong number errors are still significant for pick-by-vision solutions (compare Figure 4 sourced from Guo et al., 2015).

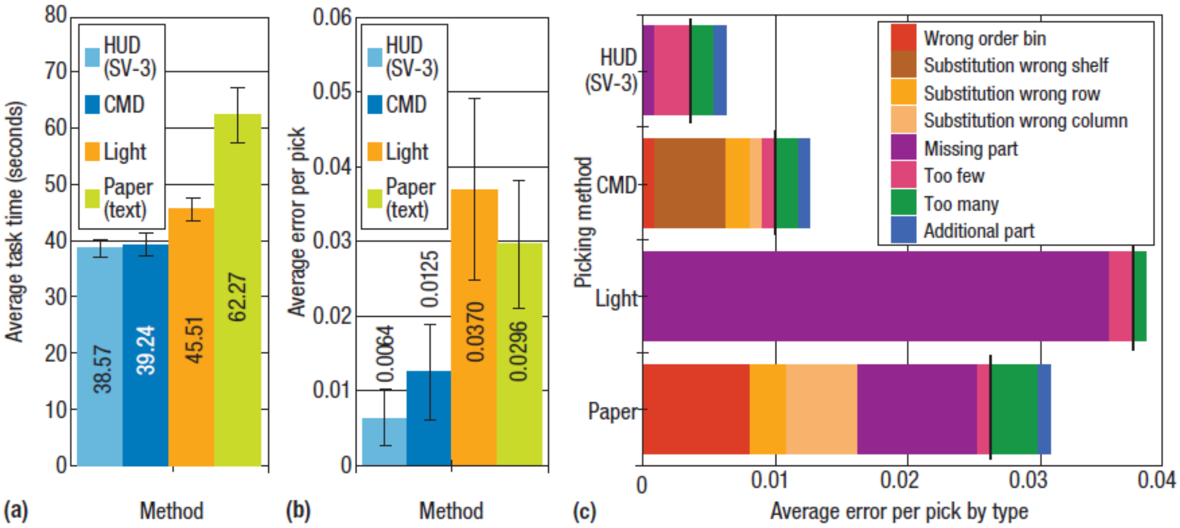

Figure 4: Comparative performance of different assistance solutions. (a) average task time, (b) average error per pick, (c) average error per pick by type (source Guo et al., 2015)

3 Process integrated work step confirmation using the RFID Wristband

Kirch et al., 2014, have described the initial development of the RFID Wristband by the Fraunhofer IFF with the focus on verifying picking processes in automotive assembly processes. This paper already included a comparison of the RFID based solution with barcode based picking verification solutions. Starting from a first application in assembly processes, the RFID Wristband has been evaluated in further applications in logistics operations.

3.1 System overview

The RFID Wristband is a mobile RFID reader (UHF at 865.6 to 867.6 MHz) which is worn at wrist level to enable the identification of RFID tagged items within manual handling processes. By that the RFID Wristband allows hands-free operation. The complete electronics, consisting of the RFID reader, a microcontroller, the ZIGBee based communications interface, the RF antenna and an exchangeable battery, is integrated in the RFID Reader Module. The Reader Module is attached to user individual Strap via magnet. With an overall weight of approx. 120g, the RFID Wristband can be worn throughout complete shifts without causing fatigue.

As shown in Figure 5 the RFID Wristband is used to scan RFID tags (1), which are identifying e.g. picking areas or boxes. The RFID read data are then transmitted to an external device (e.g. a workplace computer) where the read tag ID is further processed (3). Based on the result of the logical operation (e.g. comparison target against actual) feedback signals can be send back to the RFID Wristband via the ZIGBee interface (4).

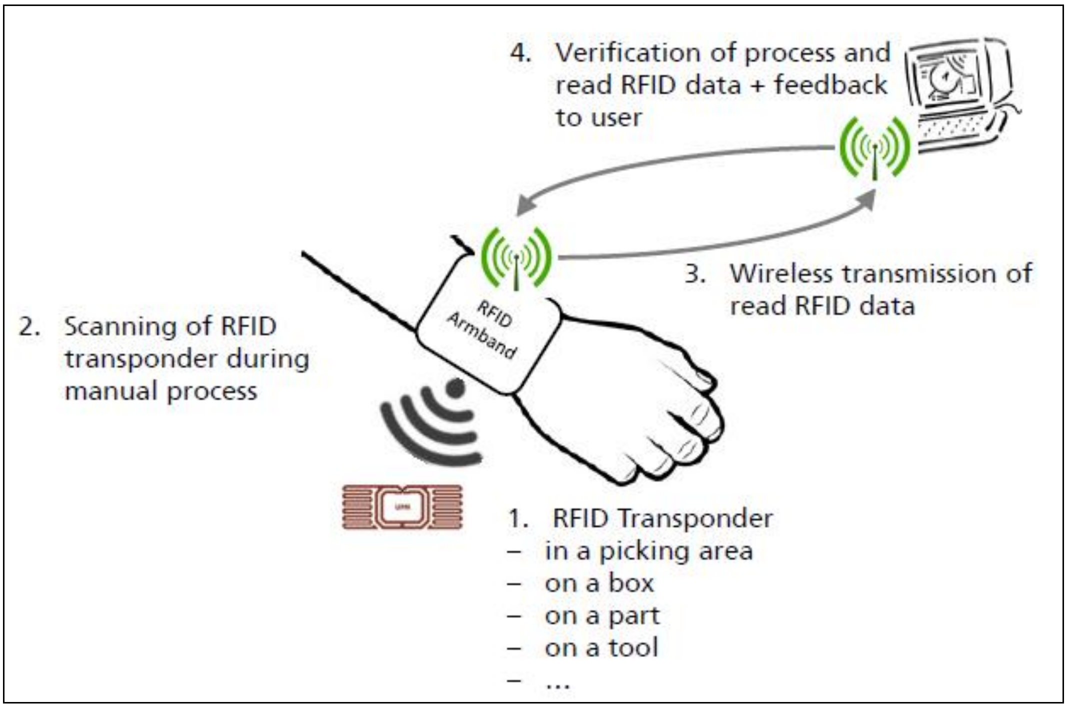

Figure 5: Application principle of the RFID Wristband (source: Fraunhofer IFF)

Optimized for near field identification of RFID tagged objects, the read range of the RF field, which is located below the arm wrist, can vary from 1 to approx. 40cm (depending on reader output power setting and on RFID tag sensitivity). The RFID Wristband is not designed for far field RF reading, as higher reading distances will cause false-positive reads in most of the picking and placing environments.

3.2 Use Cases

In the current design of the device the RFID Wristband can be used for any manual processes in that RFID tags are scanned below the wrist level. This includes typical order picking – handling of objects from picking them out of bins or shelves and putting them into bins or onto shelves – as also supplying processes, where the put-away of bins into storage locations needs to be controlled (see Figure 6).

The advantage of the wearable RFID scanner over other mobile devices for process verification like Barcode or RFID handhelds is the process integrated scanning of the picking location. This is saving time and securing a higher process reliability, as picking and scanning are not separated process steps.

Figure 6: Typical use cases. (a) control of storage, (b) control of picking, (c) control of putting (source: Fraunhofer IFF)

Besides the already mentioned use case in the automotive industry (Kirch et al., 2014), a comparative study has been carried out in an order picking process, where the RFID Wristband was compared with barcode scanning and operation without scanning. With using the RFID Wristband more than 3,500 picks have been carried out by different workers. The picking rate in these tests reached an average of 176 picks per hour, which equals the average picking rate without scanning. Compared to that, the barcode scanning only allowed an average of 137 picks per hour with a still significant error rate of 0.25 percent (Schulze, 2016).

3.3 Improvement potential

In its current form the RFID Wristband is giving feedback information (e.g. correct pick / wrong pick) to the user via a signal LED and an acoustic beeper. This is sufficient in relatively fixed work environments, like picking work places or assembly benches providing a screen visualizing all relevant process information.

Especially in applications where the user has to move through a warehouse or has to work within a noisy environment the feedback features of the device are not sufficient. Because of that, it is often a requirement to visualize process related context information on a display. To keep the ergonomic usability of the RFID Wristband (especially low weight, meaning not extending the battery for further power consuming features) the approach for extended visual guidance is to combine the RFID Wristband with a HMD in an integrated system solution.

4 Integrated wearable solution of RFID Wristband + HMD

In the ongoing funded R&D project AR-LEAN both wearable solutions are integrated into a completely mobile assistance solution. Figure 7 shows a first experimental setup of combining HMD provided information (processing and visualization by HMD) and picking verification (identification by RFID Wristband). AR-LEAN is an international EUREKA project with a duration of 19 months (July 2016 to January 2018). The German Federal Ministry for Economic Affairs and Energy funds the German project part of Fraunhofer IFF and Ubimax under the funding reference 16KN045445.

Combining the wearables HMD and RFID Wristband will enable a completely mobile and flexible system solution with the HMD used for processing all necessary logics. The RFID Wristband will be connected to the HMD via Bluetooth Low Energy (BLE). It will transmit the RFID read events and receive feedback signals and process related reader settings. Fraunhofer IFF and Ubimax are developing the process logics for synchronizing the use of both devices based on their long-term experience of integrating the devices in productive environments.

Figure 7: Combined use of HMD and RFID Wristband in a first experimental setup (source: Fraunhofer IFF)

The technical tasks within the project furthermore include hardware developments on the RFID Wristband (interfaces for bi-directional communication with the HMD via BLE), the IT integration of RFID Wristband and HMD (communication protocol, process logics) as also the development of a platform for the flexible generation of process related applications for industry partners. The platform also will enable the integration of further mobile and wearable devices such as tablets or smart watches.

The project aims at the testing and demonstrating the integrated wearable solution in a productive process environment. The target applications are focusing on the use cases described above for HMDs and the RFID Wristband – combining the advantages of both solutions for an efficient picking instruction and control. Based on the findings of the aforementioned evaluations of HMDs and the RFID Wristband it is expected that the benefits of the partial solutions will add up in an integrated system solution.

Currently the hardware of the RFID Wristband is extended to offer enhanced connectivity and to include further user interface triggers which will be used to verify picked item quantities. For connecting RFID Wristband and HMD with the limitations of BLE communication, a shared communication protocol is developed.

A first demonstration setup of the integrated system solution shall be available at the end of September 2017. Following these first demonstration the integrated solution will be examined in productive process environments to evaluate the actual benefits of the system compared to other assistance solutions. Based on that evaluation further required steps for the product development will be defined.

5 Relation of the wearable assistance solution to the concept of the Physical Internet

The approach of the Physical Internet aims at enabling further logistics process automation by standardizing the different levels of load carriers (PI containers as described by Montreuil, 2012). But even with a higher level of automation the manual handling of small containers and especially of single items in containers will remain crucial (Ballot, 2016). For that reason, assistance solutions for manual operation like the described wearable devices will play an important role for ensuring error-free and efficient processes, once the Physical Internet is completely implemented.

5.1 Physical Internet scenarios employing wearable assistance solutions

Within the concepts of the Physical Internet the PI containers are described as Smart Containers. The level of smartness may reach from basic possibilities for identifying a container (e.g. via passive UHF RFID) to more complex sensing solutions (e.g. with active location tracking and state monitoring). Yet it is unclear whether the same level of smartness will be required or even be useful on all container size levels. To relate the wearable devices HMD and the RFID Wristband to the Physical Internet, several use case scenarios can be discussed:

- **RFID-based identification of PI containers** – Standardized PI containers can be identified by the RFID Wristband in manual handling processes where automation is not feasible but process reliability needs to be secured → this can be seen e.g. in C-Part management processes, when small containers flexibly need to be stored in correct locations;
- **AR context information about PI containers** – PI containers with a higher smartness level can directly communicate with HMD applications via wireless communication to provide process related context information → this can be relevant in processes where certain object states need to be included for process decisions – e.g. to keep FIFO rules or to first pick items in a critical state;
- **Interaction of other wearables with PI containers** – as PI containers will provide wireless interfaces, also other wearables like smart watches can come into focus for process control interaction. Wearables can be used as control and decision support devices – e.g. to assign single PI containers to follow-up processes.

The definition of the smartness level for PI containers will fundamentally influence the possibilities for interacting with these containers not only in automated but also in manual handling operations.

5.2 Current developments for smart load carriers

There is a vast field of concepts and R&D projects for designing and developing smart container solutions. Yet on practical level, there are first products and applications in place where higher volumes of smart load carriers are used. E.g. on pallet level first pallet pools are entirely equipped with passive UHF RFID. Poenicke et al., 2016, described the development and RFID integration in such retail pallets.

On a smaller container level, there are ongoing projects for standardizing RFID tagged containers like the KLTs (Kleinladungsträger) in the German Automotive Industry (see press release of AIM, 2017). Also in the development of PI containers the integration of passive track and trace capabilities for identifying and distinguishing containers are defined as a main function (Landschützer et al., 2015). As Ballot, 2017 stated the necessary standards for using and exchanging the RFID data are already in place (see also GS1, 2016 and VDA, 2016).

Besides the identification solutions based on passive RFID, R&D projects as also first industrial products based on active technologies showed approaches for smaller load carriers with an enhanced smartness (see also Emmerich, 2012 and Hoffman, 2014). Currently emerging Low Power Wide Area Network (LPWAN) technologies like LoRa or NBIoT will further enable new applications for tracking, tracing and monitoring also small load carriers in an efficient and economical feasible way.

6 Summary and Outlook

As an innovation contribution the paper with focus on IT and digitalization gives an overview on the ongoing R&D project AR-LEAN which is focusing on the integration of wearable devices like HMDs and RFID Wristband to assist manual logistics operation. Such assistance solutions still will be relevant in Physical Internet based process environments, as manual processes will remain crucial especially for the handling of small PI containers.

In this context, the debate about the Physical Internet will need further discussions about potential automation levels in current manual processes like order picking. In addition, the possibility for automation of logistics processes needs to be discussed with respect to small and medium sized logistics operators.

Concerning the connectivity of PI containers – be it for interfacing with wearable devices or also stationary infrastructure – the Physical Internet community needs to focus more on R&D activities to ensure that several developments like the 'Internet of Things' create logistics related standards in line with the Physical Internet approaches. This will e.g. require discussion about what level of IoT functions or smartness is needed for different PI container sizes.

The standardization of information and communication functions on the side of containers will also enable the standardization of assistance applications like the described wearable solution integrating Smart Glasses and RFID Wristband.

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Microzoning: A grid based approach to facilitate last-mile delivery

Boukje Schellens MSc[1], Dr Frans Cruijssen[2]

[1]ArgusI, Breda, the Netherlands
[2]ArgusI, Breda, the Netherlands
Corresponding author: b.schellens@argusi.org

Abstract: *Microzoning is a method which makes (last-mile) road transport more efficient and sustainable. The method generates small compact areas, called microzones, which can be used as building blocks to design efficient service zones. The innovative methodology uses a grid of an area, heuristic methods and routing algorithms to develop the service zones. Stakeholders' preferences can be incorporated into the model to generate industry or company specific microzones. This methodology has been applied by Argusi during a project for a parcels delivery company located in the Netherlands to facilitate their last-mile transport.*

Keywords: *service zone, microzone, last-mile delivery, Physical Internet*

1 Introduction

The current growth in e-commerce marked a new era in last-mile delivery. Consequently, route planning for last-mile delivery is becoming more and more difficult. To facilitate the daily route planning this paper introduces microzoning. A method which divides an area into small pieces, called microzones, and consecutively generates efficient service zones based on them.

Microzones can be seen as basic units, which are the building blocks of a service zone. Creating service zones is also called districting or territory design. Districting is applied in a wide variety of applications such as emergency districting or political districting (Kalcsics, Nickel, & Schröder, 2005). The innovation introduced in this paper, however, focuses on the transport sector.

Currently postal codes are often used as basic units to generate service zones for transportation. But postal codes have inefficient shapes and are highly unbalanced with respect to geographical properties such as population density, driving time and travelled kilometres. Figure 1 shows three examples of inefficient PC5 areas in the Netherlands. Where PC5 refers to the four numbers and first letter of the Dutch postal code. Another problem of postal codes is the size of the area which it covers. The Dutch postal code system is very detailed, so one postal code covers a relatively small area, but postal codes in other countries in Europe and America cover a much larger area. One postal code in Belgium for example, covers a whole municipality. This is in many applications already too large for a service zone, so definitely not suitable as basic unit. Microzoning can overcome those inefficient situations. Efficient microzones can be developed for case specific situations and stakeholders' preferences can be incorporated.

