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Revealing mutual Relationships between Truck Platooning and Smart Hyperconnected Physical Internet Systems

Wolfgang Schildorfer[1], Matthias Neubauer[1], Oliver Schauer[1],
Andreas Kuhn[2] and Walter Aigner[3]

1. University of Applied Sciences Upper Austria,
Department of Logistics, Steyr, Austria
2. Andata: Artificial Intelligence Labs, Austria
3. HiTec Marketing, Vienna, Austria

Corresponding author: wolfgang.schildorfer@fh-steyr.at

Abstract: *Sustainability has become a core issue of organizations. In the logistics domain, the vision of the Physical Internet aims to create sustainable logistics networks. Sustainable transport in such networks will still be a core contributor for achieving sustainable operations. This paper investigates contributions of truck platooning, a means for safe and efficient freight transport, to physical internet systems vice versa. The results reveal relationships especially in the PI areas (i) connectivity, (ii) collaboration and coordination as well as (iii) sustainable, safe and secure supply chains.*

Keywords: *Truck platooning, Hyperconnected Systems, Sustainable Transport, C-ITS*

1 Introduction

Sustainability receives increasing attention not only by academics and experts but also by companies and organizations. Within the logistics domain, the vision of the Physical Internet emerged in 2011. The Physical Internet aims to design the way physical objects are moved, handled, stored, realized, supplied and used all over the world in a more sustainable way. The core idea to reach this aim is to build a global logistics network capable of providing real-time information in order to optimize logistic activities. (Montreuil 2012; Montreuil et al. 2011)

However, research and development related to PI is far from being complete. Currently, the European technology platform ALICE[1] (Alliance for Logistics Innovation through Collaboration in Europe) supports the development of a comprehensive strategy for research, innovation and market deployment related to the PI. In this context, the following R&D roadmaps have been developed: (i) IS for interconnected logistics, (ii) sustainable, safe and secure supply chains, (iii) corridors, hubs and synchromodality, (iv) global supply network coordination and collaboration, and (v) urban logistics. Sustainable transport means are an

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[1] https://www.etp-logistics.eu/

important aspect of PI systems, even if the naming of the given roadmaps does not immediately reveal their importance. Developments in the field of connected and automated driving promise to increase sustainability and as such represent an important enabler for sustainable transport operations in physical internet systems. Vice versa interconnected logistics systems may contribute to optimize automated transport vehicle operations. One development strand in the field of connected and automated driving focuses on truck platooning, which is a promising means to enhance efficiency and safety of freight transport.

In this paper, the contribution of truck platooning to smart hyperconnected physical internet systems will be investigated. Doing so, related work to truck platooning and initial results from the Austrian platooning flagship project Connecting Austria will be summarized in the subsequent section. Furthermore, mutual relationships between truck platooning and smart hyperconnected physical internet systems will be derived.

2   Related Work

Truck platooning represents a promising means to improve land transport. Via decreasing distances between trucks – thanks to slipstreaming - fuel consumption as well pollutant emissions can be reduced. Typically, distances between trucks are controlled using latest state of the art of automated driving technology. Developments related to truck platooning actually date back to the early 1990s, starting with projects to illustrate the technical feasibility up to projects investigating the potential of fuel savings. In a recent European project – the European Truck Platooning Challenge - original equipment manufacturers even demonstrated platooning across European countries and illustrated that truck platooning could become a day one application of automated driving. The adoption of truck platooning can be structured along the SAE levels for auto-mated driving systems ranging from "Driver Assistance" (level 1) up to "Full Automation" (level 5) (Graeter et al. 2017).

Reviewing recent truck platooning projects and research projects different objects of investigation can be revealed. Energy efficiency related to truck platooning is still a relevant object of investigation. In general, energy efficiency related to freight transport may be increased via means like (i) optimized transport planning, (ii) energy efficient & green vehicles, (iii) energy efficient driving patterns or (iv) intelligent traffic management systems / infrastructures supporting traffic flow optimization. However, the results related to energy efficiency of truck platooning in terms of fuel savings vary across different projects. Simulations related to theoretical potentials of fuel savings result in very promising numbers even up to 10% fuel savings in average within a platoon of three trucks. On the other hand, real life tests reveal lower results, e.g. the EU Companion project observed in average around 5% fuel savings within a platoon of three trucks. Beyond, real life tests in the US (Bevly et al. 2017) revealed that at a speed of 105 km/h fuel savings at a distance of 10 meters were even lower (8.65% for the following vehicle) that at a distance of 15 meters (10.24% for the following vehicle). Furthermore, contextual influence factors like weather conditions, traffic flow, road surfaces or vehicle conditions affect fuel savings. For this reason, actual fuel savings of truck platoon under different circumstances remain an important object of investigation.

Another important object of investigation represents the authorization of truck platooning in different driving situations. Restrictions vary across different truck platooning projects and road authorities, e.g. allowance of platooning in tunnels, at roadwork areas, at "known" critical road sections or motorway intersections are still under debate. Therefore, further investigations related to the 'permission of truck platooning' are necessary to inform authorities like road

operators or governmental institutions. Evidence-based simulation models and real life test are a suitable means for developing such "permission guidelines".

Further objects of investigations are for example truck drivers' issues (Neubauer et al.), interaction with other road users, safety & security, awareness of truck platooning, multi-brand and multi-fleet platooning, or legal aspects. Beyond, the road infrastructure perspective received little attention related to truck platooning so far, e.g. (i) the contribution of intelligent traffic infrastructures towards truck platooning in terms of Infrastructure-to-Vehicle communication and Collaborative Intelligent Transport Systems (C-ITS) or (ii) dynamic infrastructure constraints (traffic situation, weather, road conditions,…).

2.1   Connecting Austria initial results

The Austrian flagship project Connecting Austria[2] brings technology leaders and end-users together to demonstrate and evaluate four specific use cases for semi-automated and energy-efficient truck platoons. Key objective is the evidence-based evaluation of energy-efficient truck platoons as a pre-requisite for the competitive strength of Austrian industries such as logistics, telematics and infrastructure providers, automotive suppliers, as well as vehicle development and cooperative research. The national flagship project's unique contribution is its specific focus on infrastructure issues and on parameterized traffic perspectives when evaluating energy-efficient and semi-autonomous truck platoons. This particularly includes platoons at intersections before entering motorways and after leaving motorways. Key question in Connecting Austria:

- 'What is needed to safely and efficiently set up an energy-efficient truck platoon, to maintain a platoon, and to go back to a regular transport mode?
- What are pre-requisites and accompanying measures to prepare the future of energy efficient and safe (semi)autonomous truck platoons.'

One preliminary result of Connecting Austria represents the general R&D-Approach. The project studies have been aligned along the potential benefits of automated driving (comfort, safety, vehicle efficiency, traffic efficiency and traffic effectiveness as the overall key performance indicator). In a first run, each of these categories are assessed individually by evaluation of their theoretical limits and potentials. Knowing from (Stadler and Hirz 2014) that practical system effectiveness is normally dramatically less, and from (Kuhn et al.) that all these categories are conflicting each other, in a second run the practical effectiveness ratings of the categories are evaluated as well as the potential risks. The theoretical effectiveness hereby is a good indicator where to spend most development and research effort, for the detailed evaluation (benefit categories with few theoretical potentials will not be exploited into the very last details, research will be concentrated to the categories with the most expected effects). At the end, all the categories with promising potentials will be combined afterwards to a common multi-criteria effectiveness assessment, balancing the individual potential according the desired policies. All effectiveness assessments will be executed for the four selected use cases by intensive scenario management, resulting in the impact layers (infrastructure & V2X & traffic control, vehicle control strategies, laws & guidelines and the dynamic road risk map). Naturalistic driving studies and real traffic observation, delivering representative statistics and reference bases will accompany the assessments.