The service zones resulting from a combination of microzones are robust and therefore only have to be generated once. Based on the service zones daily routes can be created. All demand points which belong to the same service zone also belong to the same route. So, on a daily basis only the shortest or fastest route which visits all delivery locations within one service zone has to be determined, which reduces computation times significantly. Another advantage of this approach is that truck drivers serve the same area every day so they become familiar with the regions and customers will recognize their carriers.

An initial version of the microzoning method has been applied by Argusi during a project for a parcels delivery company located in the Netherlands. Currently there exists an improved version of this method, which has been tested on parcel delivery data in Belgium. The next section provides an overview of this improved version of the microzoning approach.

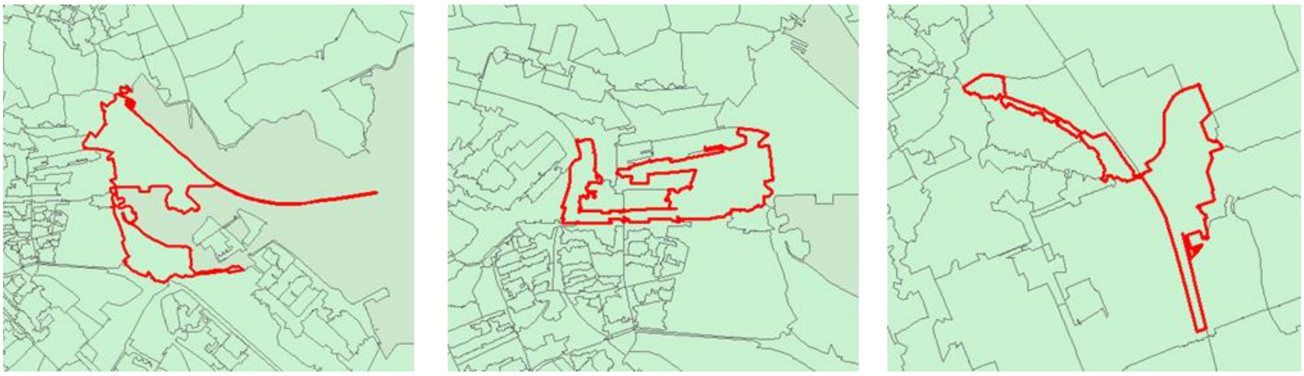

Figure 1: Example of inefficient postal code areas in the Netherlands

2 Methodology

By interviewing stakeholders and a literature study, the properties of a microzone were defined. The microzones should satisfy the following hard criteria, therefore they occur as constraints in the developed model:

1. Complete and exclusive assignment: Every piece of land should belong to exactly one microzone.
2. Contiguity: a microzone should consist of a connected aggregation of land.
3. Compatible with natural and physical barriers
4. No holes: a microzone cannot be located completely within another microzone.

Besides hard criteria also three soft criteria were determined. Those criteria should be optimized and therefore occur in the objective:
1. Minimize the number of microzones
2. Minimize workload (e.g. in case of parcel delivery driving and stop time)
3. Compactness: a microzone should be spatially compact

The importance of each objective might differ among stakeholders or per application therefore the model has the flexibility to assign priorities to each of the objectives.

In order to generate the microzones, a grid of an area is used as starting point. Besides the modelling advantages of a grid, this can also be beneficial for future standardisation since recently European countries are providing statistics based on squares of 100 by 100 meter.

Since microzones should be compatible with natural and physical barriers polygons are generated based on geographical boundaries. The following boundaries were taken into account to determine the polygons: country borders, highways, railways and main waterways. For each polygon a grid was generated. The size of the grid cells depends on the purpose of the microzoning. Together with historical demand data this is used as input for the model.

An iterative model has been created which exist of two phases. In the initiation phase, an initial solution is generated which fulfils all the predefined constraints. Besides the four fixed constraints mentioned above the model can incorporate other application specific constraints such as a maximum workload or a maximum surface per microzone. The initial solution is obtained by merging grid cells until every cell is assigned to a microzone and no more merges can be made.

The initial solution is used as input for the optimization phase. The goal of this phase is to obtain the best possible objective value. The objective function consists of the sum of the three soft criteria mentioned above where each criterion has its own weight function. To determine compactness a perimeter-area measurement has been applied. A square is considered as the optimal shape of a microzone. The workload is simply the sum of the workloads of all microzones. Optimizing the objective function is done by means of a heuristic approach. Two types of heuristics are used: simulated annealing (Kirkpatrick, Gelatt, & Vecchi, 1983) and Tabu Search (Glover, Tabu search part i, 1989; Glover, Tabu search part ii, 1990). In every iteration of this optimization phase two connected microzones are selected and grid cells are moved from one microzone to the other. Due to the simulated annealing heuristic movements which lead to worse objective values are accepted with a higher probability in the beginning to escape from local optima, but this probability decreases in every iteration. The optimization phase terminates when a predefined end temperature has been reached.

3 Case Study

The method described in the previous section has been applied on historical demand data of a parcel delivery company. Two areas in Belgium were considered; one densely populated area with many demand points and one rural area. For polygons located within the dense area a grid with cells of 300m by 300m was generated. The size of the grid cells in rural areas was set at 500m by 500m. The research has been applied on one month of historical demand data, consisting of 22 workdays.

Besides constraints mentioned in the previous section an additional workload constraint was added to the model, the restriction was that microzones could have a maximum workload of 30 minutes. Where the workload consists of driving time and stop time. This restriction was determined in collaboration with the stakeholders. Microzones with 30 minutes workload leave enough flexibility to generate service zones. If this workload would be significantly higher the possible combinations to generate a service zone decrease, resulting in less efficient service zones. Whereas reducing the workload per microzone increases complexity and computation time and results in less robust microzones.

Four scenarios were calculated to simulate stakeholders' preference regarding to the three objectives mentioned in the previous section. Table 1 gives an overview of those four scenarios, where ρ_i indicates the priority value of objective i. In the first scenario each objective is considered equally important, while the other three scenario's simulate cases where one objective is more important than the other two.

Once the microzones were generated the service zones were determined. A service zone consists of an aggregation of microzones. The service zones were restricted to a maximum average daily workload of 480 minutes (8 hour workday). The workload of a service zone consists of the sum of the workloads of all microzones located within that service zone and the driving time from and to the depot. In the determination of the service zones the geographical boundaries were no longer taken into account, meaning that microzones of different polygons can belong to the same service zone.

Based on the service zones the daily routes were calculated. A route is simply the shortest route which starts at the depot then visits all demand points located within one service zone and finally returns at the depot. To calculate those routes a TSP algorithm has been used.

Table 1: Overview of the four scenarios with corresponding priorities

Scenario	ρ_1	ρ_2	ρ_3
1. equal priority	1	1	1
2. priority minimizing number of microzones high, priority minimizing workload low, priority compactness low	2	0.5	0.5
3. priority minimizing number of microzones low, priority minimizing workload high, priority compactness low	0.5	2	0.5
4. priority minimizing number of microzones low, priority minimizing workload low, priority compactness high	0.5	0.5	2

4 Results

In total nine polygons were considered in the study of which four were located in the dense area and five in the rural area. Figure 2 shows an example of a polygon located in the dense area and the seven microzones which were generated within this polygon.

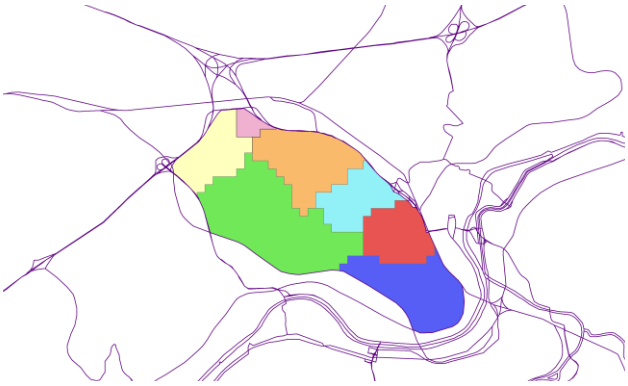

Figure 2: Polygon with seven generated microzones

The outcomes of the study showed that all four scenarios resulted in compact zones for every polygon. Minimizing the number of microzones and minimizing workload turned out to have a high correlation since scenario 2 and 3 obtained similar results in most of the polygons. In general both scenarios obtained low values for workload and the number of microzones. Giving higher priority to compactness on the other hand comes at the cost of the number of microzones and leads in the majority of the cases to more workload, while the compactness score only slightly improves. Those results can also be observed from Figure 3 which shows the outcome for each of the four scenarios for the polygon shown in Figure 2. In this case scenario 2 and 3 resulted in seven microzones, while scenario 1 and 4 resulted in nine and eight unique microzones respectively. It can be observed that each of the four scenarios for this case resulted in compact microzones assuming that a square is the most compact shape of a microzone. According to the numerical results represented in Table 2, scenario 1 turned out to have the best compactness score but this is hardly visible in Figure 3. Unlike the results of all other polygons, scenario 1 also achieved the lowest workload score for this polygon. For all other polygons considered in this study, scenario 2 or 3 obtained the lowest workload. This also indicates the unpredictability of the outcomes of scenario 1 where all objectives are considered equally important.

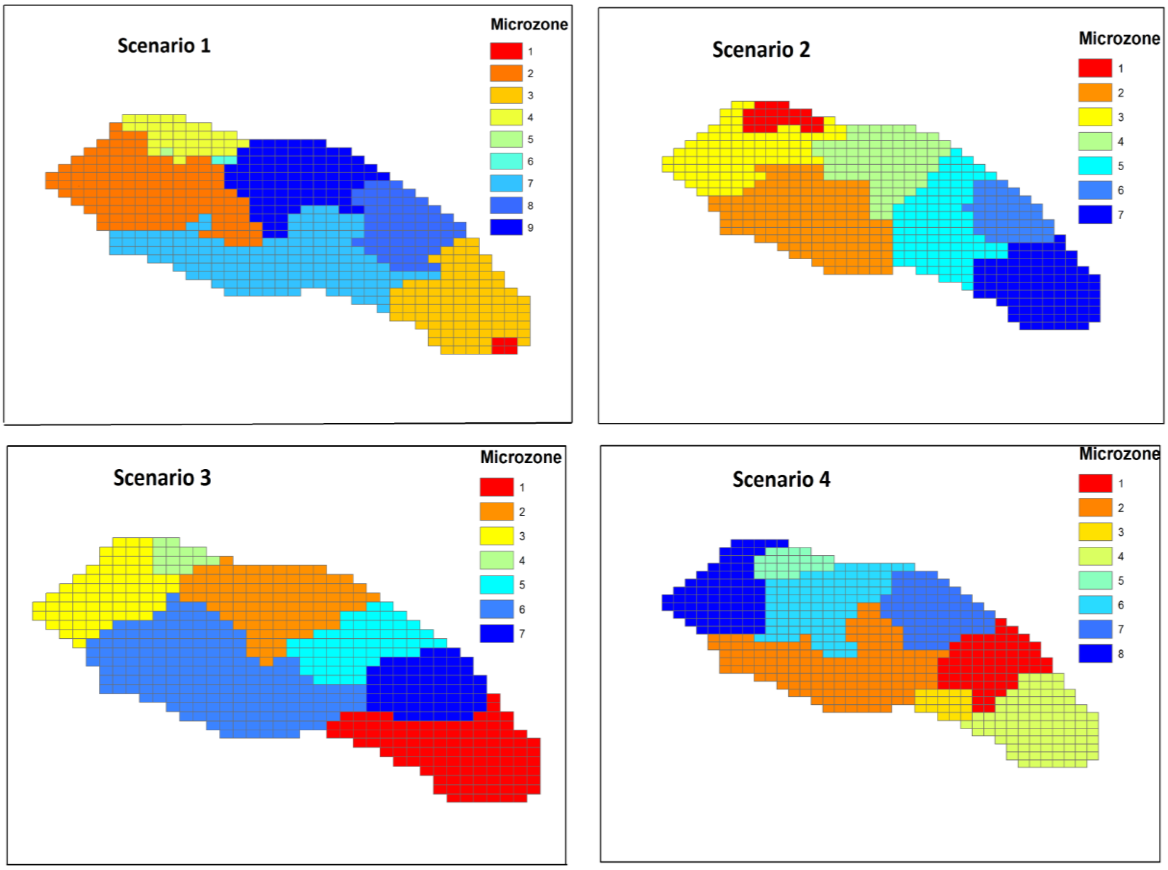

Figure 3: The microzones resulting from the four scenarios for a polygon located in the dense area

Table 2: Numerical results of the four scenario's shown in Figure 3

Polygon 1	Microzones	Total Workload	Compactness	Average Compactness Per Microzone
scenario 1	9	4134.162	2.020564	0.775493
scenario 2	7	4167.718	1.805535	0.742066
scenario 3	7	4140.67	1.667751	0.76175
scenario 4	8	4218.144	1.823981	0.772002

In total six service zones were developed based on the generated microzones, two for the rural area and four for the dense area. For each zone the daily routes were generated. It turned out that the routes were quite robust with a coefficient of variation between 0.1 and 0.17 for all service zones.

Even though the microzones which were developed for this case are company specific, Argusi is aiming for standardised microzones, just like the standardised π containers in physical internet (Montreuil, Meller, & Ballot, 2010). Possible improvements of this approach are the incorporation of public data such as population density and land use. Also, the generation of microzones with different levels of detail needs further investigation. One can think of different layers of microzones, like the NUTS classification (EUROSTAT, 2013) only with significantly smaller areas and specifically designed for logistic purposes.

5 Conclusion

This paper introduced microzoning, a method which develops basic units which can be used to create service zones for last-mile delivery. The microzones provide a solution to the current lack of efficient basic units that can be used for logistical purposes. Furthermore the use of microzones reduces computation time in daily route planning. The developed method introduced in this paper generates efficient and compact microzones and can incorporate stakeholders' preferences. A case study has been carried out based on data of a parcels delivery company. This study proved the effectiveness of this method in the daily route planning. More research should be done on standardization of the microzones and possibly the generation of different layers such that they can become the standard for all logistics applications and facilitate the physical internet.

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A Multi Simulation approach to develop Physical Internet.

David Ciprés, Carlos Millán, Lorena Polo, Alberto Capella and David Escuín
ITAINNOVA, Zaragoza, Spain
Corresponding author: dcipres@itainnova.es

Abstract:
The Physical Internet (PI) concept has many different connotations at various levels of business, from the strategic point of view of the company, the horizontal collaboration with other companies, down to the operational integration of the processes. Complexity reduces the sense of control in the logistics operation. These intricate relationships of PI make logistics flows more complex, but the final result from a point of view of resources is a more efficient and environmentally friendly process. This paper describes how the use of different types of analytical models and simulation models could help to create trust and confidence around the PI concept. The simulations help to analyse business models, to evaluate the relationship between the main variables, to visualize the flows, to understand the dynamics of the processes and to evaluate numerically the impact of the new flows of products.

Keywords: *discrete event simulation, system dynamics, multi-agent simulation, multi-simulation.*

1 Introduction

Simulation is used in many different disciplines and application areas. In the domain of production and logistics, simulation is a well-accepted tool for the planification, evaluating and monitoring relevant processes. The relationships between stakeholders under PI concept is complex due to the considerable amount of interactions, high variety of products, different operations, many types of transport and different information systems. There are different simulation techniques useful to represent the product flow under the PI framework: System dynamics, Discrete event simulation and Multi-agent simulation.

System dynamics (SD) is an approach to understand the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delay. It is a method to enhance learning in complex systems to help us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies Sterman (2004). It is a computer-aided approach for analysing and solving complex problems with a focus on policy analysis and design. Much of the strength of System Dynamics comes from its ability to be used in two related, but different ways Coyle (1996). On the one hand, it can be used qualitatively to portray the workings of a system as an aid to thinking and understanding. On the other, the diagram can be turned into a simulation model for quantitative simulation and optimization to support policy design.

Simulation is the imitation of the operation of a real-world process or system over time. Discrete event simulation (DES) works by modelling system state changes occurring at specific points in time, which are probabilistically determined by historical data. Simulation involves the generation of an artificial history of system and observation of that artificial to draw inferences concerning operating characteristics of the real system that is represented.

Multi-agent simulation (MAS) or Multi-agent-based modeling (MABS) is a branch of computer simulation where multiple intelligent agents, capable of independent action and interact within environments that are typically dynamic and unpredictable. This technology is well suited to model systems with heterogeneous, autonomous and pro-active actors, such as human-centred systems where a software system (software agent) does something often on behalf of a person. Multi-agent systems are designed to handle changing and dynamic business processes.