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[2] www.connecting-austria.at
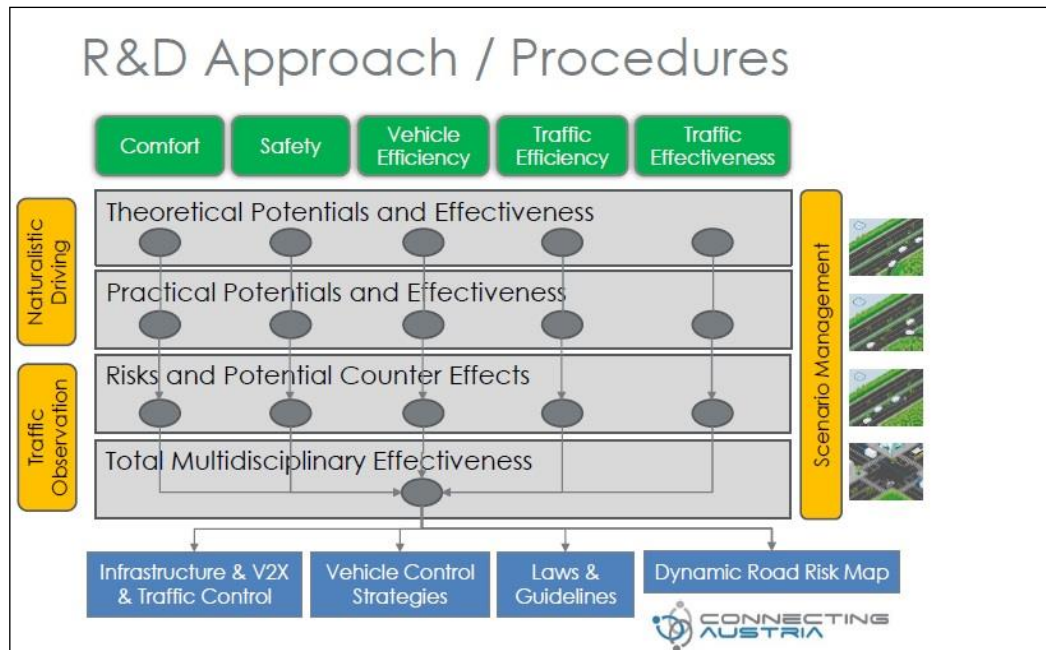
Figure 1: Connecting Austria R&D Approach / Procedures (connecting-austria.at, 2018)

Subsequently, selected results from the first project year of Connecting Austria are presented. Connecting Austria investigates especially level 1 platooning with a special focus on the road infrastructure and innovative C-ITS solutions. The results relate to the following research questions:

- What is the (theoretical/practical) potential for platooning concerning traffic-efficiency?

- What are the advantages of cooperative regulation strategies?

- Which Austrian road sections are ready or candidates for future operation under platooning modes?

- How to evaluate traffic efficiency, traffic safety, environmental impacts and the impact for the logistics industry in Connecting Austria from a systemic point of view?

What is the (theoretical/practical) potential for platooning concerning traffic-efficiency?

One of the expected benefits from automated, connected cooperative driving is an improvement of traffic efficiency and a reduced number of congestions. In technical terms, traffic efficiency means that more vehicles can pass a traffic lane per hour where there is theoretical room for more. Simply deriving from the fundamental diagram ($Q = V \cdot D$, traffic flow is speed times density), this can be achieved by reduction of vehicle distances or by increasing vehicle speeds. Platooning increases the traffic flow rates by reducing distances (increasing density) at constant speed due to reduced following distances. Figure 2 illustrates the theoretical limits for achievable traffic flow rates with given constant speeds for different vehicle distances. Vehicles are assumed to have a length of 4.4 respectively 18.75 m for passenger vehicles and trucks. This graph may illustrate the estimation of the theoretical traffic efficiency potentials. Let's assume we have a traffic situation, where all involved cars are driving 80 km/h and 2 seconds

distance on average. With a ratio of 25% trucks, this would mean, that the traffic flow rate of approx. 1500 vehicles per hour and lane could be increase to approximately 2000 vehicles per hour, if the distance is reduced to 1.5 seconds. These are the best possible values and theoretical limits. The chart can be adopted for different vehicle lengths. Nevertheless, the main issue is that the practical improvement potential may be significantly less. Currently trucks must hold a distance of 50 meters. If trucks in real traffic environments are already driving less distance under certain conditions, the potential benefits due to platooning will be accordingly less. For the investigation of this issue, the driven distances between the vehicles will be assessed in cooperation with the Austrian highway authorities. In this way, we will assess the practical potentials of platooning with respect to traffic efficiency.
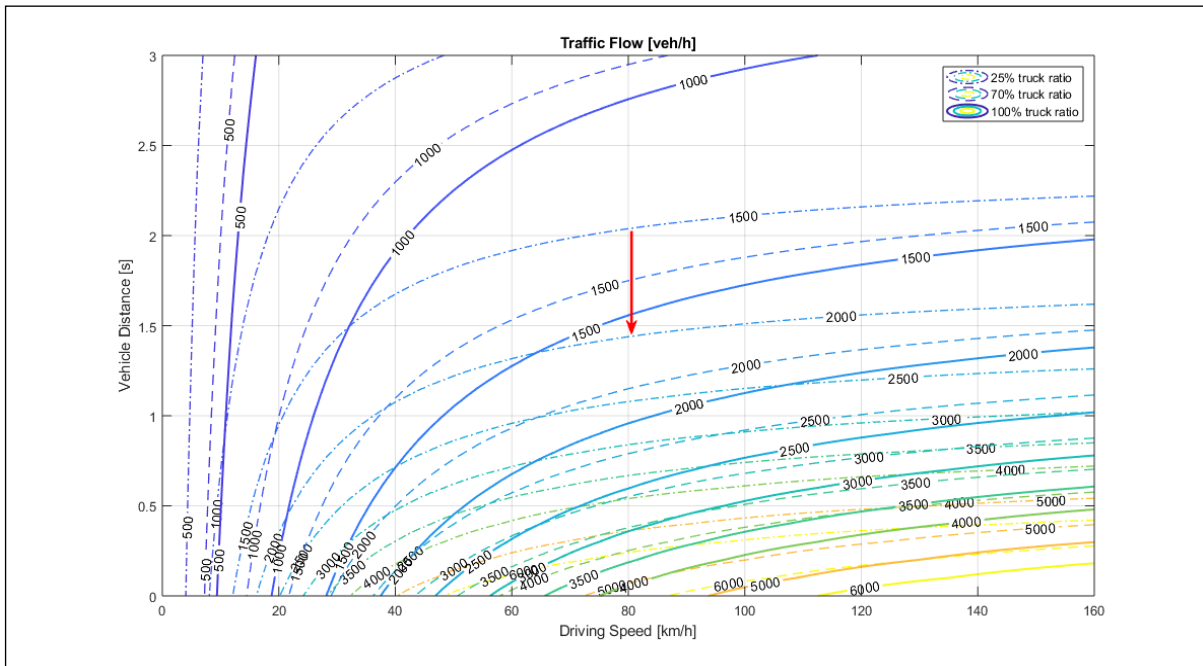
Figure 2: Theoretical traffic-efficiency potential of truck platooning (ANDATA, 2018)

What are the advantages of cooperative regulation strategies?

A unique selling point of the project is that we think of a cooperative system design that manages platoons seen from a road operator's perspective. More precisely, it is not about managing the processes of finding trucks to platoon for a given time, but to manage the traffic flow including platoons dynamically. For that reason, we identified three crucial technical focus areas: sensor, data exchange and infrastructure based control strategies for use cases in the interurban and urban area (Novak et al.). In the urban area, we are currently focusing on video-based sensors at intersections to receive a picture of the current situation on the road. The idea is to process video data and anonymize it onsite due to privacy reasons. We store the trajectories of pedestrians and cyclists in order to identify if someone is crossing the street. For a first prototype application, we fuse the data of the sensor and the traffic light controller at the intersection to detect if a pedestrian is running a red light. Similar approaches are followed by Honda (Peters 2018), the startup company Derq[3] or Continental (Lauch 2018). Information of such an anomaly is distributed to the platoon via ITS-G5 technology. As specified in ECo-AT release 4.0 system specification, we use the ITS service "collective perception" (ECo-AT

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[3] https://en.derq.com/

2018). In detail, we follow the specification of use case "collective perception of objects on the road". Its scope is to inform vehicles about obstacles on the road, vulnerable road uses as well as critical driving-situations.

Which Austrian road sections are ready or candidates for future operation under platooning modes?

To visualize road sections suitable for platooning a dynamic risk-rated map is generated in an automated way, at the beginning based on geographic information systems and in the future based on additional criteria. Based on specific criteria like

- individual length in advance to of danger zones,
- individual ranges around specific danger point annotated by GPS coordinates,
- special events (e.g. accidents),
- types of street section including individual zones around these (like tunnels, bridges, exits, lane merges, toll stations, etc.),
- topographic properties of the street (e.g. slope, curvature, surface conditions, etc.)