2 Framework description

This paper describes a framework to integrate different types of models and simulation techniques to build trust around the PI concept and to assess the concept under different scenarios. This framework has two levels to deal with the high complexity. The first level is the strategic level, as it is shown in Fig 1. It is a representation of the whole picture of the PI model, but with a reduced level of detail. Only the main factors are included. The flow of material and the flow of information is important at this level. Also the links between stakeholders and the time dependencies and delays in the processes. The best simulation technique to deal with this type of elements is system dynamics.

In system dynamics models the ratios are used to describe the flows and the process involved. This values, or ratios must correspond with the values in the real world. Thus it is important the connection between the strategic level and the operational level with a feedback mechanism to keep updated these values.

At the operational level, the level of detail required is higher, and additionally, the different models needs diverse analytical models and simulation techniques. In this level we can find various processes which are interconnected between them like the supply chain strategies, the transportation modes and routes, the handling operations at the distribution center or the behavior of the final customer. Depending on the sector additional elements could be added to this framework.

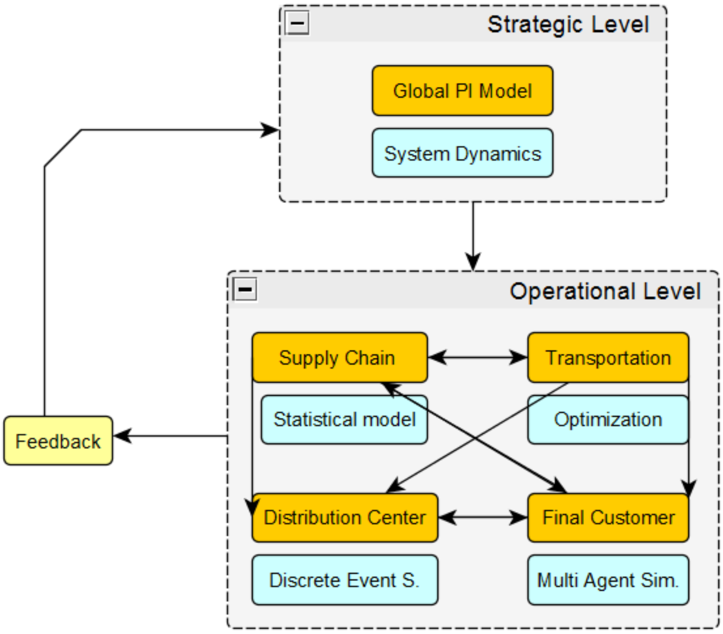

Figure 1: Multi-Model Physical Internet Framework

3 Simulation Models

In the following lines we show some examples of different models that can be used to represent the elements in a Physical Internet framework.

3.1 Global System Dynamics

The system dynamics (SD) method has proved to be particularly good at supporting a strategic point of view, in the sense of matching very closely the concerns of top-level decision-makers. By supporting the modelling of the forces underlying a system's evolution into the future.

System dynamic models allows to evaluate the representation of high level of the processes. Physical Internet flows are complex. SD technology allows to represent the dynamic through a stock and flow diagram. The diagram shows the relationship between the main variables that influence the dynamics of these flows and feedback from other point from the flow. With these models the user can easily evaluate the effect of small changes in the parameters on the global behavior of the system.

The flow in this model could represent, for example, the flow of products in different distribution channels, or the number clients in a certain region. The variables used in these models are related to objectives like service level objective, effect of delays in deliveries or price variations. Through this representation we can evaluate the impact changes in the behaviour. They can make the flow increase, decrease, or because of some decisions the behavior begins to oscillate.

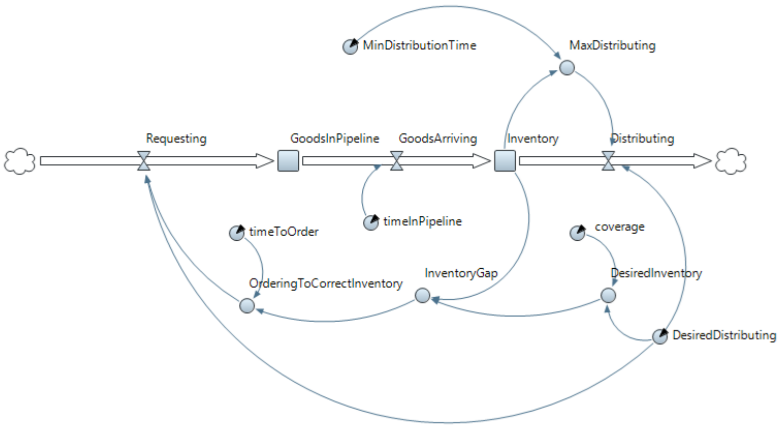

Figure 2: System dynamic supply chain representation

3.2 Supply Chain

Simulation and statistical models are often used to get a better distribution network design. One of the applications of supply chain simulation consists of an impact analysis of Vendor Managed Inventory. Production lot-sizing has a great impact on inventory, particularly under seasonal fluctuations of demand and constrained production capacity. Many companies adopt the MTO (Make To Stock) policy in which products are not built until a confirmed order for products is received by the manufacturer. Other companies maintain high levels of inventory (stock) to face periods of uncertain demand. However, a production schedule which does not adjust accurately the real demand may lead to overstocks for some products and stock-outs for other. Inventory sizing by product is especially important under uncertainty, when the inventory is necessary to guarantee a service level in a stochastic environment. One of the integration practices that can contribute to reduce inventory in the supply chain is Vendor Managed Inventory (VMI). VMI programs allow for consumer demand information to be disseminated up the supply chain, thus mitigating upstream demand fluctuations due to the bullwhip effect Govindan (2015) and Kwangyeol (2013). Due to this demand anticipation, VMI may allow to reduce logistics and manufacturing costs, reduce overall leadtimes, improve service level and reduce transportation costs.

With a simulation model under a PI framework we compare the performance of VMI and MTO strategies in the two-echelon serial supply chain with finite production capacity Kwangyeol (2013). The purpose of using simulation is to provide a simplified environment into which a number of situations and ideas can be tested. From the simulation outputs, the effect of the strategies on manufacturing on-costs, inventory holding costs and transport costs will be quantified and discussed.

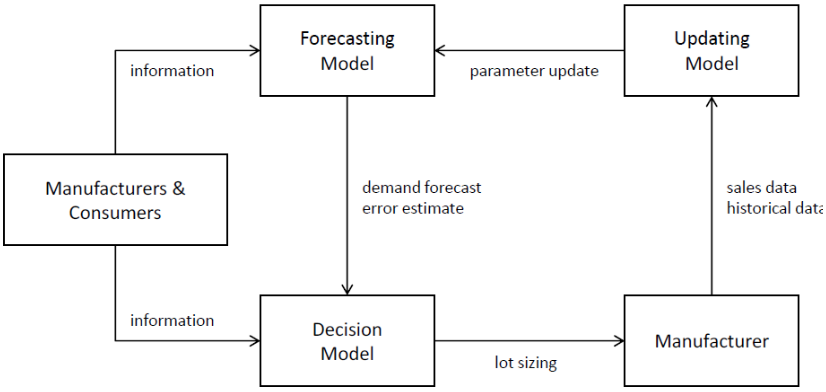

Figure 3: Information flow in a supply chain model

The model simulates the collaborative VMI, taking profit from the PI advantages, and traditional supply chain MTO strategy in a scenario which previously has been configured with the forecasted demand of the customer. During the rolling horizon, the designed network of supply chain makes replenishment orders to cover the forecasted demand with the objective of minimizing the total costs. Decisions made by each customer individually affect in the decisions taken in the assigned manufacturers in terms of inventory levels and quantity production. The simulation of the supply chain policies requires to previously forecast the demand for each day of the rolling horizon. Capturing the time-varying stochastic patterns within the replenishment policy is a key factor in order to ensure cost minimization.

3.3 Transport

Regarding the transport network, the main idea is to capture the main concepts of passenger transport and translate them into the freight distribution. Physical Internet should not only be fed by the network performance but also for other transport status. In the following example we propose a freight transport network similar to the carriage of passengers.

In a PI network the nodes represent the distribution centers, or warehouses, the starting and ending point of the movements. Between two nodes, there exists a set of connections, each one with a mode of transport (bus, train, car), and certain capacity (volume, number of seats, etc) and a set of frequencies. The set of frequencies may be represented as a weekly basis with their timetables.

When we have to design the optimal way to transport one order from an origin to an destination, as done in Royo (2016), as well as we do when searching for a passenger trip. In addition to this, the orders must be served inside the boundaries of their corresponding time windows, although the waiting time is allowed on certain defined occasions. As a general rule, we always select the shortest path with the minimal cost, measure as a global function with money, time and quality service.

This is what we have done with the long distance simulation model: get inspired by the passenger decisions and deploy transport network to “route” orders. But here we face with a small but challenging issue: a passenger only thinks on her/himself. Nevertheless, the system deployed think on “all the passengers” (all the orders).

This research objective is to find the least distance to serve all the orders of the customers selecting the lowest way under different boundary conditions and constraints values.

The figure 4 shows an example of our long distance transport network: three warehouses and two connection. Each warehouse node is enriched with arrival or departure type and a date. This way, the future optimization algorithm does not have to consider this constraints during the execution time. Besides that, this approach let experts to enhance the warehouse with other valuable information, depending on the environment of the problem.

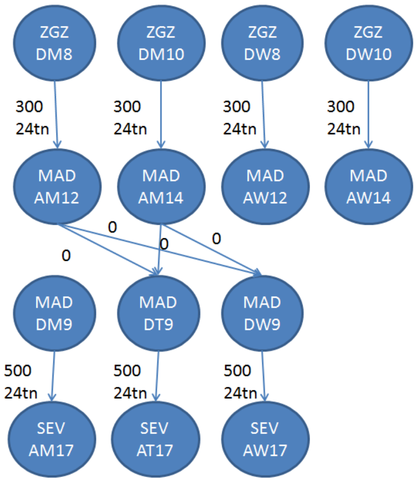

Figure 4: Transport Network representation

Virtual graph as a result of exploitation of the main network. As can be seen, the links between the virtual nodes represent real connections with a demand, date and travel time. The virtual graph can be used an input for the optimization algorithms as Dijkstra’s Algorithm. This way, the system could find an optimal way from the order origin to the final destination just by adding a temporal virtual node and linking it with the corresponding departure.

3.4 Distribution Center

The simulation includes the physical model of the layout and the most important rules of dynamics behavior of the resources used in the facility.

In Chackelson (2013) we can find that the warehouse design has become important due to its impact on service to customers and total logistics costs. Order picking is the key activity of a warehouse and an appropriate design will directly affect its overall performance. The increasing complexity of warehouses means that the main operating strategies such as storage location assignment, batching and routing need to be considered simultaneously. A Design of Experiment (DOE) approach aided by Discrete Event Simulation could help to meet these new picking design process requirements. With the DOE the relationships between the main variables are obtained. This data could be used in other network simulation or in the Supply chain dynamics.

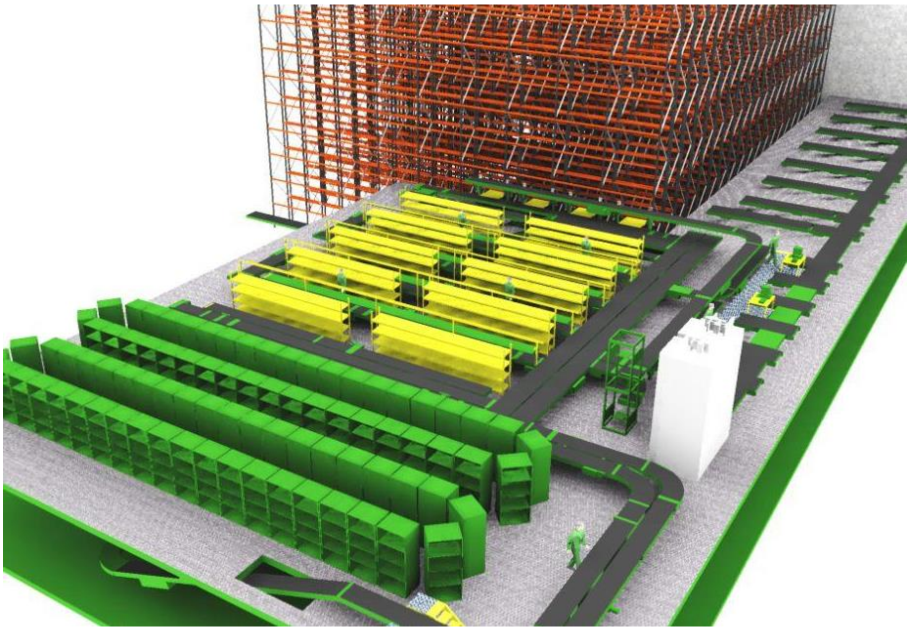

Figure 5: Discrete event simulation from a distribution center

Won and Olafsson (2005) have highlighted that although previous research traditionally focuses on improving system throughput (total picking time and effective use of equipment), the primary concern of customers is often fast delivery of their orders (order maturity time). Nevertheless, it is possible that some initiatives to improve one of these performance measures might impact negatively on other order from the PI framework. In this context, analysing performance evaluation trade-offs is an important task in order to align warehouse efficiency measures with PI customer requirements.

This type of simulation is very interesting to evaluate the performance from new handling strategies related with Physical Internet like handling operations related with PI-containers, cross-docking operations, multi-client picking strategies or consolidation process to increase the fill factor.

3.5 Customer behavior

Due to effects like the high level of globalization and short product launch cycle the behaviour of customer is not easy to anticipate. There is a need of new tools allowing to take the key element of such consumer-centric production systems, such as people and their behaviour, into account when trying to understand and predict the behaviour and performance of these systems. The behaviour of humans differs notably among people and therefore the heterogeneous and diverse nature of the actors needs to be taken into account during the service design and the processes to provide de services. At this point is where multiagent simulation systems and technologies play a key role.

A particular consumer-centric domain where people's behaviour has a huge impact in production systems and logistics services is Ecommerce. Ecommerce represent a revolution not only for retailers but also for Logistics Service Providers (LSPs) in terms of range of products, order fulfillment, delivery points, time windows restrictions or returns processing among others.

For this reason this paper proposes MAS as one of the key technologies that will help to assess, analyze and support the business decision process taking into account the buyers and end users behaviour and much more in a collaborative approach proposed by physical internet paradigm integrating the conduct and the performance of each stakeholder involved in the delivery of goods between producers and customers along the supply chain.

There are several logistics processes and activities that can benefit from MAS. From a tactical perspective, simulating and understanding buyers behaviour, their motivations and their habits can improve the predictive analysis and demand forecasting processes, that represent the starting point and the source of information for downstream processes. Once the forecast provides more accurate information companies can manage the uncertainty and enhance their planning processes regarding inventories, logistic-facilities such as warehouses or distribution centers, human resources or fleets of vehicles.
From an operational point of view the results and conclusions from these multi-agents simulation systems could help to take complementary decision at day or shift level such us: change cutoff times, production scheduling, order batching fulfillment, time windows restrictions, route calculation, deliveries and collection integration or vehicles assignment.

4 Conclusions

This paper describes a framework to evaluate different aspects of the Physical Internet framework to build trust among stakeholders and to assess the concept under different scenarios and conditions. It shows examples from the strategic point of view and from the operational point of view to help to identify the critical points and generate confidence for companies to be involved

The strategical level, deals with socio-economics aspects from the PI initiative. These models are mainly designed through the high-level relationships that exist between the business variables and the flows of goods and resources. The models at this level are evaluated under the technique of dynamic systems.

The operational level evaluates the process with a higher level detail. In this layer the processes are evaluated from the supply chain point of view, from the supplier to the final consumer (machines, conveyors, containers...). These models include information of products and, especially, on process attributes like process capacity, vehicle occupancy, travel times, productivity ratios, etc. In this level it is also important to consider the behavior of the agents involved in the supply network.

The combination of all this powerful simulation tools gives a complete vision from the complexity of PI flows. The feedback between this models helps the analyzer to take into account multiples input from different processes.

As final remark is important to mention the importance of involving different people, which are related to the decisions about Physical Internet flow, in the development and validation of the models, to create confidence, to evaluate the risks and to detect problems of integration in the early stages.

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BRAZILIAN LOGISTICS UNSUSTAINABILITY: A CONCEPTUAL REVISION APPLYING PHYSICAL INTERNET

Denise Alessandra Defina[1] and Benoit Montreuil[2]
1. FEA-RP/USP, Ribeirão Preto, Brasil
2. Georgia Institute of Technology, Atlanta, USA
denise@fearp.usp.br
benoit.montreuil@isye.gatech.edu

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Abstract

Logistics in Brazil is very unsustainable, inefficient and precarious. Transport matrix, composed of 61% of highways, 21% of railroads and 14% of waterways, when at least 60% of this matrix should be anchored in railroads and waterways. Lack of investments in the logistics and multimodality network, as well as technological resources to facilitate the systematic arrangement among all the agents involved. The physical internet that adds concepts of an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. The Physical Internet enables an efficient and sustainable Logistics Web that is adaptable, efficient, systemic and resilient. These features can answer for some Brazilian logistics problems. This paper reviews the main foundations and constituents of the physical internet theory in order to try to answer the main logistics problems that Brazil faces in trying to find possible solutions. In the end, it is concluded that, in fact, it is possible as long as the country creates investments for the infrastructure and technological resources, however, more studies can help in this matter.

1 INTRODUCTION

Brazil is known for its important role concerning the export of commodities. The main problem from a logistical point of view in Brazil is infrastructure. Just over 10% of our roads are paved, which amounts to less than 250,000 km. There is no point in trying to compare this situation with developed countries. Still, if we want to compare this situation with the other BRIC members, Brazil is far behind. Russia has more than 600,000 km of paved roads while China and India each have about 1.5 million km of paved roads (PUGA; PIMENTEL, 2016).
And it is worth remembering that the highways are our "strong point". Brazil has just 30,000 km of railways against 63,000 kilometers of India, 77,000 kilometers of China and 87,000 kilometers of Russia. Just to put these numbers in perspective, the US has more than 220,000 miles of rails. With regard to ships, the situation is no different. We have 14,000 km of waterways. Russia and China has more than 100,000 km each. In Brazilian ports, it is estimated that the handling cost per ton is US $ 13 while the world average is US $ 7. Transport matrix, composed of 61% of highways, 21% of railroads and 14% of waterways, when at least 60% of this matrix should be anchored in railroads and waterways.
Brazil loses the equivalent of US $ 83.2 billion per year with logistical costs due to problems ranging from high bureaucracy to the limited infrastructure of roads, railways, ports and airports. The loss represents around 5.6% of the Gross Domestic Product (GDP). Companies are now looking to offer their products and services quickly, cheaply and better than their competitors. For this, a good infrastructure of transport modes is required, since these are the ones that determine the time of delivery and even final cost differentials. The lack of infrastructure in Brazil is something that is visible. There is precarious equipment, roads, a shortage of skilled labor, and a lack of efficient public policies. Today, entrepreneurs already recognize logistics as one of the main factors of competitiveness, as many have lost space in the market due to lack of logistics efficiency.

Add to this the fact that highways are the main means of transportation in Brazil, and you have the revenue for an expensive, inefficient and inconsistent distribution. Brazilian products lose competitiveness and the consumer pays a high price. If the roads are not in good condition, it increases the cost of transportation, which is inevitably passed on to the consumer. Freight is one of the main components of logistics costs. Road transportation in Brazil corresponds to 58% of the national logistic system. However, according to the National Confederation of Transportation, 69% of the Brazilian roads are in bad conditions. The most damaged ones are those located in the North and Northeast of Brazil, preventing the economic development of these regions.

According to the CNI (Conselho Nacional da Indústria), productive sector spends R$ 108.4 billion annually with transportation costs - including freight, tolls, transhipment costs, terminals, port fees - which corresponds to 4.5% of the Product Gross Domestic Product (sum of the riches produced by the states of the region). According to the document, if the planned investments are not made, logistical costs can rise to R $ 162.8 billion in 2020.
Cargo theft is still a problem in Brazil. In 2009, more than 1 billion reais were recorded in theft losses. This cost is also passed on to the final consumer. Also, if companies do not manage demand properly, they end up with expensive, expensive stocks. With the amount of data available today it is possible to make an excellent forecast of demand, keeping inventory levels lower without causing breakages.
The low investment in logistics in Brazil is due to the difficulty of the government plan this sector, the need to improve the regulatory framework, the development of funds structures and the incentive of the private sector. One of the challenges is to think about the different

modalities of transportation in an integrated way to avoid costs in freight transport for which railroads are more efficient and sustainable. That is one of the possibilities of solution

In the current economic environment and technological development has increased sharply the importance of logistics. On the one hand the high financial cost, higher value-added production and the wide range of product types require the implementation and execution of streamlined inventory and distribution processes. On the other, the high fuel prices and the growing prospects of intermodality, lead to the search for more intelligent solutions in transportation.

2 Background

Nowadays, there is great communication between countries. The Internet has brought greater flexibility of relations, particularly with regard to free trade between countries. This change in business relationships brought an increased flow of products that are produced and shipped to final destination. The distribution, packaging, storage, transport were begun to grow with them. This fast growth has imposed a need to improve the distribution procedures.

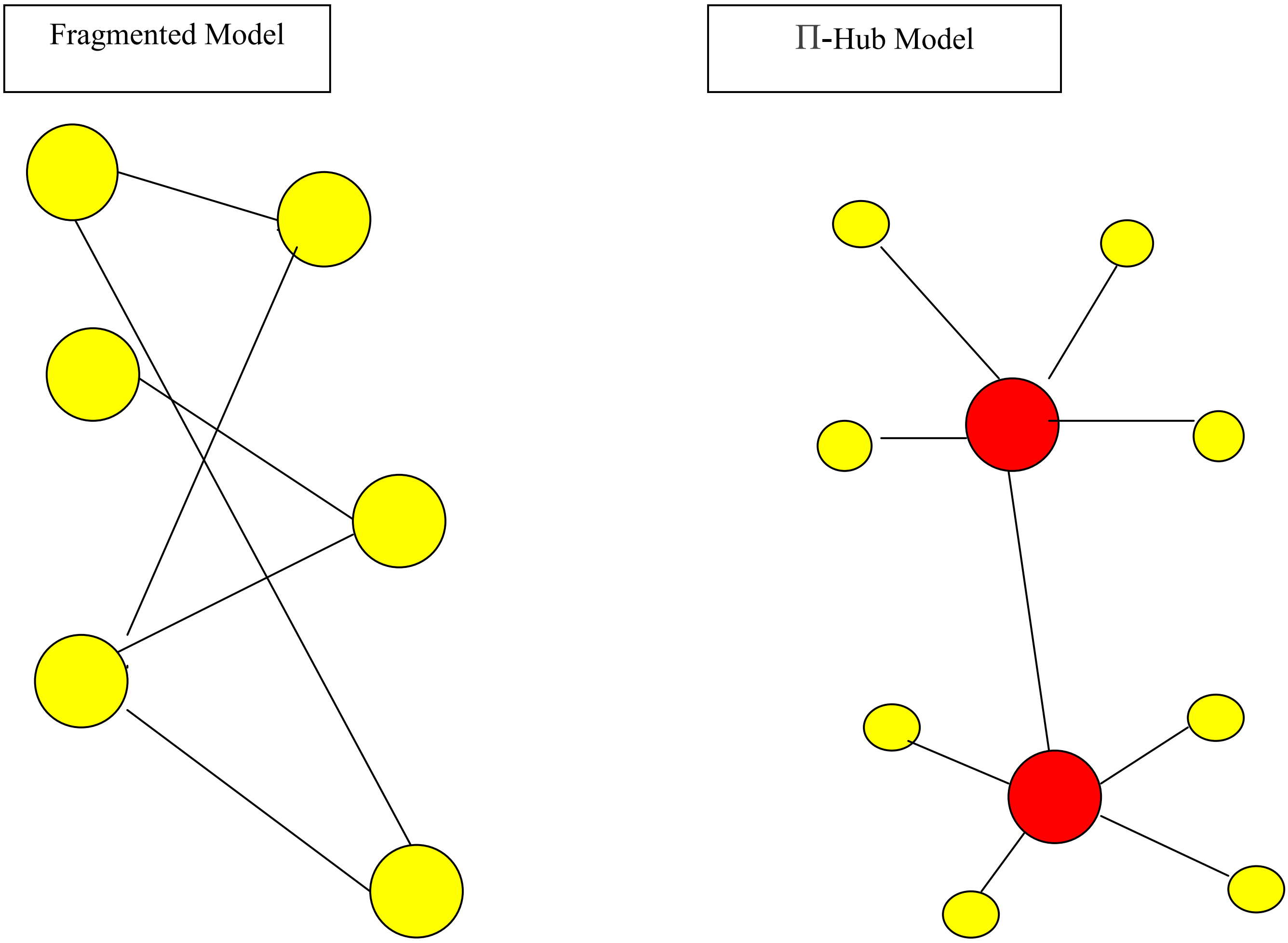
As an alternative to solve this demand, rises The Phyical Internet (PI, π) that was presented by Montreuil as a response to the Global Logistics Sustainability Grand Challenge. It covered three aspects of sustainability: economic, environmental and social, using symptoms from today´s logistics system as evidence of unsustainability of our present system. The Physical Internet is defined as an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. The Physical Internet enables an efficient and sustainable Logistics Web that is adaptable, efficient, systemic and resilient.

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, 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.

The aim of a road-rail π-hub is to efficiently and sustainably transfer containers from trains from one line to trains from another line or from and to trucks. The basic idea of the road-rail π-hub is: 1) to never dismantle trains to avoid very strict safety constraints; 2) to enable a real network with many destinations available with short lead-times; 3) to smoothly interconnect with truck services.

To reach these goals, the mission of a road-rail π-hub is: 1) to receive trucks and handle their inbound π-containers so they can be loaded in time in their assigned train and railcar so as to move them to their next rail-based π-node; 2) to receive trains and handle their inbound π-containers so they can be loaded as pertinent either on a truck called to pick them up or on a subsequent train so as to move them to their next π-node or their final destination; 3) to handle and sort π-containers in connection with either a truck or another train.

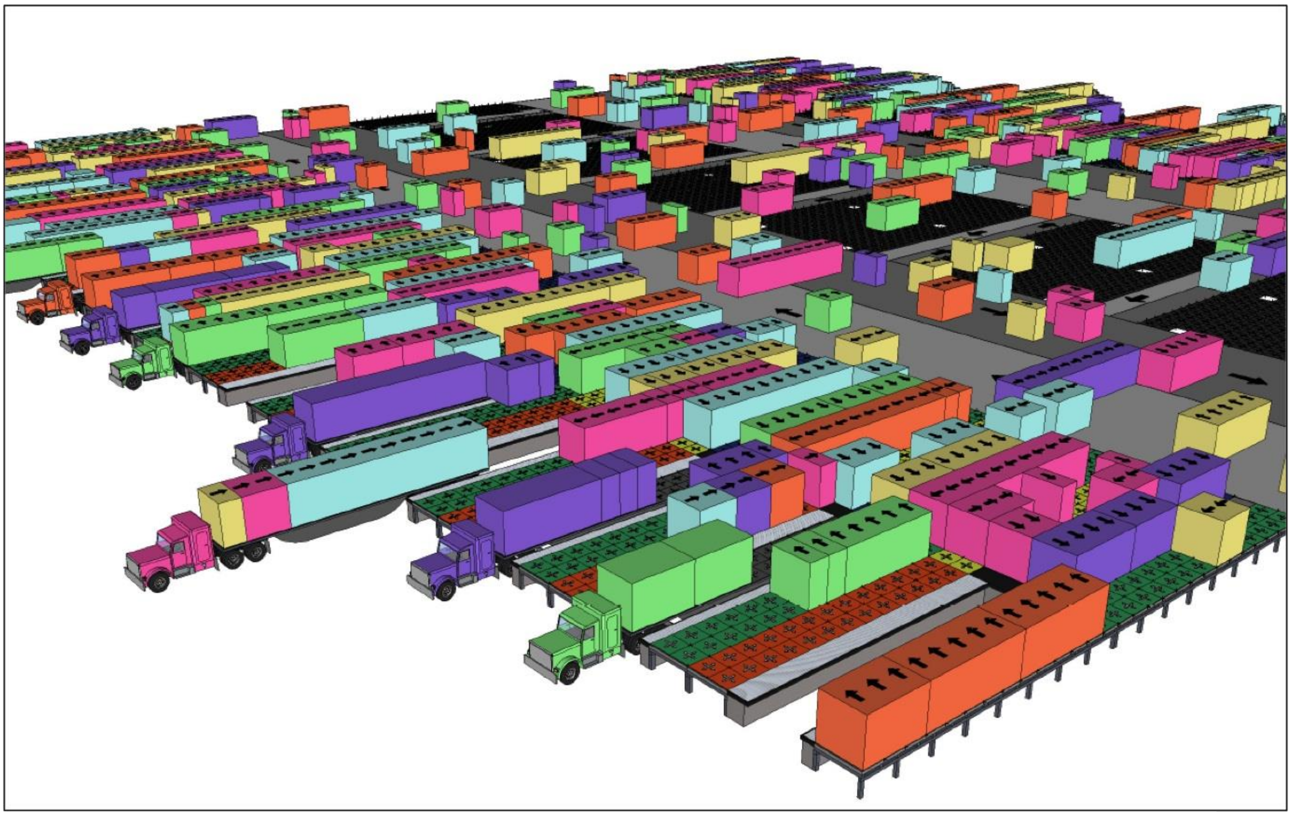
Figure 1 – Logistics Model



Source: by the author from Benoit (2011)

The fragmented model shows that the flow is ineficient and can spend more time that the π-hub model, that´s why the first one must be change for the hub model configuration. Each π -hub is a logistics platform and it can allow concentration of flows on each platform and can be sent to each location from the next available, located by the manager of each π -hub. If it is provided with terminals multimodal technologies could lead to transfer of cargo to railway wagons or for the which will carry out the more "legs" that connect the π-hubs.

Figure 1: Conceptual Drawing of Physical Internet Hub



Source: Kevin Gue (wordpress.com)

The global logistics sustainability grand challenge cannot be addressed through the same lenses that have created the situation. The current logistics paradigm must be replaced by a new paradigm enabling outside-the-box meta-systemic creative thinking.

From an economical perspective, the way goods are flowed is hugely costly. In most developed countries, it accounts for a significant fraction of the gross national product like in the U.S.A. provides a vivid example. Based on statistics from the 2009 Department of Transportation reports, transportation represents about 10% of the U.S. Gross Domestic Product, or roughly about 1.4 trillion. From an environmental perspective, the stakes are also high. Brazil doesn´t follow the same way.

Beyond such big-picture numbers, the societal, environmental and economical unsustainability of logistics across the planet can be grasped through numerous symptoms. Several of them are below. For each, goes with commentaries in relation to Brazil:

1. We are shipping air and packaging

Most of part, the products are in the Brazilian ports waiting for containers are full and then they will shipping. Sometimes, it takes from a month to four months until it´s happen.

1. Empty travel is the norm rather than the exception

Logistics in Brazil is non-systemic. There are logistics operators that works in a independent way for a specific industry or a group of them.

2. Truckers have become the modern cowboys

It can be said that in Brazil they end up assuming the same role. They are not integrated into a system and are limited to just driving a truck from one point to another, often in extended journeys, which leads to fatigue and in some cases, accidents

3. Products mostly sit idle, stored where unneeded, yet so often unavailable fast where needed

This is a constant in Brazil, since the logistics service always works independently and uniquely, without connecting with other products that are marketed by other companies. This lack of systemic communication leads to inefficient and expensive storage and mismatch between inventory and product delivery.

4. Production and storage facilities are poorly used

This is a constant in Brazil, since the logistics service always works independently and uniquely, without connecting with other products that are marketed by other companies. This lack of systemic communication leads to inefficient and expensive storage and mismatch between inventory and product delivery

5. So many products are never sold, never used

There are many cargo thefts in Brazil which further elevates this item. This leads to the contracting of cargo insurance, which raises the final price to the consumer.

6. Products do not reach those who need them the most

Failures in logistics infrastructure, misuse and underutilization of multimodality, and discontinuity of delivery generates inefficiencies as products that do not reach their destination in a timely manner.

7. Fast and reliable intermodal transport is still a dream or a joke

Multimodality is not yet a reality in Brazil. Lack of investment and technological adequacy to have a logistical system that is economically and socially sustainable.

8. Getting products in, trough and out of cities is a nightmare

The more distant the product of the consumer, the more logistical resources must be used to guarantee the delivery of the product in perfect conditions in the shortest possible time. In Brazil, it happens all the time, specially, in extreme regions of the country.

9. Products unnecessarily move, crisscrossing the world

Logistic action that works in an unintegrated way can lead to unnecessary routes and could be better used if they were globally interconnected.