a map will be generated with automated annotation of relevant zone for the allowed vehicle control strategies, like allowed/recommended/forced minimum/maximum distance/speed, etc. The constraints may be adapted with respect to local conditions, traffic conditions, weather, temporal/spatial incidents.
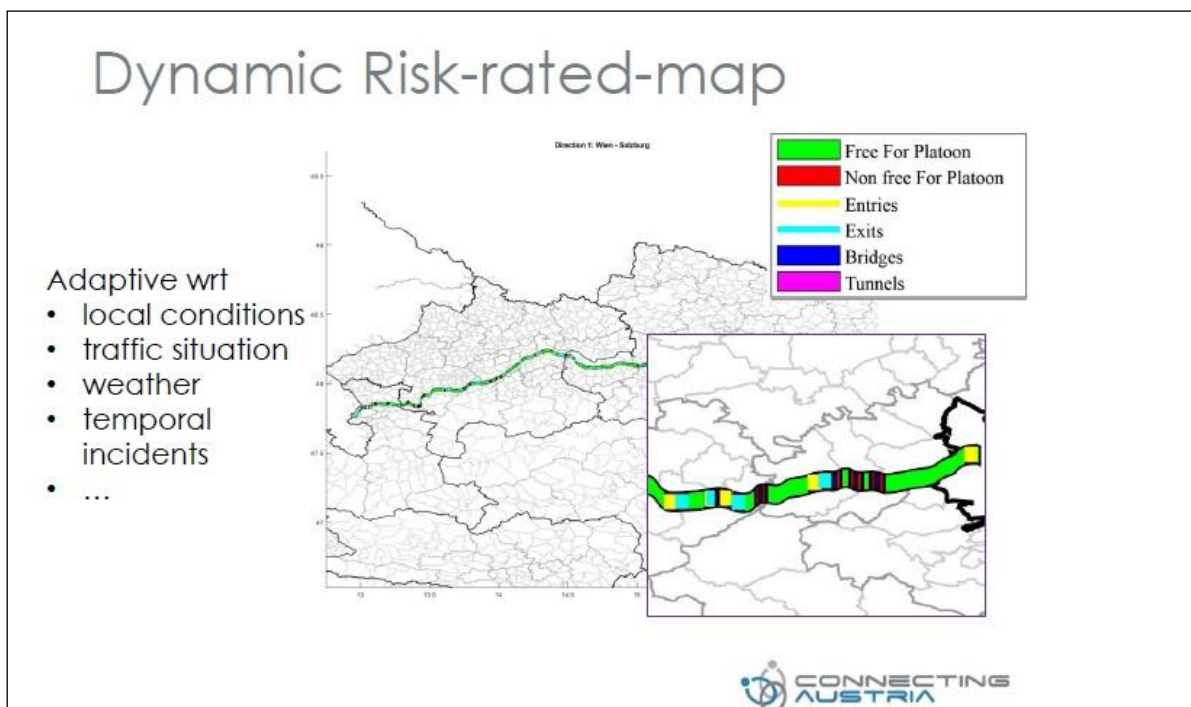
Figure 3: Dynamic risk-rated map prototype (ANDATA, 2018)

How to evaluate traffic efficiency, traffic safety, environmental impacts and the impact for the logistics industry in Connecting Austria from systemic point of view?

As for many emerging CCAM (cooperative connected automated mobility) innovations, it is not entirely clear how they should be assessed without undue anti-innovation bias from outdated methods or lack of large scale validation data. Therefore, in Connecting Austria we have set up a rather large evaluation task force and we have been going the long way of also coming up with innovative assessment and evaluation approaches. Our key baseline is the direct

comparison of platooning-type of truck mode to conventional non-platooning type truck mode – all with SAE level 1 and an experienced truck driver with both hands on the steering wheel in each truck. In an effort to avoid too fuzzy concepts and prematurely touching slippery ground we have focused on L1 truck platooning in the specific infrastructure context of Austrian roads and Austrian laws. Key objective of this task force and effort is to come up with validated sound information for decision makers in Austrian road authorities, road operators and transportation stakeholders.

From this objective, each research group in the project has come up with ambitious questions, e.g.:

- What is the platooning potential with regard to truck-efficiency caused by slipstream-effect?

- What is the platooning potential with regard to traffic efficiency caused by increased traffic density?

- What is the platooning potential with regard to energy efficiency caused by predictive power train regulation?

- What are minimum distances of trucks in a platoon without safety risks?

- Which Austrian road sections are ready or candidates for future operation under platooning modes?

- What are advantages of local and temporary densification?

- What are advantages of cooperative regulation strategies at intersections?

- What are validated efficiency gains with platooning?

- Where/when and how would platoons be a safety risk?

- When would ad-hoc platooning make sense with regard to energy-savings?

- What are bottom line platooning benefits for the logistics sector?

- What is the platooning potential for vehicle-safety and traffic-safety?

- What accompanying technical and procedural infrastructure measures are necessary?

- Which organisational and legal changes are necessary in Austria to implement the envisaged advantages?

- How does the behaviour change due to platooning (including other participants)?

- What would be negative logistics impacts from "mandatory" platoons?

Regarding studies related to the logistics impact dimension, results with respect to truck platooning acceptance are presented in (Neubauer et al.). These results indicate that related work in the area of HMI provides insights in how interface designs for platooning should be designed and what are crucial acceptance factors for truck drivers, e.g. related to information provision or situation awareness. Furthermore, existing simulator studies and studies with research and development prototypes in real-world tests provide insights related to the application of platooning. These studies provide for example findings on acceptable distances between trucks, trust between truck drivers or trust in technology as crucial elements for deploying truck platooning.

In general, the results of the empirical acceptance studies conducted in Austria in 2018 confirm the observations presented in the related work. However, there are some differences. For example, within the related work safety and comfort are identified as the main reasons for truck drivers to use automated driving functions. The results of the empirical studies showed that truck drivers do not think that platooning will increase safety. Beyond, the observation indicated that the general intention to use assistance systems may influence the adoption of truck platooning.

2.2 Truck Platooning in Physical Internet Systems

Puskás and Bohács (2019) discuss truck platooning explicitly in the context of physical internet systems. They conclude that platooning systems may contribute to physical internet systems to increase sustainability and that physical internet systems may support interconnectivity e.g. when building ad-hoc platoons between physical internet participants and thereby synchronizing vehicle routes. In their contribution Puskás and Bohács (2019) propose a concept so called "virtual transfer point" for route optimization in physical internet networks.

In addition, Bhoopalam et al. (2018) review platoon planning approaches (scheduled platoon planning, real-time platooning, opportunistic platooning) which may be adopted by physical internet network actors to become platoon members or even platoon providers.

3 Potential Contributions of Truck Platooning to the Physical Internet vice versa

In the previous section related work regarding truck platooning, initial results from the Austrian flagship project Connecting Austria and literature results target towards truck platooning and physical internet systems is presented. In this section, potential contributions of truck platooning to physical internet systems vice versa will be derived.

3.1 Connectivity

Information and Communication Technology (ICT) has become pervasive within the last decades. Thereby, ICT has been a main driver for innovation in the production and the service sector. Recent trends like the Internet of Things, Cyber-Physical Systems, Industry 4.0 or the Physical Internet (PI) represent endeavors to digitize organizational workflows and ensure competitive advantage. These trends aim to further integrate the physical and the digital world to enable communication and collaboration among different organizational actors (people, machines, and even things) and among diverse organizations in real-time (cf. hyper-connectivity, horizontal- and vertical process integration).

With the advent of the Internet of Things the vision of the Physical Internet emerged in the logistics domain. The Physical Internet aims to design the way physical objects are moved, handled, stored, realized, supplied and used all over the world in a more sustainable way. The core idea to reach this aim is to build a global logistics network capable of providing real-time information in order to optimize logistic activities. Thereby, universal interconnectivity among all supply chain stakeholders is considered to be a core enabler. In the context of PI, universal interconnectivity subsumes (1) digital interconnectivity related to connecting diverse, heterogeneous IT-systems, (2) physical interconnectivity in terms of modular load units and interfaces, and (3) operative interconnectivity regarding the alignment of protocols and procedures (Maslarić et al. 2016)

When it comes to platooning connectivity also represents a crucial means. Thereby, connectivity may refer to

(1) technical connectivity, e.g. V2V communication and I2V communication supported by the different technologies (e.g. WLAN ITS G5, 5G), or

(2) organizational/individual connectivity, e.g. multi fleet platooning.

With respect to technical connectivity truck makers' and start-ups' approached truck platooning rather with independent developments than cooperative development efforts. All stakeholders have set-up their own tailor-made truck platooning-prototypes and first demonstrations. This technology-push indicates a quite high technology readiness level. On the other hand, the small number of public tests and already existing truck-platooning vehicles indicates a quite low market readiness level (Hasenauer et al. 2016; Schildorfer et al. 2017) . Peloton[4] – offers commercial level 1 truck platooning services for transport operators and is available in the US. TuSimple[5] - offers all prospects truck platoon journeys; so to experience their platooning solution on public roads. Starksy Robotics[6] – offers truck platooning services in the US since April 2017. Embark[7] – is operating truck platooning since 2017 in the US. Einride – develops the t-pod together with DB Schenker (Edelstein 2018). Plus AI[8] – is operating in China and the US. Uber – stopped its truck programme in 2018. Tesla - Tesla's eTruck 'Semi' does not offer platooning functionality. Volvo[9] – focus on platooning tests in closed areas and research on new business models). Daimler – announced at CES 2019 to stop truck platooning up to level3 (Cannon 2019). MAN – tested with DB Schenker in Germany within the EDDI project[10]). Scania, DAF and IVECO are involved in the ENSEMBLE project[11]; DAF is involved in the UK platooning test[12]. Additional information on truck platooning projects as well as the important role of infrastructure operators in the deployment of truck platooning are mentioned in the Austrian position paper on truck platooning (Hintenaus 2018).