10. Networks are neither nor robust

Logistic networks in Brazil work in isolation with little connection to other modes. Freights are basically road freights with poorly maintained roads and holes.

11. Smart automation and technology are hard to justify

The Ministry of Transport of Brazil has a logistic development plan, but investments and studies that justify these investments are lacking. Companies have little interest in building partnerships for this.

12. Innovation is strangled

The lack of research and study investments to make efficient multimodal logistics economically sustainable leaves innovation more distant..

Based on these and other important points can be noted that the way physical objects are transported, handled, stored, produced, supplied, designed and used throughout the world is often not sustainable. Brazil mostly fits with the above assessment. A continental country where the logistic map could be efficient, fast and modern suffers from being essentially reliant on a road transport infrastructure that is poorly distributed and maintained, with roads in precarious conditions, inducing the emission of gases harmful to both human health and the environment. Rail transport is insignificant. Transport by rivers with potential for navigation still needs more incentives for logistics development. For abroad trade, ports are misused and have an extremely precarious structure, focused in Port of Santos, the major Brazilian port. The Brazilian Ministry of Transport has a national logistics plan, but it is still in the implementation phase.

In recent years there has been growing concern about the environmental effects of global human activity. This explains the increased attention to the popular classes, in government appointments, in the academic literature and also the general public. Stakeholders including government agencies and society are increasingly aware and they pressure companies to take responsibility for any negative effects that their business activities may cause. The increasing attention to more sustainable solutions includes logistics. Indeed it plays a very important role since it is a major source of pollution and resource use.

3 RESEARCH METHOD

This paper was classified in Physical Internet Fundamentals and Constitutes topic and Sustainability research field. It aims to deepen theoretical knowledge regarding the Physical Internet and its application in the Brazilian logistics. It is not the object of this study to exhaust all the concepts and fundamentals of the physical internet but to relate the basic principles with the logistic problem with relevance to the question of sustainability, considering that the Brazilian logistics is extremely inefficient and not sustainable as pointed out previously.

Explanatory research records facts, analyzes them, interprets them, and identifies their causes. This practice aims to broaden generalizations, define broader laws, structure and define theoretical models, relate hypotheses to a more unitary view of the universe or productive scope in general, and generate hypotheses or ideas by virtue of logical deduction (LAKATOS; MARCONI, 2010).

Explanatory research requires greater investment in synthesis, theorization and reflection from the object of study. It aims to identify the factors that contribute to the occurrence of the phenomena or variables that affect the process. Explain why things and try to understand them. That is made during this study. The results can be discussed in a conclusion.

4 CONCLUSION

Based on the explicit theoretical framework, it can be seen that the Brazilian logistics presents serious problems of infrastructure, maintenance, management, investment, multimodality, sustainability, transport, handle, storage, realized and supplied. All these problems are involved in the concepts of Physical Internet.

Brazil is among the leading developing countries with the highest growth potential in the world. It is currently among the twenty largest exporters in the world and only does not perform better due to lack of physical infrastructure. In this sense, the great brake of growth is the lack of quality of transport modes. The country has a good infrastructure of information, but it does not want to be in the physical infrastructure, especially with regard to the railway, road and maritime system.

The current framework of the country's cargo transportation structure has presented many limitations to the expansion of economic growth. With an existing transportation problem, the country is wasting billions of reais, with cargo thefts, operational inefficiencies, resulting in a significant loss of competitiveness. The inappropriate use of the modalities ended up generating a great dependence on the modal road, due to the low prices of the freights. Despite the huge coast and navigable rivers, the highways have a prominent role. According to the Transport Mystery, about 60% of national cargo is transported by highways.

The logistical problems are mainly concentrated in a discontinuous, disintegrated system with few technological resources. The concept of Physical Internet seems to address the key points of Brazilian logistics problems because in logistics, Physical Internet is an open global logistics system founded on physical, digital, and operational interconnectivity, trough encapsulation, interfaces and protocols. The Physical Internet does not manipulate physical goods directly, whether they are materials, parts, merchandises or yet products. It manipulates exclusively containers that are explicitly designed for the Physical Internet and that encapsulate physical goods within them.

It was aimed that the road-rail π-hub is to efficiently and sustainably transfer containers from trains from one line to trains from another line or from and to trucks. The basic idea showed of the road-rail π-hub is: 1) to never dismantle trains to avoid very strict safety constraints; 2) to enable a real network with many destinations available with short lead-times; 3) to smoothly interconnect with truck services.

The term, Physical Internet, employs a metaphor taken from the Digital Internet, which is based on routers, all transmitting standard packets of data under the TCP-IP protocol. A core enabling technology to make the PI a reality exploit is the encapsulation of goods in modular, re-usable and smart containers. This will make it possible for any company to handle any company's products because they will not be handling products per se and its make sense for commercial products in Brazil. Instead they will be handling standardized modular containers, just as the Digital Internet transmits data packets rather than information/files. Modulars Brazilian containers can be provide for this specific purpose.

Another enabling technology of the Physical Internet is an open standard set of collaborative and routing protocols. Modularized containers are much easier to route through transport networks as individual "black-box" loads instead of heterogeneous loads of different sized cases and pallets that are used today in Brazil. But the efficient routing of modular containers over a collaborative network can only be realized if there is a standard set of routing and digital protocols, as well as business and legal conventions that apply across a community of users. Scale gains can be achieved when the standardized container containers dispatch products in a continuous flow without the need to stand in the port waiting for release for shipment. In Brazil, this wait can reach 120 days, which will burden the logistics process as a whole.

Beyond of handling and digital interfaces are needed to ensure reliability, security, and transparency as well as that the quality of the product being handled is not compromised through its movements. These interfaces cannot be proscribed, but the functional requirements need to be so that innovative interfaces may be developed.

Conception like the vision of the Physical Internet involves encapsulating goods in smart, ecofriendly and modular containers ranging from the size of a maritime container to the size of a small box would be good for Brazil. It thus generalizes the maritime container that succeeded to support globalization and shaped ships and ports, and extends containerization to logistics services in general. The other like the Physical Internet moves the border of the private space to be inside of the container instead of the warehouse or the truck is good too.

These modular containers would be continuously monitored and routed, exploiting their digital interconnection through the Internet of Things.

Although this is a compelling vision for the future of logistics, there are any reasons that some ponderations should be done to deploy the Physical Internet today, specially in Brazil, where there are some infrastructure and financial obstacles to implement some improvement in some specific sector. First, there is no agreed-upon standard for various container sizes outside of the international shipping containers. This, and the lack of standard contracts and other operational issues, mean that collaborative distribution is difficult to initiate and maintain. And expanding collaborative distribution is limited by the fact that there is not a centralized exchange for freight based on a standardized specification of a load, with the lack of standardized specification of a load due to the lack of standard containers. Other circular arguments on the use of the rail system, due to the currently time-inefficient design of switch yards, the lack of innovation due to the difficulty in justifying innovation when what is handled is so diverse, and the inability to construct facilities that will act as the backbone of the PI until there are users of the PI, all mean that there are a number of research questions and business issues that must be addressed before the Physical Internet is to become a reality.

Considering the following Brazilian logistic characteristics:

1. Increased level of transport service;

2. Expansion of the railway network, deteriorated during the period of public monopoly;

3. Increase the capacity and efficiency of port terminals;

4. Accessibility to Ports;

5. Expansion of the storage system, including for stock control purposes;

6. Expansion of waterway and pipeline activities (for ethanol, mainly);

7. Balancing the transport matrix;

8. Balance when assessing the environmental impacts resulting from logistical interventions

It is observed that the Physical Internet concepts are applicable to the Brazilian logistic context, either in the need to enable the transport of products, or in the standardization of modular containers, in multimodality, or in sustainability, which is intrinsic to the proposed model.

Studies can be done to raise the main deficiency points of the logistic system and apply the physical internet based on simulations that indicate results that can be applied by the main Brazilian stakeholders.

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Simulation-Based Optimization in the Field of Physcial Internet

Christian Haider[1], Erik Pitzer[1] and Michael Affenzeller[1]
[1] Heuristic and Evolutionary Algorithms Laboratory
School of Informatics, Communications and Media
University of Applied Sciences Upper Austria, Hagenberg Campus, Austria
{christian.haider,erik.pitzer,michael.affenzeller}@fh-hagenberg.at

Abstract: *One of the biggest challenges in the field of Physical Internet (PI) is the optimization of material flows within global transportation networks. Within such real-world logistics networks, complex problems with many restrictions have to be considered. As such problems are highly dynamic, standard formulations and algorithms of already known problem models are difficult to apply. Thus, it is necessary to develop new methods which allow a stable optimization of PI logistics networks. One solution approach is simulation-based optimization. Realistic models of real-world environments are created to be able to consider all complex restrictions. It has to be decided how simulation and optimization nodes work together and communicate with each other. These considerations have to be made due to the required coupling process between the simulation and optimization.*

This paper shows how the optimization of a PI problem is interrelated with its simulation. It is demonstrated how simulation is used to evaluate possible solution candidates of the optimization process. Furthermore, it is presented how the simulation uses the optimization algorithms to generate new feasible candidates. The developed solution approach is realized by using the frameworks HeuristicLab and Easy2Sim. HeuristicLab is used for optimization and Easy2Sim for simulation parts. Moreover, it is presented how simulation and optimization parts communicate with each other. Therefore, an interface for the exchange of data between the simulation and the optimization pars is implemented. As a result, components can be programmed in different languages and different data structures can be used.

Keywords: *simulation, optimization, real-world problems, logistics networks, physical internet*

1 Introduction

Every day a lot of orders are placed through internet shops, retailers or distributors. Due to the huge amount of just in time orders, new methods concerning logistics transportation have to be developed to be able to still handle such orders in the future with available resources (Montreuil, et al., 2012).

Nowadays, different existing logistics networks are not fully interconnected with each other and logistics providers often use their own network to ship goods (Sarraj, et al., 2013). In contrary to that, with the so-called Physical Internet, also called PI, all autonomous transportation networks of logistics providers are merged into one big global network (Montreuil, et al., 2012).

To achieve such a global network, the idea of the internet is used as a model. Mainly the concepts of the TCP/IP protocol and Open Systems Interconnection Model (OSI) are applied to PI problems. As already pointed out, all these problems and new solution approaches are difficult to handle. Therefore, new solution methods for the successful realization of such a global network have to be developed (Montreuil, et al., 2012).

Since the field of physical internet is still a young topic, there are no ready to use solutions for most of the problems which can be applied. The PI represents a very large and difficult problem which should be modeled and solved, also in terms of logistics optimization problems. Due to the novelty of this topic, there is also no suitable optimization algorithm which can be used out of the box. There are examples, which show that optimization with metaheuristic methods can achieve good results concerning logistics optimization problems. One example where metaheuristic methods are applied successfully is the Vehicle Routing Problem (Dantzig and Ramser 1959, Toth and Vigo 2014). However, all these methods face only single aspects of the real world, whereas the PI model contains a lot of aspects that need to be taken care of. These aspects are restrictions such as time constraints, capacity constraints, etc. Therefore, standard metaheuristic approaches cannot be used to model the problem. For this reason, the aspect of simulation-based optimization comes into account. With simulation-based optimization, a meta-heuristic optimization framework is used to create new feasible solution candidates and a simulation-framework is used to evaluate all these candidates (Affenzeller, et al. 2015).

In this paper, we present the simulation-based optimization, which is suitable to solve such kinds of problems. The optimization framework HeuristicLab (Wagner et al 2014), which allows to couple many different optimization algorithms with the simulation framework easy2sim[1], is used. The easy2sim framework acts as an external evaluator for the given solution candidates.

One reason why simulation-based optimization is such a suitable concept is that simulation can use optimized parameters from the optimization process to update its model. Besides, the optimization can take use of a detailed model that evaluates the new solutions candidates, which it creates (Affenzeller, et al. 2015).

The paper is organized as follows. Section 2 gives an overview of different variants of simulation-based optimization and how they might be used in the PI context. In Section 3, the coupling between the optimization part and the simulation part is covered. Section 4 gives a conclusion about simulation-based optimization in the field of PI.

2 Simulation-Based Optimization

Due to the fact that modeling of the PI has many restrictions to be aware of, standard implementations of optimization algorithms and standard problem formulations cannot be applied. This is why simulation-based optimization approaches are discussed in the following section.

Within simulation-based optimization we can distinguish between:

- control optimization
- and parametric optimization (Affenzeller, et al. 2015 and Gosavi 2003)

In the following two subsections, the control optimization and parametric optimization are applied to possible implementations concerning the PI.

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[1] http://www.easy2sim.at/

2.1 Low-Level Optimization

During a so-called low-level optimization, considerations regarding specific PI scenarios are made. Within these scenarios, different operational planning problems are optimized and evaluated. Examples for such operational planning problems are the Vehicle Routing Problem, the Lot Sizing Problem (LSP) and Scheduling Problems. The VRP calculates the cost optimal route between a given amount of customers, one or more depots and a set of transportation vehicles (Toth and Vigo 2014). With Lot Sizing Problems, the problem of minimizing costs, such as production costs or storage costs, by planning the optimal amount of to be produced products, the lot size, is described (Pahl and Voß 2010). Within Scheduling Problems, so-called production jobs are assigned to time critical resources (Fink and Voß 2003). Moreover, with low-level optimization, high-level scenarios can be evaluated, as explained subsequently in 2.2

Another designation for low-level optimization is control optimization or *dynamic optimization* (Gosavi 2003). As shown in Figure 1, the simulation part is the master process and the optimization process gets called if certain events occur. If an event is triggered, the optimization process is used to make a decision and this decision is sent back to the simulation (Affenzeller et al. 2015).

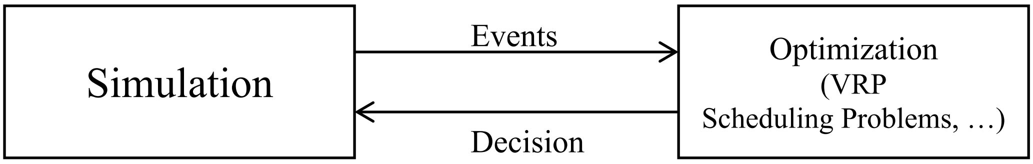

Figure 1: Control Optimization (Affenzeller et al. 2015)

For the PI, various operational planning problems have to be considered within one framework, as different organizations with different planning problems should work together within one framework. With the here described low-level and control optimization, the challenges of modeling already existing operational planning problems, such as the VRP, and also new ones, which could emerge via the further development of the PI, and at the same time validating results of necessary optimizations, should be conquered.

2.2 High-Level Optimization

While the low-level optimization covers the operational planning process, the high-level optimization is in charge of strategic and tactical planning processes. During such processes, different scenarios are considered. One example is the Plant Location Problem, which decides if new depots are opened or not under consideration of depot opening costs and delivery costs (Sridharan 1995). Another example is strategic or tactical production planning, where the allocation of an organization's resources to be able to serve the needs of all customers, is covered (Boysen et al. 2009). On basis of these considerations (depot costs, fleet costs, construction costs, administrative expenses, etc.), the optimization potential of a specific PI scenario can be estimated and strategic (long-term) and tactical (mid-term) decisions can be made.

In Figure 2, the schematic illustration of high-level optimization is shown. Whereas simulation is the master process at the low-level optimization, at the high-level optimization the optimization part is the master process. The optimization creates feasible solution candidates which are passed to the simulation. Inside the simulation process, parameters get evaluated. Moreover, a value representing the fitness of the solution candidates or even a set of values in case of multi-objective optimization, is returned (Affenzeller et al. 2015).

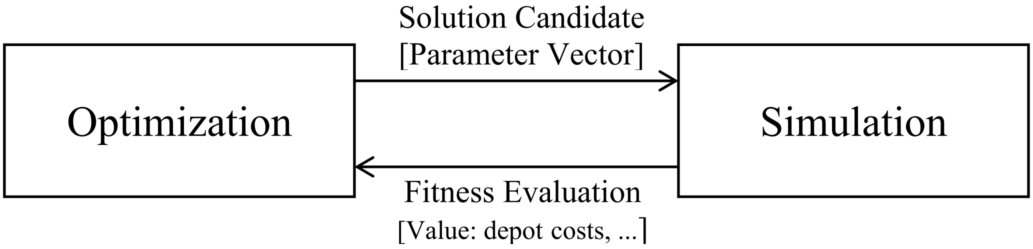

Figure 2: High-Level Optimization (Affenzeller et al. 2015)

3 Communication between Optimization and Simulation

As it comes to simulation-based optimization one challenge is to define an appropriate way to communicate between the optimization framework and the simulation environment. This is done by defining an interface that describes the way how both sides communicate with each other. As mentioned before, the HeuristicLab Framework is used on the optimization side. This offers the possibility to use a generic interface implementation (Affenzeller, et al. 2015) to communicate with external processes like the simulator easy2sim.