However, a key lesson learnt from the European Truck Platooning Challenge[13] was the need for multi-brand platooning. In other words, the ability to form platoons between different truck OEMs. This key lesson learnt was also confirmed in our stakeholder dialog with fleet operators. They mentioned the necessity of a huge number of trucks equipped with platooning functions and a European harmonised regulatory framework for organizing ad-hoc multi-fleet and multi-brand platooning. Otherwise, they will not invest in any truck platooning technology. This requirement demands for standardized communication protocols. The H2020 multi brand truck platooning project ENSEMBLE is addressing this issue is ENSEMBLE.

In addition to the technical connectivity, organizational and individual connectivity have been identified as vital ingredient for truck platooning. These results are presented in the subsequent section, which is dedicated to global coordination and collaboration in global physical internets.

3.2 Coordination and Collaboration

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[4] https://peloton-tech.com/

[5] http://www.tusimple.com/index-en.html

[6] https://www.starsky.io

[7] https://embarktrucks.com

[8] https://plus.ai/en/about/

[9] https://www.reuters.com/article/us-volvo-autonomous/volvo-shows-off-selfdriving-electric-truck-with-no-cab-idUSKCN1LS2QP

[10] https://www.bmvi.de/SharedDocs/DE/Artikel/DG/AVF-projekte/eddi.html

[11] https://platooningensemble.eu

[12] https://www.daf.com/en/news-and-media/news-articles/global/2017/q3/30-08-2017-daf-trucks-participates-in-uk-truck-platooning-trial

[13] https://eutruckplatooning.com

In a first step, large fleets might adopt truck platooning. Smaller fleets might need to cooperate with others to find platoon partners and gain benefits from platooning. So far, building a platoon is still an important issue to be resolved. First implementations may use platooning schedules for dedicated routes. On the long run ad-hoc platooning on motorways could be feasible depending on the diffusion rate of platooning capable trucks. However, initial results related to individual aspects indicate that the connectivity between drivers and especially trust will be a crucial ingredient for successfully implementing semi automated truck platooning. With regard to literature on the adoption of truck platooning of fleet operators the analysis of Bevly et al. (2017) showed, "*respondents felt that initially platooning would likely be implemented within-fleet. In terms of platooning with trucks from other fleets, it was noted that trust, assurance, and inter-operability must be clearly established.*"

In order to support platoon building physical internet actors could share planning information and might receive more opportunities for platooning than without collaboration. Aside to collaboration support physical internet actors like platoon providers could support the coordination of platoons. Furthermore, gain sharing between platoon participants needs to be considered. Gain sharing could be realized either by central intermediaries or even via decentralized approaches like blockchain solutions.

3.3 Sustainable, safe & secure supply chains

Truck platooning may reduce fuel consumption and pollutant emission. Nevertheless, with respect to environmental sustainability, the results of diverse truck platooning projects vary regarding fuel savings (cf. related work above). For this reason, actual fuel savings of truck platoons under different circumstances remain an important object of investigation as well as the related emission savings via platooning. These results are relevant for designing transport networks in physical internets. Furthermore, actual fuel savings are directly linked to the economic sustainability for fleet operators. Fleet operators require means to evaluate the impact of truck platooning for their company and to take informed decisions when adopting truck platooning. Furthermore, relevant acceptance criteria such as trust among drivers, reduction of workload, trust in the system, system safety & security are relevant for decision makers. To achieve social sustainability also guidelines for determining situations in which platooning is feasible on certain roads (e.g. depending on weather, traffic situation and road type) are required for decision makers (e.g. road operators, politicians, law).

4 Conclusion

Truck platooning might become a near-term automated and connected driving function. However, truck platooning deployment faces many opportunities and challenges (Engström et al. 2019). Expected benefits from logistics and society tend to be high (Janssen et al. 2015). In order to deploy truck platooning successfully, collaboration among diverse stakeholders will be crucial. Truck platooning system providers will need to ensure technical connectivity as well as system safety & security between diverse truck platooning systems. Fleet operators will need to collaborate to gain fuel and cost savings. Truck drivers will need to collaborate to drive safely in a semi-automated platoon. Truck platooning system developers, road authorities, and governmental institutions will need to develop guidelines for determining situations in which platooning is feasible (e.g. depending on weather, traffic situation and road type).

In this contribution, relationships between truck platooning and physical internet systems have been discussed with respect to (i) connectivity, (ii) collaboration and coordination as well as (iii) sustainable, safe and secure supply chains. Thereby, both may benefit from each other – physical internet systems may support connectivity as well as collaboration and coordination

of truck platoon actors; platooning may serve as sustainability means for efficient and safe transports within physical internet networks.

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Intelligent Road Space Management for Freight' (IRoMF)

Simon Barnes, Business Fellow of the Connected Places Catapult
University of Kent, Rothford, Giles Lane, Canterbury CT2 7LR, Kent UK
s.f.barnes@kent.ac.uk

The intention of this paper is to explain our research into the intelligent management of key network road space for road freight vehicles in Kent, to examine with foresight as technology moves toward semi-autonomy and full autonomy of Heavy Goods Vehicles (HGV's)

Road transport, and in particular road freight transport, is vital in Kent, 80 per cent of powered goods vehicles travelling from Great Britain to mainland Europe use the Dover Strait Port Group[i] and the sector is a significant employer. Semi and autonomous technology is the future, there is a need for reliable journey times right, so we have an opportunity for innovation.

Currently, severe disruption at either Dover Docks or Eurotunnel or in France, all have the potential to quickly reduce capacity through across the Channel. Under these circumstance HGV's are held at a number of locations in Kent on public (this was referred to as Operation Stack in 2015, and currently both is Operations TAP and BROCK). French terminals have up to four times the parking capacity and a larger number of routes to the Port and Tunnel, the impact of disruption is less.

When the impact of Operation Stack was last quantified the immediate impact on the local economy of Kent and Medway been estimated at £1.4 million per day. If this is extended to include the impact outside Kent and Medway this increases to £2.0 million per day.[ii]

In our research we believe taking a systems approach now and establishing that approach for semi-autonomous and autonomous freight is the right one.

Using data from Highways England we have observed the following pattern of arrival on the A2 close to Dover.[iii]
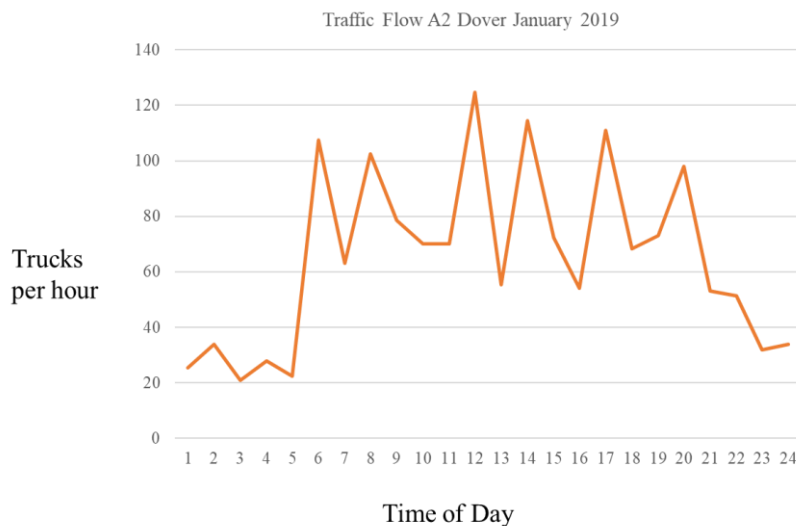
The graph above illustrates an example of the pattern of large Heavy Good Vehicles on the A2 during January 2019 weekdays. With the volume of trucks peaking at 120 per hour or one every 30 seconds, this is a single carriageway road to the Port.

This peaking makes the traffic highly sensitive to delays in the Port due to poor weather or industrial action for example, with queues quickly building at peak times. Operation TAP (trucks queue on public roads close to Dover) is used up to 200 times per year.[iv]

Lorries in Operation TAP, Dover, March 2019, Storm Gareth – Sunday Times
The University of Kent is researching how to proactively manage this pattern when delays occur.
Our objective is to ensure we can manage trucks before they arrive on the Kent road network.
We have simulated the potential impact of placing these trucks into a virtual management service, in the case of delays a volume of trucks are 'paused' at facilities outside of the county. This will be achieved by trucks registering in the virtual queue management system and the driver and haulier being notified of a 'hold' pattern for the appropriate time as the delay requires. In a similar way to the current operation of Air Traffic Control. We call this a Virtual Queue (VQ).