Whenever communication between different frameworks, programming languages or platforms is performed, the problem of interoperability has to be considered. For example, the HeuristicLab Framework is fully written in C# and the simulator framework easy2sim is Java code. To solve the problem of serializing structured data sending between the frameworks, Google’s protocol buffer framework is used. Right now the current version of the Protocol Buffers is proto3. With this version it provides implementations for several different programming languages like Java, Python, Objective-C, Go, JavaNano, Ruby and C# and implementations for other languages are already planned. The reason why Protocol Buffers is used for the serialization of structured data is, because it performs a lot better than similar techniques like XML. The main reasons why we use protocol buffers over XML:[2]

- simplicity
- smaller size
- faster speed
- less ambiguous
- generated data access classes that are easy to use programmatically[2]

The most important reason why to use Protocol Buffers instead of XML for the communication between processes is its speed. As optimization processes are often time consuming, all possiblities for saving time have to be used. In Figure 3 a model in XML format is shown, in Figure 4 the same model is represented in the Protocol Buffers text format.[2]

```
<person>
    <name>John Doe</name>
```

---

[2] https://developers.google.com/protocol-buffers/

```
    <email>jdoe@example.com</email>
</person>
```

Figure 3: XML representation of a model person with two attributes name and email. This example is taken from googles developer site[3]

```
Person {
    name: “John Doe”
    email: “jdoe@example.com”
}
```

Figure 4: Protocol buffer representation of the model person with two fields name and email, taken from googles developer site[3]

In the human-readable format of the XML and Protocol Buffers format shown in Figures 3 and 4 there is no big difference in size, but if the Protocol Buffers format is translated into its binary format that is used over the wire, the size will shrink to approximately 28 bytes and will take about 100-200 nanoseconds to parse. Whereas the XML format has a size of at least 69 bytes what will take on the order of 5000-10000 nanoseconds to parse[3].

4 Conclusion

With already known problem formulations, only single aspects of the real world can be modeled. However, when speaking of the PI, modeling the real world is very complex and highly dynamic, as multiple planning problems have to be considered. This is where simulations-based optimization offers a huge benefit. It does not only allow to model a much more complex and closer model to the real world, it also allows to improve the model by taking advantage of optimized parameters from the optimization process. Two different patterns of simulation-based optimization are shown. The parametric approach where the simulation part of the simulation-based optimization, is used as an external evaluator and the optimization is the leading part, is the common way. The control based optimization pattern is another strategy for solving highly complex real-world problems with various restrictions.

The second part of the paper is focusing on the interfacing method between the optimization and simulation. It is very important that the coupling between these two parts of the simulation-based optimization is very tight. To connect both sides with each other the benefits of the optimization framework HeuristicLab are used, which offers a generic interface. For the data exchange and serialization process, the protocol buffers framework is presented. It is shown that the protocol buffer gives a lot of advantages to other formats for the serialization like XML. The biggest benefit here is timesaving and size reduction of the model representation.

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[3] https://developers.google.com/protocol-buffers/docs/overview

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Physical Internet
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4th INTERNATIONAL
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4th-6th July, 2017 in Graz: Graz University of Technology, Austria

Potentials and key drivers of a cross-company reusable modular secondary packaging system in E2E FMCG chains

Yanyan Yang[1] and Eric Ballot[1]
1. MINES ParisTech, PSL Research University
Centre de Gestion Scientifique - I3 - UMR CNRS 9217, Paris, France
Corresponding author: eric.ballot@mines-paristech.fr

Keywords: *Modular box, Standardization, Physical Internet, FMCGs*

Innovation Paper Abstract

Packaging is the technology of enclosing and protecting products for distribution, storage, sale and use. It is one of key cost drivers across the supply chain which facilitates transport, storage and handling of products that together represent 12-15% of retail sales price (Kearney 1997). A challenge ahead current supply chain for packaging is the different solutions used by many stakeholders when assembling unit loads. That is, the packaging is often designed from half chain view where each actor focuses on his own part rather than on an across chain total optimum. This results in a wide variety of unit load dimensions and too many standards differing from country to country. Established international standards are not always used. Global inefficiencies arise by the diversity of packaging solutions such as poor fill level of packaging units and transportation means, poor storage space utilization, negative environmental impacts, inefficiencies in handling, etc. This is where the real challenge takes place.

Under this context, the innovative logistic concept Physical Internet (PI) proposes a set of modular standardized handling containers (Montreuil, Ballot, and Tremblay 2015) as generic packaging solutions to interconnect heterogeneous logistics networks into an open global logistics system (Ballot and Montreuil 2014, Meller, Lin, and Ellis 2012). These references (Meller, Lin, and Ellis 2012, Landschützer, Ehrentraut, and Jodin 2015, Sallez et al. 2016) take out further studies for the design, sizing and conception of standard modular containers that are also called modular boxes. Continuing the research stream, the objective of this paper is to study the global potential and key drivers of standard modular boxes on a cross-chain packaging system in Fast Moving Consumer Goods (FMCGs) E2E chains. To this aim, we firstly produce a reduced set of typical FMCGs chains according to each geographic area or country in order to size the price and identify quick wins. Then a set of assumptions and a calculation model in a spreadsheet is proposed to quantitatively identify quick wins. To simplify the problem, we apply a small set of standardized modular boxes proposed by (Meller, Lin, and Ellis 2012), which is demonstrated as one of the best set of modular boxes by an optimization study. This work was also confirmed by the FP7 European project “Modulushca”. Business case studies with industrial partners are further taken out. Results and analysis are further validated together with industrial partners.

From the results analysis of case studies and qualitative analysis, we conclude the following five key drivers for modular boxes, as shown in Figure 1: 1) Improved handling productivity such as by less non-value adding handling operations, by

automation handling system through standardization, adapted solution directly to shelves; 2) High space utilization in box, handling unit and transportation means levels by such as less void through modularity, stackability of modular boxes and encapsulation of different products in the same boxes; 3) Improved quality such as by reduced damage through automatic handling systems; 4) Improved service through reduced lead times, improved shelf availability; 5) Low cost reverse logistics by significantly reduced transportation cost through standardization of boxes, etc.

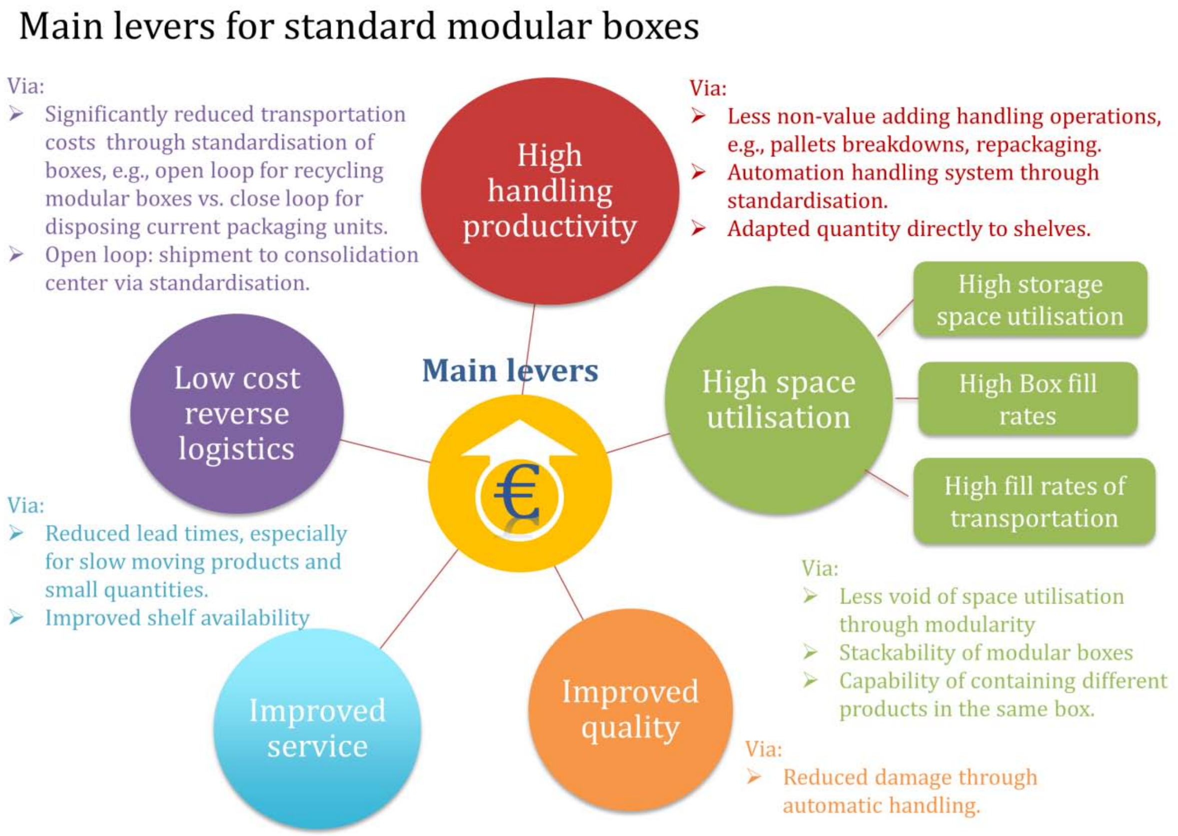

Figure 1- Main levers for modular boxes

Furthermore, as to performance difference to different FMCG chains, we conclude that the profits marge would be the biggest for the slow-moving expensive goods with small volume and Piece Picking as the handling complexity is quite high and it demands storage for this scenario. A conclusion of trends of potential is shown in Figure 2.

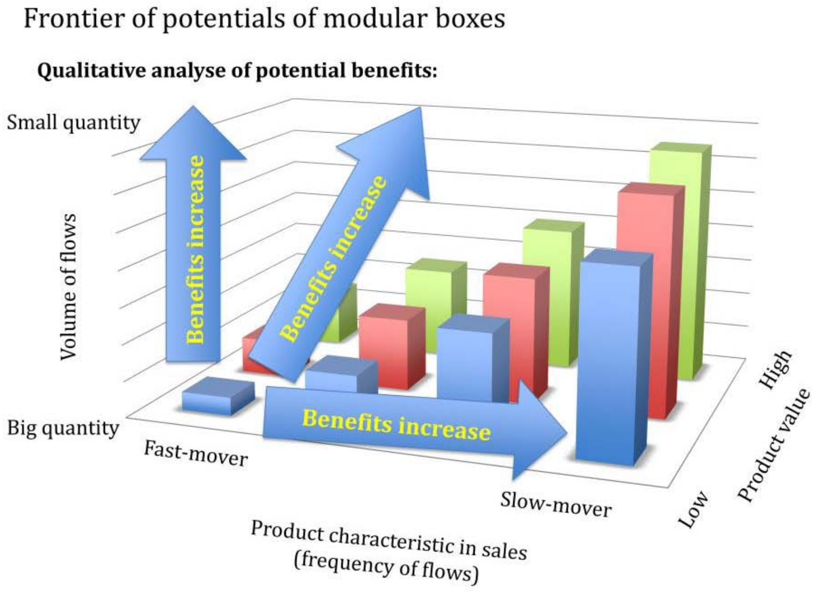

Figure 2- Potential benefits trends analysis

In a word, different actors among the E2E chains should work together for the application of modular boxes as to improve overall logistic efficiency. Further case studies with industrial partners under different scenarios need to be done to demonstrate the qualitative analysis results and actual potential.

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POSTER ABSTRACTS

Possibilities for the joining mechanism of a modular Physical Internet handling container

Stefan Roth BSc[1] and Dipl.-Ing. Florian Ehrentraut[2]
1. Graz University of Technology - Student, Graz, Austria
2. Graz University of Technology – Institute of Logistics Engineering, Graz, Austria
Corresponding author: s.roth@student.tugraz.at

Keywords: *Physical Internet Container; MODULUSHCA; concepts for modular Physical Internet container; concept design*

Poster Abstract

One of the core elements for the realization of the Physical Internet (PI) are the PI-containers. These PI-containers should offer standardized sizes to fit perfectly together on EUR-pallets without any lost space and are mainly used for FMCG´s to ease their handling during the transportation process. They also should be reusable, interconnectable and built out of modular panels to fulfill all the requirements mentioned by Montreuil (cf. [1]). First concepts for the interlocking mechanism have been developed in an earlier research within the project MODULUSHCA by a team of the Institute of Logistics Engineering of Graz University of Technology (cf. [2]). Based on the concept developed in MODULUSHCA the focus of the presented research work was set on finding methods to join the reusable panels together, to further make the idea of building PI handling containers out of modular panels instead of building a rigid box possible. A requirement for this research was that mechanism can be built with available parts and knowledge. This poster shows the methods, results and concepts (see fig.1 & fig.2) of the development step mentioned before acquired within the research by Roth.

Used Methods: Requirement specification, methodological design (VDI 2221 & 2222), brainstorming, feasibility and benefit analysis, CAD – design visualization

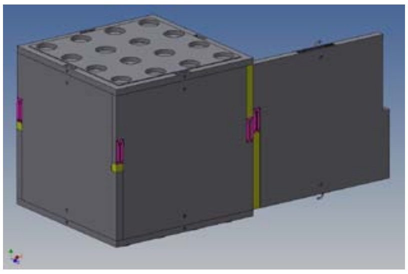

Figure 2: Concept 1

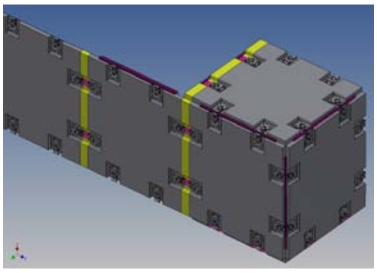

Figure 1: Concept 2

Literature (excerpt):

[1] Montreuil, Benoit: Toward a Physical Internet: meeting the global logistics sustainability grand challenge. In: Logistics Research Bd. 3 (2011), Nr.2-3

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Protection of goods inside PI-handling container

Konstantin Reinmüller[1] and Dipl.-Ing. Florian Ehrentraut[2]
1. Graz University of Technology - Student, Graz, Austria
2. Graz University of Technology – Institute of Logistics Engineering, Graz, Austria
Corresponding author: k.reinmueller@student.tugraz.at

Keywords: *Physical Internet, PI-handling container, protection of goods, VDI 2221*

Poster Abstract

The Physical Internet deals with the strategy to increase the efficiency, flexibility and sustainability of the global flow of goods. The protection of goods within the PI handling container is as well affected in the Physical Internet, which is responsible for the protection of the goods against external influences, that could damage it or affect it negatively. The protection of goods is used in the PI-handling container, that fulfils already the strategy of the Physical Internet. The technical realization and material as one of the most important properties is of utmost interest. The goal of this research work is to derive alternative concepts on the basis of existing solutions and to derive a catalogue of PI-requirements for the protection of goods inside PI-handling container.

Literature and manufacturer catalogues supplies a solid overview about the most popular solutions e.g. packing chips or bubble wrap (Figure 1) and materials, which are actually used. The information gained out of the comparison between actual solutions and the developed catalogue of PI-requirements are used in the concept development according to the VDI 2221 (Figure 2). The goal is to develop alternative and reusable protection of goods concepts. The manipulation of the PI-handling container is accounted as a main function with its sub functions loading and unloading. A complete automatisation of the manipulation increases the efficiency and the flexibility of the protection of goods. A protection of goods whose loading process can be easily automated and whose material is reusable and recyclable is expected as a result in order to generate a global standard.

Figure 1: "flo-pak", Christopher Bauer GmbH

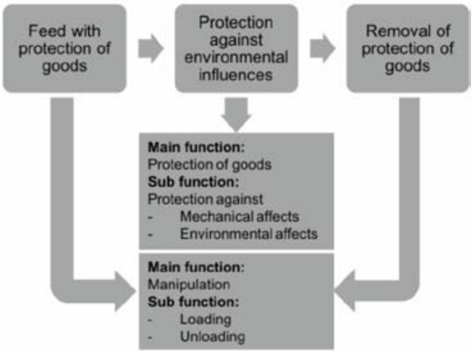

Figure 2: Function structure

Physical Internet
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4th INTERNATIONAL
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4th-6th July, 2017 in Graz: Graz University of Technology, Austria

Atropine – Fast Track to the Physical Internet

Simmer[1], Plasch[1], Haller[1], Kalt[1] and Neubauer[1]
1. University of Applied Sciences Upper Austria, Steyr, Austria
Corresponding author: laura.simmer@fh-steyr.at

Keywords: *Atropine, business model, legal framework, optimization, simulation*

Poster Abstract

Making the Physical Internet (PI) a reality will require radical changes with respect to the roles and responsibilities of many stakeholders. It takes levels of industrial co-operation, asset sharing and supply chain transparency well above those prevailing today. “Atropine - Fast Track to the Physical Internet” is a multi-disciplinary cross-industry project funded under the Strategic Economic and Research Program "Innovative Upper Austria 2020”, which aims to raise the awareness and the willingness to cooperate in the participating companies. Moreover, the project team will develop new business models, test different scenarios by simulation and optimization and bring key elements of the Physical Internet to life in real business environments. Three peer groups were set up to cover the topics legal, business model and simulation and optimization. At the end of the project the simulation and a demonstrator will be evaluated and recommendations for further actions can be derived. The project makes the Physical Internet a more prominent agenda item in Upper Austria and will show the participating project partners benefits, challenges and solutions of co-operation and asset sharing.

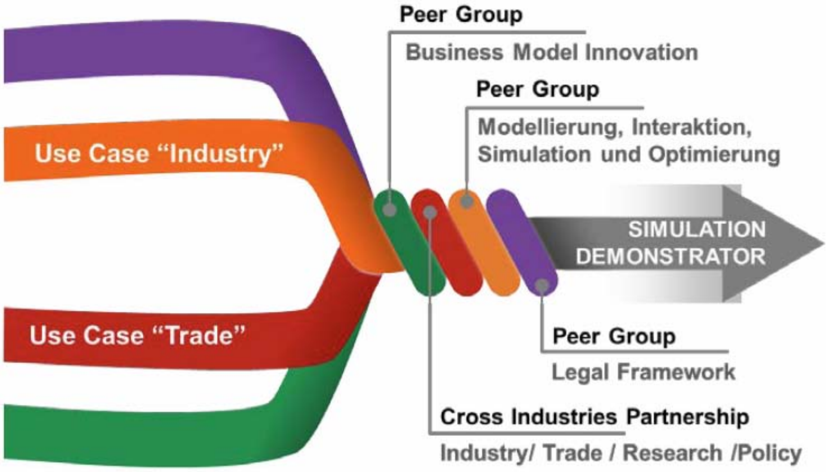


Figure 1: Peer Group approach and context of Atropine

Research on the Physical Internet – Status Quo and Future Research Directions

Lena Krammer[1]
1. Graz University of Technology – Master Student, Graz, Austria
Corresponding author: lena.krammer@s.wu.ac.at

Keywords: *Physical Internet, Structured Literature Review, Research Projects, Strengths, Risks, Challenges, Implementation Barriers*

Poster Abstract

The poster contains insights of a review of current and past research projects in the field of the Physical Internet as well as the results of a structured literature review. Around 50 relevant pieces of literature were identified and a structured overview of the treated topics is provided. The analysis highlights that many papers deal with the topics container development as well as hub and inventory management while other relevant research areas are still not sufficiently explored. Based on the literature, possible strengths, risks and challenges of the Physical Internet concept as well as potential barriers of implementation are shown.

Hyperloops: New transport mode enabled by the Physical Internet?

S. Pfoser[1], L.M. Putz[1], O. Schauer[1], G. Hauger[2], M. Wanjek[2],
C. Berkowitsch[2], R. Schodl[3], S. Eitler[3], K. Markvica[4], M. Prandtstetter[4]
1. University of Applied Sciences Upper Austria, Steyr, Austria
2. Vienna University of Technology, Center of Transportation System Planning, Vienna, Austria
3. University of Applied Sciences bfi Vienna, Vienna, Austria
4. AIT Austrian Institute of Technology, Center for Mobility Systems, Vienna, Austria
Corresponding author: sarah.pfoser@fh-steyr.at

Keywords: *infrastructural innovations, high-speed transportation systems, hyperloops*

Poster Abstract

The hyperloop technology represents a high-speed transportation system which allows carrying passengers as well as cargo in special capsules through tubes. The transport takes place at speeds up to 1220 kilometers per hour. Hyperloop Transportation Technologies, an organization dealing with hyperloop projects, characterizes hyperloops as “the physical version of the Internet”. This is due to its high performance potential which is going to innovate physical transportation in a way the internet did to the digital world.

Benoit Montreuil stated in the Physical Internet Manifesto (2012) that open infrastructural innovation such as the hyperloop system could be enabled through alignment with the principles of the Physical Internet. Montreuil argues that even if it would be technically feasible to build high-speed infrastructure such as hyperloops, their logistics performance would be impeded due to the insufficiency und unsustainability of current systems. The present work will give an overview how the realization from currently unreachable innovations such as hyperloops can benefit from the paradigms of the Physical Internet and will demonstrate potential synergies between hyperloops and the Physical Internet.

Results illustrate that the Physical Internet is a viable solution to encounter transport challenges including higher transport volumes with more frequent and small packages. Hence, the Physical Internet is appropriate to indicate how the hubs and connections of the logistics network, but also the technical layout and engineering of the entire infrastructure must be designed to effectively use infrastructural innovations. It can be therefore concluded that it is advisable to regard the interdependencies between hyperloops and the Physical Internet to introduce both successfully.

Requirements for a web-based cargo management tool to enable coopetition

Andreas Gasperlmair BA MA[1], FH-Prof. DI Hans-Christian Graf[1],
Sophie-Therese Hörtenhuber BA[1], Ass.Prof. DI Dr.techn. Christian Landschützer[2]
1. University of Applied Sciences Upper Austria – Logistikum, Steyr, Austria
2. Graz University of Technology – Institute of Logistics Engineering, Graz, Austria
Corresponding author: Andreas.gasperlmair@fh-steyr.at

Keywords: *Cargo Management Tool, Web-Platform, Coopetition*

Poster Abstract

The objective of the governmental funded project “protoPI” is to identify inefficient part loads and single unit loads between Styria and Upper Austria within the existing supply chains and to improve transport efficiency as well as to reduce traffic by implementing an intelligent cross-company (“smart”) logistics-system.

As the "Physical Internet" (PI) is also based on cross-company collaborations and cooperations in order to avoid waste of resources, protoPI wants to enable and simplify cross-company consolidation of part loads by creating a prototype for a partly automated cargo management web-platform. Therefore, requirements and conditions of the local shipment market had to be gathered to be able to create a market-oriented prototype.

The poster displays the protoPI concept and its organizational, technical and legal requirements and constraints for the proposed web-platform. For instance, when implementing this kind of multi-stakeholder platform different burdens have to be overcome: design and accessibility of interfaces, credibility of the platform compared to classical logistics service providers, financial clearing models, contractual burdens and document management with frequently changing partners.

ProKapa: Dynamic capacity management to support the development of Physical Internet's framework conditions

Georg Brunnthaller[1], Sandra Stein[1] and Wilfried Sihn[1]
1. Fraunhofer Austria Research GmbH, Vienna, Austria
Corresponding author: georg.brunnthaller@fraunhofer.at

Keywords: *Capacity Management, Freight Transportation Planning, Logistics Service Provider, Physical Internet*

Poster Abstract

Dynamic in freight transport is increasing. Disruptive developments such as „Physical Internet“, „Cyber-Physical Production Systems“, or „Sharing Economy“ bring along consequences for logistics and its stakeholders, which are not yet known. A continuous preplanning and surveillance of transport demand offers potential to react proactively to changing market conditions. Approaches that seize on such potential for logistics service providers or fragmented provider independent carriers are not existing.

ProKapa aims at enabling logistics service providers to react flexibly and adaptably to dynamic market changes and to challenges of „Physical Internet”. Transport demand within an abstract transport network is continuously modeled by extensive use of data. According to the transport demand, capacities of transport means and staff are plannend close to real time and resource allocation is optimized within the network. Resulting from remaining capacity constraints, transport demand is smoothed by measures in pricing strategies, horizontal and vertical cooperation as well as sales.

Expected results are suitable methods and tools for the preliminary planning of transports, a stronger interconnection between data sources and recommendations of actions concerning the adjustment of capacity, the allocation of resources and pricing. Furthermore, higher acceptance of integrated planning systems is expected.

NOLI, A Proposal for an Open Logistics Interconnection Reference Model for a Physical Internet

Jean-Yves Colin[1] Hervé Mathieu[2] Moustafa Nakechbandi[1] and Nouara Djema[1]
1. LITIS, Le Havre University, Le Havre, France
2. ISEL, Le Havre University, Le Havre, France
Corresponding author: moustafa.nakechbandi@univ-lehavre.fr

Keywords: *Logistics, Physical Internet, OLI model, Networks, OSI reference model*

Poster Abstract

This poster presents a New Open Logistics Interconnection (NOLI) reference model for a Physical Internet (Table 1 and Table 2), inspired by the Open Systems Interconnection (OSI) reference model for data networks. This NOLI model is compared to the OSI model, and to the Transmission Control Protocol/Internet Protocol (TCP/IP) model of Internet. It is also compared to the OLI model for a Physical Internet proposed by Montreuil.

The main differences between the presented NOLI model and all the other models named above are in the appearance of definitions of physical objects in different layers and not just the lowest one. Also, the NOLI model we present locates the containerization and de-containerization operations in the topmost layer, and not in the layer below as does the OLI model.

Table 1. The "end-users" layers of the NOLI reference model:

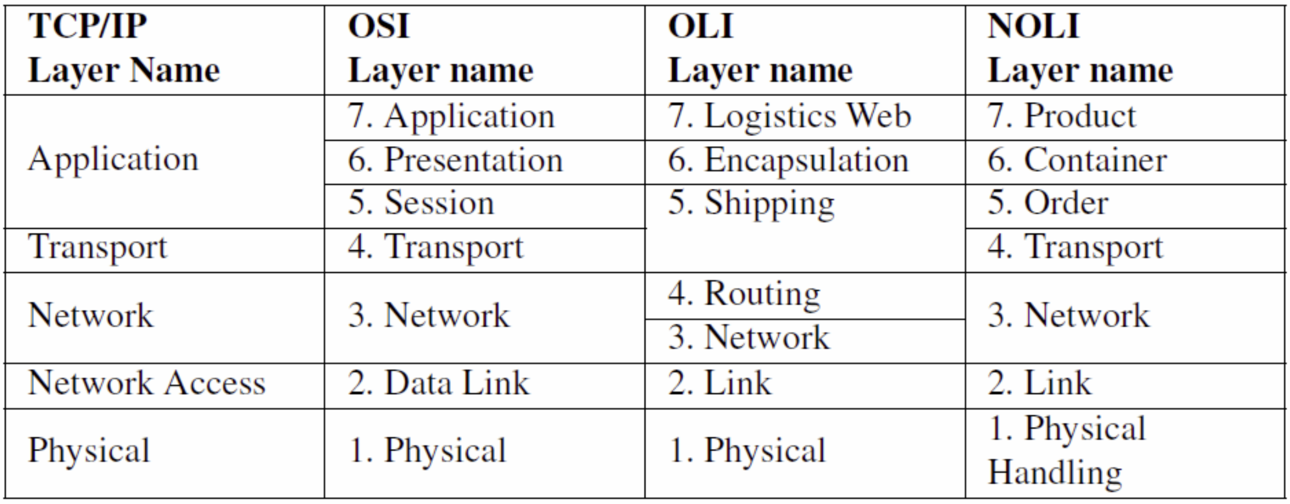
Position in the NOLI model	Layer Name	Role of the Layer
7	Product Layer	Defines the possible products or goods that can be transported inside π-containers. It fills the π-containers with the products and establishes the related contracts.
6	Container Layer	Defines the physical characteristics of the π-containers allowed on the Logistics Network. It will check the physical integrity of the π-containers and combine them into "sets" according to their characteristics.
5	Order Layer	Receives sets of π-containers from the Container Layer. It will create the orders according to the specified constraints (deadlines, client whishes, starting and destination point, etc.), and assigns the π-containers to the orders.

Table 2. The "network layers" of the NOLI reference model:

Position in the NOLI model	Layer Name	Role of the Layer
4	Transport Layer	Receives orders made of π-containers from the Order Layer. The transport Layer creates "loads" from the received orders, and manages the end-to-end trip for each load.
3	Network Layer	Receives loads of π-containers from the Transport Layer and creates "blocks" from the loads. The Network Layer defines a path across the network for each block.
2	Link Layer	Manages the individual steps (point-to-point movement) of π-containers on π-means.
1	Physical Handling Layer	Physical characteristics description of the π-means used to move the containers.

The NOLI model is closer to the TCP/IP and OSI models than the OLI model, keeping the integrity of the Link Layer that the OLI model divides in two layers, and keeping separate the Session and Transport OSI Layers that the OLI model unites in just one layer.

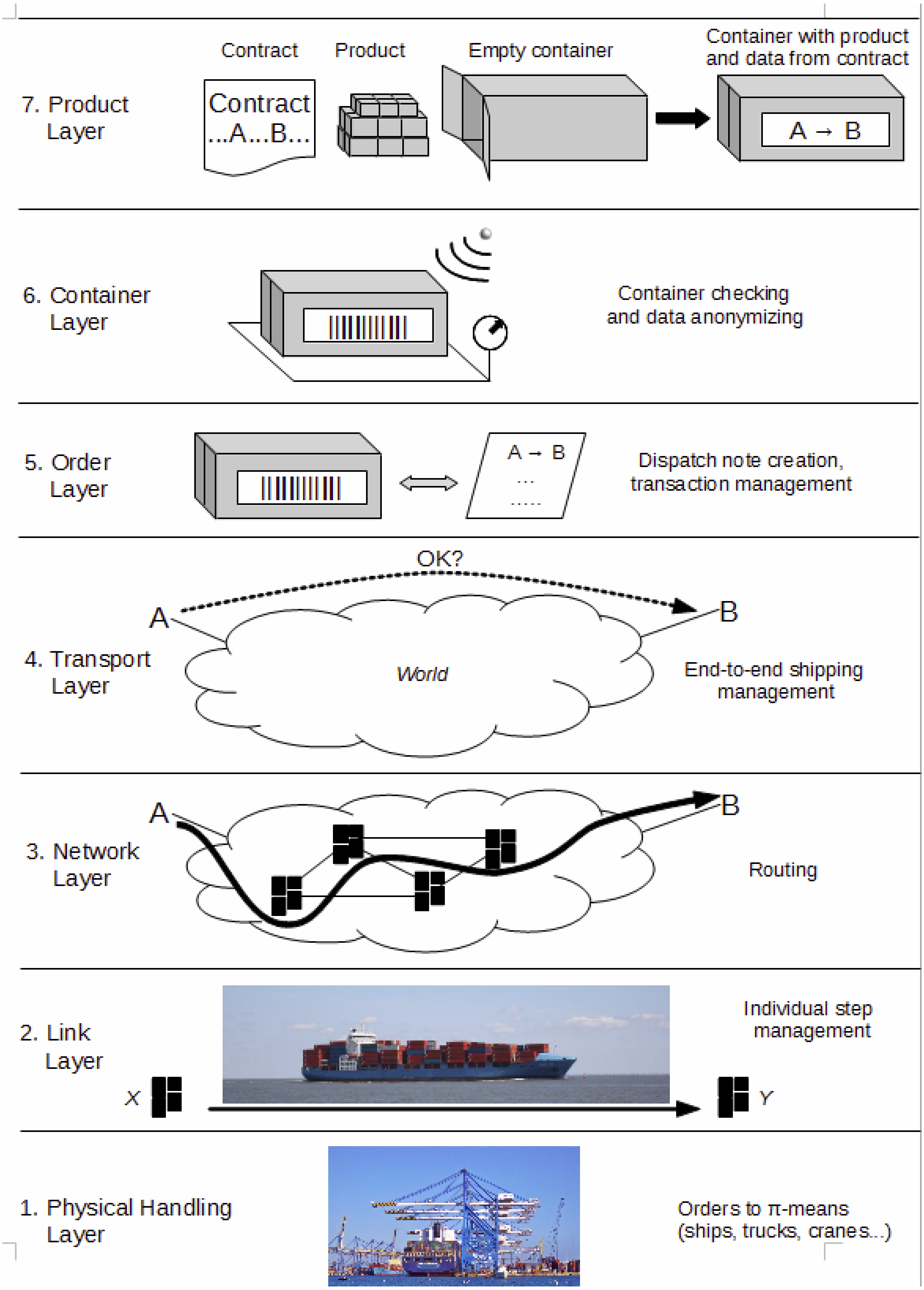
Table 3. Comparison between the layers of the TCP/IP, OSI, OLI and NOLI models:



TCP/IP Layer Name	OSI Layer name	OLI Layer name	NOLI Layer name
Application	7. Application	7. Logistics Web	7. Product
	6. Presentation	6. Encapsulation	6. Container
	5. Session	5. Shipping	5. Order
Transport	4. Transport		4. Transport
Network	3. Network	4. Routing	3. Network
		3. Network	
Network Access	2. Data Link	2. Link	2. Link
Physical	1. Physical	1. Physical	1. Physical Handling

Finally, in Figure 1 an example of some functionalities of each Layer of the NOLI model is presented.