Frequency of Parking
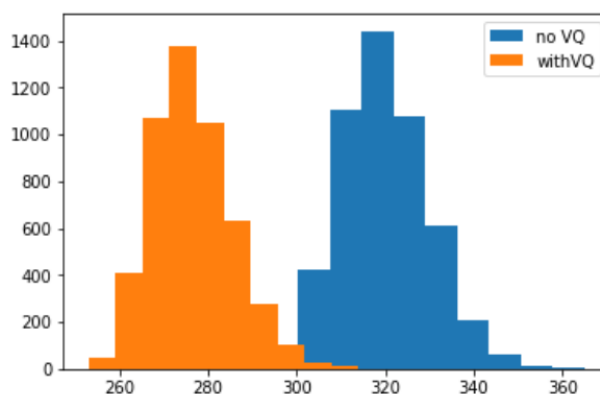
Parking spaces required at Dover

Our simulation has combined Highways England Data and with regional economic activity to purpose the United Kingdom location of the HGV's travelling to Dover. We have then compared the simulated scenario between when we have no Virtual Queue to that of the current condition of no VQ. Due to the balance of pattern of arrival and origin of trucks even without any proactive management the VQ we can reduce the parking required at Dover by approximately 14 per cent; this is our baseline degree of influence. The baseline of influence

needs further refinement and sensitivity analysis as well as understanding the impact of peaking. This will be the next element of our work.

In the case of a delay, when we start to proactively manage the queue, we can use the additional 14 per cent capacity as a buffer (to avoid queues on public roads) as the impact of proactive management of the queue is affected.

So, a systems approach can start to reduce the likely frequency of queueing. But how do we effect the management of the trucks? We believe the first approach is a commercial one. To analyse this we have teamed up with SNAPaccount, an international truck servicing company, whose offer includes parking, tolls and fuel for example. SNAP have access to over 40,000 trucks. These trucks can be contacted directly and shown the nearest available parking across 150 sites in the UK. In effect we have a total of 150 holding areas with an estimated capacity of 7,500 vehicles. We plan to establish a platform to allow different users (truck companies, shippers, ferry companies and tunnel operator) to 'see' the trucks in the queue. The system when in operation will allow us to hold and release trucks via Virtual Queue trucks to be routed directed to the port.

As part of the business case we can hypothesise the cost of parking, payment can be made via Automatic Number Plate Recognition, making the management of the system seamless. The attraction of early adoption is therefore one of information, visibility and convenience of not being part of Operations TAP or BROCK; along with the wider SNAPaacount benefits.

The outcome of the VQ system will be to reduce the need for Operation BROCK (which has replaced Stack); in May 2018, £30m was allocated to Highways England to set up Operation Brock. As well as the financial cost there are the wider benefits of the free flow of traffic, lower emissions (due to reduced stop start) and greater road safety.

In the future we plan to integrate the VQ systems into Border Force customs clearance as part of their Trusted Trader Scheme.

The nest stage in the commercial management of road freight will link the VQ to a platform for platooning. Platooning of three HGV's is likely to require a commercial platform to be effective, in effect a consolidator for the new technology. VQ can be integrated into this.

For full autonomy management of HGV's is critical to optimising traffic capacity. VQ is in effect extended and considerations such as journey time, destination, traffic speed, road conditions need to be ingrated to ensure the optimisation of traffic on the strategic road network. This should initially be focused on where the network has least capacity and resilience – Road to Dover and Eurotunnel.

Automated delivery of shipments in urban areas

Franz Kopica, Walter Morales-Alvarez and Cristina Olaverri-Monreal
Johannes Kepler University - Chair for Sustainable Transport Logistics 4.0, Linz, Austria
{franz.kopica, walter.morales_alvarez, cristina.olaverri-monreal}@jku.at

Abstract: Fully automated delivery of goods in urban areas with small hybrid or electric vehicles can reduce CO2 emissions in cities. We contribute to the "last mile and city logistics" topic by proposing a case study for an autonomous logistics system for delivering packages and mail. For this purpose, electric vehicles and standardized autonomous transport boxes are used. The operator at the distribution center (DC) keeps track of vehicles and transport boxes based on Global Positioning Systems (GPS) information. The boxes are equipped with Radio-Frequency Identification (RFID) tags that contain a microchip to store and retrieve the information from the inventory database records in the central operating platform. Through RFID the recipient is informed about the delivery and then authorized to open the transport box with a Near Field Communication (NFC) enabled smartphone which sends a text message to the operator.

1. Introduction

Urban agglomerations are continuously growing, testing the limits of transport and infrastructure resources and causing extremely congested traffic areas in cities (OECD, 2010; Statistik Austria, 2019). As a consequence, travel time increases, which results in higher CO2 emissions.

Rising CO2 emissions and the expansion of transport infrastructure affect certain services and lead to circumstances that contribute to climate change and/or increased energy prices and transportation costs. In order to reduce long-term logistic cost to these systems and to limit global temperature increases (less than two degrees Celsius), sustainable transport needs to be considered as an integral part of strategies for sustainable development according to the United Nations (United Nations, 2019).

Fuel consumption and CO2 emissions reduction requires new vehicle concepts as well as efficient transportation systems. The expansion of fully electric vehicles into the market provides opportunities for sustainable mobility and a new technological era (Helmbrecht *et al.*, 2014) while also presenting a promising alternative to vehicles with internal combustion engines for urban goods mobility demands. In addition, time-critical deliveries can hardly be realized if the vehicles have to charge for hours in the middle of the delivery process, or are subject to an insufficient charging infrastructure. Therefore, small hybrid or electric vehicles are an optimal approach for the urban area (Heine, 2018). In line with this, we contribute to the International Physical Internet Conference by addressing the "last mile and city logistics" and "Autonomous Road Transports and Logistics Operation" topics proposing a case study that describes the application of an autonomous logistics system for delivering packages and mail in line with the goal of using autonomous technologies to increase efficiency of freight transport

and logistics operations (Alliance for Logistics Innovation through Collaboration in Europe, 2019).

By using delivery hybrid- or electric vehicles that contain standardized autonomous transport boxes with electronic labels it is possible to optimize delivery cost and times. They drive from a strategically located logistic or central operating platform (distribution center or hubs) to a predefined destination where their load is distributed according to the information that they receive.

The delivery vehicles are stationed in a central location and are operative until all the autonomous transport boxes that they contain have been delivered. The autonomous transport boxes are able to operate the delivery vehicle's rear door to exit and enter before and after each delivery.

The proposed autonomous system for transport logistics relies on a multi-agent architecture. The different entities in the architecture are interconnected through mobile networks for the internal exchange of information (e.g. the state of the processes of each unit or its location) or for external communication to acquire data related to the surrounding road users or customer information to which the delivery is scheduled.

The remainder of the paper is organized as follows: the following section describes the related work in the area. Section 3 presents a general description of the architecture of the proposed system starting by explaining the operation of the different entities, detailing how they communicate and ending with a particular use case. Section 4 explains in detail the design of the autonomous transport box and their main hardware and software components. Section 5 describes the components of the transport management system (TMS) implemented in the distribution center. Finally, section 6 concludes the work.

2. Related Work

In the previous section we introduced the idea of an autonomous multi-agent system as an alternative for traditional shipment, whose main components (DC, vehicles, autonomous transport boxes) intercommunicate between them exchanging information (location, surrounding road users, box and package's information) with which each entity can make independent decisions to deliver a package to a particular location. Multi-agent systems (MAS) offer advantages such as increased speed, efficiency and robustness in operations, scalability, cost reduction and reusability of agents (Nikos, 2007; Balaji and Srinivasan, 2010).

Multiple intelligent, semi-autonomous agents can be applied in several contexts with a variety of finalities as for example to facilitate the process of capturing software products functionality that simultaneously represent different characters that pursue defined goals (Olaverri-Monreal *et al.*, 2013; Olaverri-Monreal *et al.*, 2014).

The advantages of using autonomous system of control in logistical processes of a multi-agent system makes this technology particularly useful and therefore its implementation over the years has been abundant as in the work of Karageorgos *et al.* (2003) who used it for logistics and planning optimization, Leung *et al.* (2016) who designed a case-based multi-agent wave picking decision support system for handling e-commerce shipments or Hribernik *et al.*, (2010) that in the context of internet of things (IoT) for transport logistics proposed an MAS-based approach to connecting information flow so that the objects were able to process information, and make decisions. The authors included in their work an extensive overview of relevant work in a number of areas, including holonic manufacturing, smart resources and intelligent products.

Most of the research in the area of transport logistics in the last decades has focused on the development of models for the management of information. Therefore we contribute to the research in the field by implementing an architecture that includes the development of autonomous entities that do not require a human operator to deliver goods from the transport vehicle to the final destination.

Although The McKinsey Institute (2016) forecasts that driverless vehicles such as delivery robots will make up 85 percent of last-mile deliveries by 2025, until the day there are no conclusive studies on their use in cities. The cases of shipping robots are scarce and mostly private, such as the prototype announced by Amazon or Fedex that seeks to transport packages from Monday through Friday during daylight hours (Mashable 2019). The company that stands out the most in the implementation of autonomous robots for sending packages is an Estonian company called Starship Technologies. The company developed autonomous food delivery bots that were capable of carrying two grocery bags (Venturebeat, 2019). Although the vehicle designed by Starship works efficiently, it only focuses on transporting food to a certain location. In our case we propose a general architecture for an urban environment, automating the delivery process as a proposal for transport logistics in a completely digital era.

3. System Overview

As mentioned in section 1, we implement a multi-agent system (MAS) using the principles of autonomous control in intelligent products that conform a hierarchical organization to meet the objective of shipping a package to a particular place. This use case was selected because of the need in modern society to implement intelligent systems with automated technology as a solution in shipping companies (e.g. Fedex, Amazon, DHL) to reduce consumption of fossil resources, decrease CO_2 emissions, increase consumer comfort and improve shipping's security. The physical smart entities that make up the proposed organizational architecture are as follows:

- The distribution center where the different packages to be transported are located;
- The autonomous transport boxes that are the containers of the packages to be transported and constitute at the same time the entities with which consumers interact personally to pick up their order and
- The electric vehicles that are in charge of transporting the boxes or smart containers to the recipient neighborhood.

In this first approach, the packages to be sent are non-perishable objects whose total weight does not exceed 10 kg.

a. General Architecture

Initially in the central operating platform hub or distribution center the goods are unloaded from the carriers into small hybrid or electric vehicles (e.g. vans), that are in constantly communication with the central operating platform and therefore are able to receive all the information pertaining the distribution of the load from the leading information technology (IT) system, such as delivery address, recipient's personal information, traffic, route and changes in delivery schedule.

The distribution center is in charge of the real-time supervision of the packages using servers that contain a database of the autonomous transport boxes including tables for the description of the load they contain, recipients and shipping route information. Through an electronic communication system for network connection, it monitors the surrounding road users in urban areas in order to calculate the most optimal routes for the vehicles and the transport boxes

(considering an optimal balance between distance to the recipient's address and travel time but also being able to consider other parameters as in Olaverri-Monreal *et al.,* 2016).

The autonomous transport boxes are smart containers that contain integrated sensors such as RFID tags to allow the final customer to access their content. The tags can read data from the recipient phone through NFC. As autonomous units the transport boxes are capable of making decisions based on the data they acquire through sensors such as video cameras, ultrasound, GPS and RFID tags. They also have communication capabilities to inform the recipient about the delivery location and schedule.

The smart containers are capable of maintaining constant communication with the distribution center throughout the whole delivery process by using a global system for mobile communications (GSM) module, which turns the transport box into an access point to the network in an urban environment. It is important to note that we do not consider using a Wi-Fi module to connect the autonomous transport box to the network because in urban environments these kind of networks fluctuate, as they depend on routers with private access and reduced coverage, unlike cellular networks that depend on antennas that have total coverage in cities, being only necessary a SIM card from the telephone provider to access them. Figure 1 illustrates the system architecture.
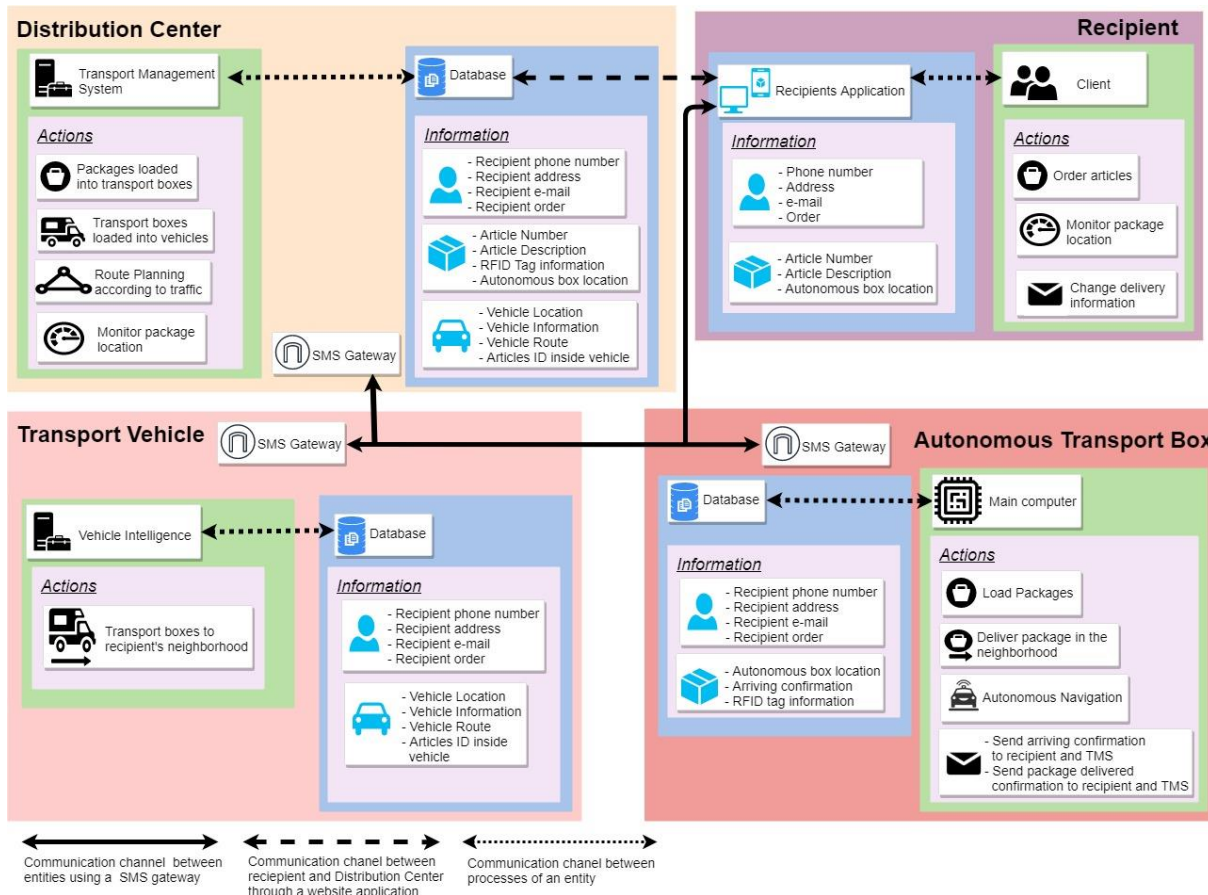
Figure 1: System architecture

b. Communication

As for the communication between the entities in our system, a transport management system in the hub DC included additional communication capabilities through GPS and short message service (SMS). This communication was achieved thanks to the fact that on the part of the

transport box there is a SIM7000E device that works as a GSM module and that together with the program SMS Server tools generates an SMS Gateway that connects with the DC's gateway. Figure 2 illustrates the communication process.
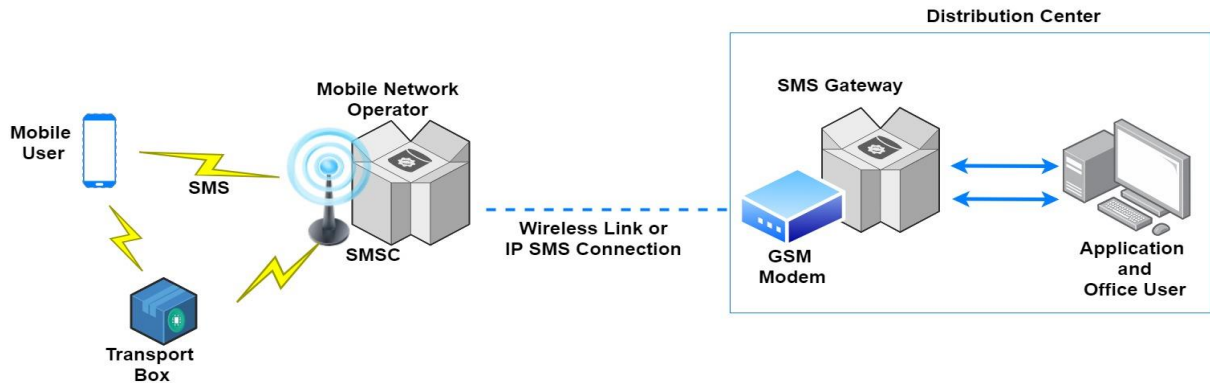
Figure 2: Communication architecture designed through a SMS gateway.

The SMS gateway is an interface for communication that uses mobile networks between smart entities. It offers a framework to process the messages transmitted between the devices, and it has functionalities such as the HyperText Transfer Protocol application programming interface (HTTP-API)[14], that handles the data acquire through the HTTP protocol from the network or the email to SMS functionality. This allows the DC to send a message to the autonomous transport box based on the emails that it receives.