Figure 1. Example of NOLI layers functionalities:



Lean tools to help to transform the traditional logistic in the Physical Internet

Luis López-Molina[1], Angel Cervera Paz[1], Vanessa Rodríguez Cornejo[1], Rosario García García[1] and Adela Catalina Popa[1]
1. University of Cadiz, Cádiz, Spain
Corresponding author: luis.lopez@uca.es

Keywords: *Physical Internet, Lean Manufacturing, Hyperconnected Logistic*

Poster abstract

Just as Lean manufacturing has revolutionized the world of production, this synergy of concept development, can be used to improve future logistics. This development should not be viewed as a final conclusion, but rather as a step towards helping to implement more efficient logistics, in one hand in terms of resources and in the other for our environment.

Lean Thinking (Womack and Jones, 1996) helped us to understand the principles of lean:

- The identification of value.
- The elimination of waste.
- The generation of flow (of value to the customer).

The benefits of Lean for the logistic chain are:

- Decreased lead times for customers
- Reduced inventories for manufacturers
- Improved knowledge management
- More robust processes

Legal framework conditions and guidelines for the implementation of the Physical Internet in the D-A-CH-region (Germany, Austria, Switzerland)

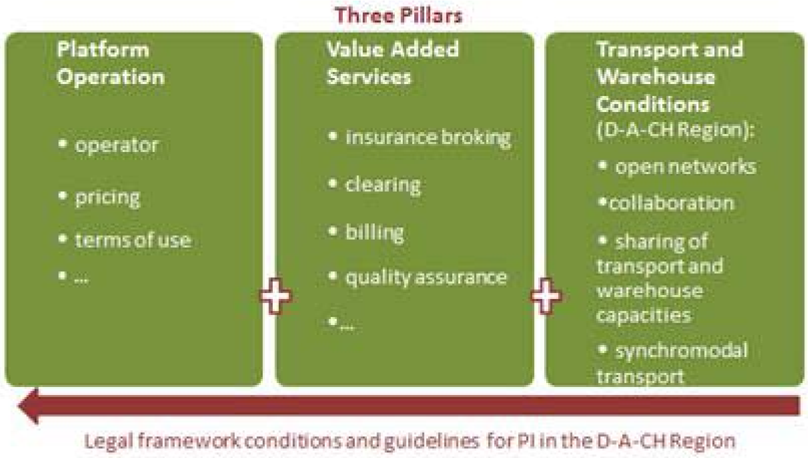
Alexandra Haller[1] and Oliver Schauer[1]
1. University of Applied Sciences Upper Austria, Steyr, Austria
Corresponding author: alexandra.haller@fh-steyr.at

Keywords: *legal framework conditions, terms and conditions*

Poster Abstract

Making the Physical Internet (PI) reality will require extensive legal scrutiny. Transport law, antitrust law, contractual law, insurance law and a lot of other legal framework conditions have to be examined to enable a legally viable implementation of the Physical Internet. Depending on the respective business model, legal framework conditions and legal feasibility vary considerably. Country specific policy and regulations represent additional obstacles for an EU-wide or even global implementation of the PI.

One goal of the multi-disciplinary cross-industry project “Atropine - Fast Track to the Physical Internet” funded under the Strategic Economic and Research Program "Innovative Upper Austria 2020” is to evaluate legal framework conditions and guidelines for the implementation of the Physical Internet in the D-A-CH-region (Germany, Austria, Switzerland). First result will be presented on the IPIC 2017. Based on three main pillars – platform operation, value added services (insurance, clearing, etc.) and transport and warehouse conditions – legally viable implementation approaches will be investigated, legal barriers defined and model terms and conditions elaborated.



Vehicle Routing Problem for the Physical Internet

Yannis Ancele[1],Thanh Trung Nguyen and Ben Martellini[1]
1. Liverpool John Moores University, Liverpool, United Kingdom
Corresponding author: yannis.ancele@gmail.com

Keywords: *Physical Internet, Vehicle Routing Problem; Cross-docks*

Poster abstract

It is said that the current Supply Chain Management (SCM) is not sustainable. Therefore, researchers are working on a new concept which will considerably improve the way we handle logistics - the Physical Internet (PI). The principle is to use the Digital Internet as a metaphor for the Physical world by using world-standard modular containers and protocols to allow collaboration.

The Vehicle Routing Problem (VRP), is a central problem in Operations Research applied to transportation sciences. Therefore it represents a critical point to focus on in order to optimize the SCM. Hence, this research focuses on the way the VRP can be solved in the PI. The classical VRP consists of designing a set of routes for the vehicles between the depot and each customer locations. The total demand of each route doesn’t exceed the vehicle capacity and the total routing cost is minimized. On top of that, real-life applications need a considerable number of attributes that must be considered in this work to provide efficient solutions. The cross-docks attribute encompasses spatial and load synchronization constraints by which PI containers are consolidated. The Time-Windows attribute requires the delivery to be made within a specific time window. The simultaneous Pickup&Delivery attribute allows the vehicles to handle pickups and deliveries regardless of the order.

As a result, this study will provide meta-heuristics to deal with real-world size instances. These novel algorithms will be integrated with a visualisation module into an open source framework.

Bin-packing arising from the Physical Internet Hub

Igor Deplano[1] and Trung Thanh Nguyen[1]
1. Liverpool John Moores University, Liverpool, United Kingdom
Corresponding author: igor.deplano@gmail.com

Keywords: *Physical Internet Hub, Multi Heterogeneous Knapsack Problem, 3D Bin packing, Container Loading Problem*

Poster Abstract

A new concept, π-internet, is building the basis for a new logistic supply-chain. The aim is to improve by an order of magnitude the economic, environmental and social efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used across the world. One of the most important components in the physical internet architecture is the π-hub.

The π-hub is a cross-docking hub where π-containers are marshalled and delivered to the next destination. Π-containers are detached, consolidated and attached, the efficiency push to automatise those operation but the crucial operation lying on the background is to choose the attaching configuration in order to minimize the wasted space and the containers used while considering items priorities and destinations.

We model this problem as a Multi Heterogeneous Knapsack Problem (MHKP) with container loading constraints and this research aims to provide a scalable solution that is able to solve large scale instances.

The first contribution is a mixed integer optimisation model for the relative MHKP, the constraints considered are the items geometrical contraints in a 3D space (absolute positioning, not-overlapping, orthogonal rotations, stability), the bins weight distribution, the items load-bearing and bins weight limits. The objective is to minimize the wasted space and the bins used, considering items priorities and destinations.

The second contribution consists to build an heuristic based algorithm for deal large scale instances.

The third contribution is an open source framework for bin packing problems that binds generators with solvers and result visualisation.

EAGLE – Innovatice technical solution for automated parcel unloading

Assoc.Prof. DI Dr.techn. Christian Landschützer,
DI Dr.techn. Andreas Wolfschluckner,
DI Dr.techn. Matthias Fritz
Graz University of Technology – Institute of Logistics Engineering, Graz, Austria
Corresponding author: landschuetzer@tugraz.at

Keywords: *automated parcel unloading, simulation parcel bulk behaivour*

Poster Abstract

Distribution centres (hubs) are essential parts within efficient logistics networks. To meet increasing demands concerning the flow of goods in urban and suburban areas, successfully operating distribution centres guarantee a sustainable mobility of goods.
The unloading and infeed processes exert significant influence on the overall efficiency of distribution centres. State-of-the-art manual unloading of transport vehicles is a limiting factor in the process chain and decreases possible throughput rates of subsequent sorting processes. Especially in distribution centres of parcel services this bottleneck can be observed. Therefore, several attempts of automatizing the unloading process have been made, however, the requirements on such a system have hardly been met so far.

The project EAGLE copes with these problems by developing an automated unloading system which addresses actual and future demands on logistics networks in terms of high throughput rates, sustainability, cost-effectiveness and flexibility

The focus was lain on the following points:

the capability of manipulating large amounts of parcels in a bulk
a reliable and fast identification of unsorted goods
a flexible system adaptable to vehicles of different types and sizes
the compatibility to electric vehicles (energy consumption!)

Figure 1: Unloading process

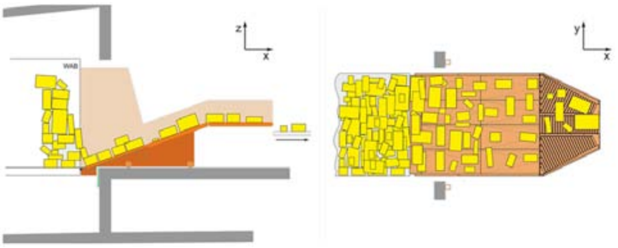


Figure 2: Excerpt simulation of unloading process

APPENDIX

Call for Papers and Contributions

(http://www.pi.events/call-for-papers)

The International Physical Internet Conference (IPIC) was founded 2014 in order to push forward the concept of the Physical Internet and quicken the exchange between industry and research. After highly successful and inspiring events in Québec, Paris and Atlanta with up to 250 participants, the conference will move to Graz - Austria in 2017. The comprehensive view on the Physical Internet from the IPIC conference merges with the technical and intralogistic view from the well-established Austrian conference "Logistikwerkstatt Graz" for a promising format in 2017 to be hosted by the Institute of Logistics Engineering (ITL) at Graz University of Technology. High ranked representatives from industry, research and politics are expected to participate in plenary sessions with selected key note speakers, networking events and guided workshops. Within several scientific- and project collaborations the conference will address a new scale in PI research and application.

The introduction of the Physical Internet (PI, π) has opened a paradigm-breaking field encompassing the hyperconnectivity and interoperability of smart logistics networks, transportation systems, manufacturing systems and supply chains, enabling seamless open asset sharing and flow consolidation on a massive scale. It aims to transform the way physical objects are moved, deployed, realized, supplied, designed and used all around the world so as to improve by an order-of-magnitude the overall induced performance in terms of economical, environmental and societal efficiency and sustainability.

IPIC 2017 aims to provide an open forum for researchers, innovators and practitioners to introduce leading edge concepts and methodologies; to review the state-of-the-art technologies and latest projects, and to identify critical issues and challenges for future Physical Internet induced research, innovation and implementation.

IPIC 2017 invites you to submit an original research or innovation contribution to the conference.

- A research contribution can for example report on conceptual research, assessment research, instrumental research and validation research
- An innovation contribution reports on novel applications and technologies, on ongoing projects and case studies, or innovative ideas and positions

The contributions may be related, yet not limited, to the following topics within the following research fields:

topics research fields	Physical Internet Fundamentals and Constitutes	Technology vs. Physical Internet	Physical Internet Implementation and Governance	Investigation and instrumentation methodologies	Hyperconnected logistics	Hyperconnected cockpits and control towers	Hyperconnected business models	Energy reduction and resource efficiency
Retail/e-commerce								
Supply chain and Industry 4.0								
Synchromodality, corridors, horizontal collaboration								
Intralogistics								
City logistics								
Industry workshops (projects)								
IT and digitalization								
Sustainability								
Supply network								
New research domains								

Contributions can take four forms: research papers, innovation papers, posters and presentations.

- All contribution abstract will be reviewed
- Research papers will be peer-reviewed by the scientific committee
- Innovation papers will be reviewed by the editorial committee
- Research papers are expected to have a background in conceptual research, assessment research, instrumental research, validation research or novel applications and novel technologies.
- Authors of papers are requested to specify their form of contribution (research paper or innovation paper)
- Research papers, innovation papers and posters will be made widely available on http://www.pi.events

- Research papers, innovation papers and posters are published in the conference summary which will be available as hard copy and e-book (both equipped with ISBN-number) in the follow-on of the conference if desired by the author
- Research papers, innovation papers and posters must respect the guidelines and templates provided on the conference website
- Authors of research papers, innovation papers and presentations will be invited to present them in related conference workshops depending on availability of free time-slots
- The best research papers will be targeted for extension toward publication in special issues of scientific journals
- The best innovation papers will be targeted for adaptation toward publication in special issues of professional journals
- Students have the possibility to participate in the PI-student paper award by submitting research papers (first authors are expected to be students)
- Posters and their authors will be the highlight of a cocktail event on the first day of the conference
- Students have the possibility to participate in the PI-student poster award by submitting research posters (first authors are expected to be students)

Examples for contributions to the topics of the conference are as followed:

- **Physical Internet Fundamentals and Constitutes**
  - Proposition of conceptual Physical Internet frameworks
  - Investigation of key enabling constituents of the Physical Internet
  - Efficiency, sustainability, resilience, security, adaptability, agility of the Physical Internet
  - PI container design & engineering: transport, handling and packaging container design and engineering; Modularization and Standardization; Smart and active containers; Panel oriented container design; Interaction with encapsulated smart objects; Container logistics and business
  - Design, engineering, planning and operation of hyperconnected handling, storage and transportation technologies, systems, facilities and infrastructures

- **Technology vs. Physical Internet**
  - Impact of new technologies and concepts such as drones, mobile robotics and 3D printing on the Physical Internet, machine learning; augmented reality, big data and data analysis
  - Exploitation of Internet-of-Things in the Physical Internet for tracking, tracing, sensing, event management and prediction
  - Technologies for container tracing and asset monitoring through the Physical Internet, such as wireless sensor networks (WSN)

- **Physical Internet Implementation and Governance**
  - Physical Internet implementation drivers and issues
  - Stakeholder incentives for PI adoption and implementation
  - Negotiation, collaboration and conflict resolution within Physical Internet
  - Impact of regulatory innovation on PI
  - Impact of PI induced innovation on regulation, taxation and duties
  - Design of the Physical Internet governance structure and processes

- **Investigation and instrumentation methodologies**
    - Novel descriptive, predictive and prescriptive analytics; modeling; simulation; optimization and gaming approaches for Physical Internet research and instrumentation
    - Qualitative and quantitative methodologies for studying proposed or existing PI induced systems, processes, phenomena & business models
    - Decision models and supports in the Physical Internet context

- **Hyperconnected logistics**
    - Hyperconnected transportation, distribution, manufacturing, supply chain and/or service
    - Novel ICT platforms enabling Physical Internet and hyperconnected logistics
    - Open hyperconnected logistics networks performance and impact assessment
    - Digital ecosystems and information sharing for freight transport and logistics (e-freight, e-booking, e-CMR…)
    - Logistics asset sharing, flow consolidation and load optimization
    - Hyperconnected synchromodality
    - Smart hyperconnected inventory deployment and management
    - Hyperconnected City Logistics and Last-Mile Delivery
    - Hyperconnected crowdsourced delivery and transportation
    - Hyperconnected cold storage
    - Hyperconnected backbone logistics networks
    - Hyperconnected modular production
    - Mobility web, distribution web, realization web, supply web and service web
    - Open Logistics Interconnection model for hyperconnected logistics service architecture
    - Hyperconnected logistics protocols
    - Event service and management in hyperconnected logistics networks

- **Hyperconnected cockpits and control towers**
    - KPIs, cockpits, control towers for hyperconnected logistics
    - Concepts, technologies and processes for hyperconnected cockpits & control towers
    - Models and algorithms feeding the cockpits, enabling the analytics, advising the decision makers and easing the open collaboration
    - Collaborative behavior of users of hyperconnected cockpits & control towers

- **Hyperconnected business models**
    - Business models, revenue models and profit models in hyperconnected logistics
    - Liability and insurance issues in hyperconnected logistics
    - Hyperconnected business model innovation

- **Energy reduction and resource efficiency**
    - Energy reduction and decarbonization of freight transport and logistics, including end-to-end carbon footprint measurement, indicators and assessment of (policy/industry) practices, etc.
    - Transport and logistics implications of the circular economy: waste avoidance and resource efficiency
    - Supply Network horizontal and vertical collaboration driving asset (vehicles, warehouses, terminals) utilization efficiency, energy and emissions reduction