The Short Message Service Centre (SMSC) is part of a global mobile network (GSM-, UMTS- or LTE) and is responsible for storing, forwarding, converting and delivering messages from the short message service.

On the other side, the TMS sends updated address information (received from the recipient) gateway to the autonomous transport boxes and vice versa using the database driven SMS as follow:
1) The information from the TMS-database is converted into a text message by a script and transmitted to the transport box through the SMS gateway.
2) The SMS is converted into a text message by a script and stored in the database of the transport box.
3) The confirmation of the change of address will be transmitted to the TMS.
4) An application from the TMS sends an email or SMS to the recipient.

As an example of messages sent between the DC and the autonomous transport box, Figure 3 shows an example of a script to send a SMS message, written in the programming language PHP that is embedded in HTTP-code.

---

[14] RESTful-API, used to handle data via e.g. http-GET or, http-PUT

```
1   <!DOCTYPE html>
2   <html>
3   <body>
4   <?php
5   $text ='Adress-change:Donaustadtstrasse/30/14/18';
6   $url = 'https://open-source/sms-gateway/?' .
7          'user='IPIC2019'.
8          '&pass='md5passphrase'.
9          '&to=004313317823'.
10         '&text=$text;
11
12  $response = @file_get_contents ($url);
13
14     if($response == '200') {
15            echo 'SMS has been sent! ';
16        }else{
17            echo 'An Error occurred: '. $response;
18     }
19  ?>
20  </body>
21  </html>
```

Figure 3: Example of a script to send a message through the SMS gateway

Figure 4 shows the code to convert an email to an SMS using the SMS-gateway and the PHP's mail function. To this end the phone number of the device to reach and the network's domain for the SMS Gateway are required. In this example we used the address for the network's SMS-Gateway 004313317823@sms-gateway.at.

```
1   <?php
2
3   if ( isset( $_REQUEST ) && !empty( $_REQUEST ) ) {
4     if (
5     isset( $_REQUEST['004313317823'], $_REQUEST['sms-gateway.at '], $_REQUEST['smsMessage'] ) &&
6     !empty( $_REQUEST['004313317823'] ) &&
7     !empty( $_REQUEST['sms-gateway.at '] )
8     ) {
9       $message = wordwrap( $_REQUEST['smsMessage'], 30,"<br />\n" );
10      $to = $_REQUEST['004313317823'] . '@' . $_REQUEST['sms-gateway.at '];
11      $result = @mail( $to, '', $message );
12      print 'Message was sent to ' . $to;
13    } else {
14      print 'Not all information was submitted.';
15    }
16  }
```

Figure 4: Code example to convert an email to an SMS.

c.   Use case scenario

To illustrate the operating mode we describe in this section a potential use case in a scenario with a single family detached house with a front yard (see Figure 5). The goods are unloaded from the carriers in the distribution center into a hybrid or electric van that drives to a target destination determined by the central operating platform following the information from the leading IT system (Figure 5b). The autonomous transport boxes then receive an updated destination with new coordinates via text message (SMS) or email that is read and interpreted automatically by the box without a third party intervention, in cases where the recipient changes the destination address. In this scenario, the change is stored in the database of the transport managing system and sent to the autonomous transport box through the communication channels mentioned.

After the autonomous transport boxes have left the delivery van they drive towards the destination (Figure 5c). A confirmation that the destination has been reached and the box can

take a parked position (Figure 5d) is made through the RFID tag located inside the transport box where a customer ID is stored. This information is transferred to the database application in the box and triggers the transmission of an SMS message with the delivery time information to the package's recipient (as listed on the database) (Figure 5e). The operator receives the same information (Figure 5f). The autonomous transport box is equipped with a warning system. If the autonomous transport box does not stay in its parked position for a certain pre-configured time, for example 5 seconds, an alarm is sent to the corresponding person (operator, recipient, etc.). Eligible receivers are smartphones with RFID/NFC functionality that can confirm the receipt. As a result, the autonomous transport box can be opened without an alarm and all involved actors get a confirmation of receipt (Figure 5h).
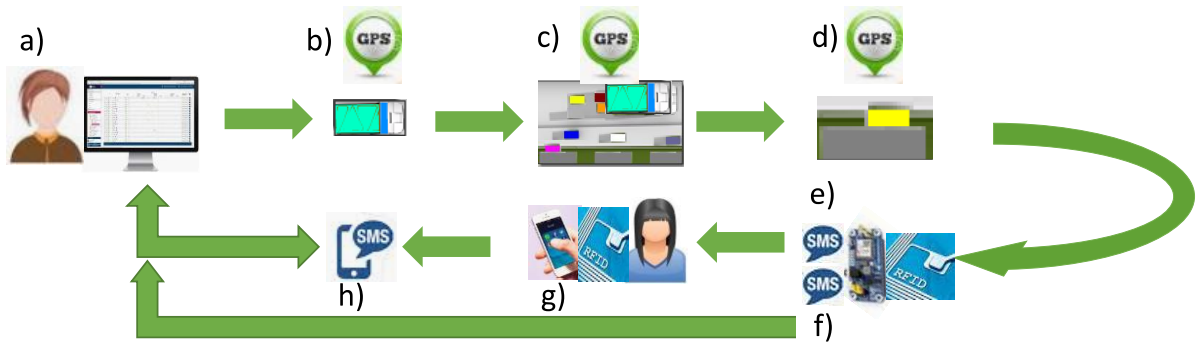
Figure 5: Use case scenario showing the process of the delivery starting with the leading IT system (a), the transport vehicles (b), the autonomous boxes traveling (c) and taking their parked position (d), the delivery of the message to the database (e) and the recipient (f), the smartphone to unblock the box (g) and the confirmation of the delivery (h)

4. Prototype: Autonomous Transport Box

As mentioned above these smart containers are equipped with all the required technology for a smooth autonomous operation. They are capable of simultaneous localization and mapping (SLAM) by constructing and/or updating a map of an unknown environment while simultaneously keeping track of their location through GPS. They are also able to perceive their surroundings through several active and passive mounted sensors (i.e. radar, cameras, ultrasonic). All units communicate changes in the delivery plan or schedule with the parent system. In addition, the autonomous transport boxes are equipped with a GPS module for localization and a global system for mobile communication (GSM) module that acts as a mobile communication modem for sending and receiving messages from the hub.

A RFID reader/writer unit is installed in the autonomous transport box. The goods are equipped with a RFID-tag that contain a microchip to store and retrieve the information from the inventory database records in the central operating platform. Through this technology, the autonomous boxes are also labeled with unique identifiers that can contain a large amount of information and make inventory tracking a faster process. To complete the system, the boxes have a Raspberry pi that stores and processes the information, enabling communication between all the peripherals and processes explained above. Figure 6 depicts the relationship between all the peripherals and processes for the exchange of information.
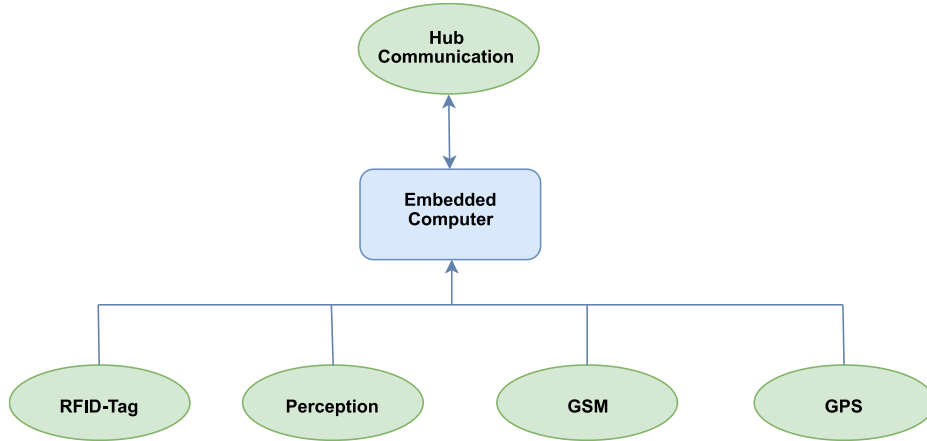
Figure 6: Relationship between all the peripherals and processes for the exchange of information pertaining to load distribution

To deliver the corresponding goods, recipients are informed via text messaging services (SMS) that are available in mobile-device systems upon arrival of the autonomous transport box. Recipients are able to open the box through the use of radio waves to read and capture information stored on the tag attached to the box using a previously installed mobile device application. This application makes it possible to operate NFC as RFID tags.

The reading distances are limited to 0.1 meters (depending on device hardware). In cases where the recipients have a mobile phone that lacks NFC functionality, the autonomous transport box has an intelligent lock with which they can open the box by providing a PIN sent via SMS.

a. Hardware

i. Raspberry pi

The main unit of the autonomous transport box to process data is the Raspberry pi. It consist of an embedded computer with an Advanced RISC (reduced instruction set computer) Machines (ARM) processor. Its General Purpose Input Output (GPIO) interface (extended 40-pin GPIO header) allows the transport box to communicate directly with the sensors and process the data that they acquire. This computer is compatible with a variety of Linux distributions such as Ubuntu or Raspbian, as well as Windows OS (Raspberry pi Foundation, 2018).

ii. Raspberry pi module SIM7000E

The SIM7000E is a Raspberry pi module that has multi communication functionalities such as NB-IoT, eMTC, EDGE, GPRS, and GNSS. The NarrowBand-Internet of Things (NB-IoT) and enhanced Machine Type Communication (eMTC) are rising IoT communication technologies evolved from 2G to LTE (4G), with advantages including low power, low cost and wide coverage. This module allows the development of applications such as remote controlling, asset tracking, remote monitoring, and mobile POS terminals. While the GSM/GPRS, and EDGE are traditional 2G/2.5G technologies capable of sending SMS or making other wireless communications. Following protocols (TCP, UDP, PPP, HTTP, FTP, MQTT, SMS, Mail, etc.) and GNSS positioning (GPS, GLONASS, BeiDou and Galileo) are supported. These functionalities makes the SIM7000E suitable to serve as an access point for the autonomous transport boxes and to communicate these smart container with both the recipient and the distribution center using mobile networks.

iii. RFID-MIFARE RC522

The MFRC522 is a highly integrated reader/writer IC for contactless communication at 13.56 MHz. This internal transmitter is able to drive a reader/writer antenna designed to communicate with ISO/IEC 14443 A/MIFARE cards and transponders without additional active circuitry. It is designed for low-power consumption and provides a robust and efficient implementation for demodulating and decoding signals from ISO/IEC 14443 A/MIFARE compatible cards and transponders. The digital module manages the complete ISO/IEC 14443 A framing and error detection functionality (parity and CRC). The MFRC522 supports contactless communication and uses MIFARE higher transfer speeds up to 424 kB/s in both directions (MFRC522 Datasheet, 2016). This module is designed for mass production and can communicate directly with any CPU board via Serial Peripheral Interface (SPI).

iv. Laser sensor

The RPI Lidar A3 is a 2D laser manufactured by Slamtec with a range of 20 m, scan rate of 16 kHz and angular resolution of 0.36 degrees (Slamtec, 2016). This sensor enables real-time localization of the transport box and mapping of the surroundings (SLAM). The decision to use this sensor is based on the fact that the company that manufactures these devices has a large amount of support in SLAM, in addition to providing ROS packages for this purpose. The laser will communicate by serial protocol with the Raspberry pi through a module provided by the company. With the data acquired, the main computer will perform SLAM algorithms, by this method estimating its localization and the trajectory that it has to follow.

v. Camera

The autonomous transport box is equipped with two RGB Raspberry pi model V2 cameras to obtain images from the environment for a real time detection of objects. Together with the data acquired from the laser it will be possible to recognize and avoid obstacles. The camera also acts a security system to avoid that the transport boxes are stolen as it can take images of individuals who try to directly steal the intelligent container or open it by force.

vi. Inertia Measurement Unit

The unit for measuring inertia (IMU) is a module used to estimate changes in the position and orientation of the autonomous transport box and to estimate its location in conjunction with the Lidar points and the camera images. The specific model used is the MPU9250 which has an accelerometer, gyroscope and compass which are responsible for calculating through the acceleration of the device, its angular velocity and magnetic fields to which it is subjected, changes in position and orientation of the container. The results of these calculations can be acquired by communicating with the device through the I2C protocol either with the main computer of the box or through a tertiary processor such as an Arduino, used in this specific case to decouple the acquisition of these data from the main computer.

vii. Motors

The transport box must be able to withstand loads up to 10 kg per shipment, travel at a speed of 0.5 m/s, have 4 wheels 15 cm in diameter, and be able to drive along paths that incline of up to 20 degrees. With these specifications, a motor that produces a torque of at least 2 Nm at an approximate speed of 6.66 rad/s is required. In order to comply with these characteristics, we used brushless direct current motors for the high power efficiency and the torque-to-weight ratio they offer. To control the velocity of the motors in the most efficient way, an Electronic Speed Control (ESC) circuit that makes the motors follow a speed reference sent from the main computer or from a third party microcontroller such as an Arduino is needed.

In most cases, the ESC receives a Pulse Width Modulation (PWM) as input in one of its terminals, which is used as a reference to transmit the necessary signals to the motor to magnetize and demagnetize its rotor and thus generate movement. It should be noted that the ESC is also responsible for sending the necessary current signals, thus decoupling the logic circuit (microcontroller) from the actuators. In our particular case, the Raspberry pi sends a speed reference to an Arduino by serial protocol that will perform the low level control and map this speed signal to a PWM. This signal is then transmitted to the ESC, which will then send the current necessary to the motor to initiate transport box motion.

viii. Power Supply

The battery to be used must be capable of supporting both the load of the computer and the load of the engines. In an approximate calculation, the transport box may need a battery with a capacity of at least 10000 mAh, a nominal voltage of at least 12V and high capacity to withstand the load of the motors. Based on these specifications and the need for a battery with relatively little weight, a lithium polymer batteries (LiPo) was chosen.

b. Software

The software run under the Ubuntu operating system and was stored in the SD card of the Raspberry pi.

i. Ubuntu 18.04 & NOOBS (New Out Of the Box Software)

The operative system installed on the Raspberry pi is Ubuntu 18.04 LTS using Noobs. Noobs is an installation assistant for the primary operating system for the family of Raspberry pi and it is highly optimized for the embedded computer with over 35,000 compiled software packages (Raspberry pi Foundation, 2018). This installation assistant sets up the Ubuntu 18.04 long-term support (LTS) operating system and it is officially supported on the x86, AMD64 and ARM architectures. As with all Debian derivatives, the program packages are divided into several package sources that can be installed through the terminal.

ii. Ubuntu - SMS Server

SMS Server Tools 3 (smstools) are an SMS gateway software for sending and receiving text messages (SMS) using GSM modems on Linux. They are especially interesting for monitoring systems to send notifications not only by email, but also by SMS. This software is the main telecommunication interface that, through the GSM SIM7000E module, allows the autonomous transport box to exchange information with the distribution center and with the recipient via SMS or email.

iii. RDBMS – Relational Database Management System

The autonomous transport box uses a database based on MySQL to store recipient's information giving the smart container an efficient and secure storage of data sent by the distribution center or by the recipient, in addition to serving as backup in cases of eventualities.

MySQL is a free open source product and it is one of the world's most common relational database management systems. It is available as open source software as well as a commercial enterprise version for various operating systems. It has a number of tools which are available for administration. Alternatively, the included command line tools or software can be used with a graphical user interface. The entire administration of the server is done by the program PhpMyAdmin that is a third-party tool for editing (Apache, 2019).

c. Apache Webserver

We use this server to interact with the TMS GPS software that needs a running server on a device to access their location. The Apache HTTP Server is a modular open source Web server with convenient functionalities such as encrypting the communication between browser and Web server (mod_ssl), the capacity to be used as a proxy server (mod_proxy) or the complex manipulation of HTTP head data (mod_headers) and URLs (mod_rewrite) (Apache, 2018). The HTML code of a page, and the design (via CSS) files are retrieved from different sources such as databases and transmitted separately to a client. Script languages, such as PHP, ensure that all individual information is connected to a document. The free source code allows it to be adapted to individual needs.

d. Robotic Operating System (ROS)

ROS is a framework for the development of robots in which it is possible to intercommunicate isolated processes through messages transported by communication channels called topics (Quigley *et al.*, 2009). This framework suits this use case perfectly because it allows the processing of the different data acquired by the systems described in section 4.1 and can control the different modules of the system. For example, with ROS it is possible to acquire the laser data, perform SLAM and with the results send signals corresponding to the motors to move to a specific location. Another important feature is that this framework has a large amount of support for its use in embedded computers such as Raspberry pi, and the great community of programmers that publish their open source packages for the developing of robots. The specific distribution configured in the transport box is ROS Melodic due to the Linux distribution installed on the Raspberry pi.

5. Distribution Center: Transport Management System

This section defines the components of the transport management system implemented in the distribution center. This system is in charge of constantly monitoring the autonomous transport box via GPS tracking software through the SMS-gateway communication explained in section 3.

a. GPS Tracking System Software

The application for the Web server, in this case Traccar, can be self-hosted in the cloud or on-premise. It is designed specifically to provide web-based GPS tracking services for a "fleet" of vehicles that run an Apache Web server. It is a fleet tracking system that is very highly configurable and scalable to larger enterprises as well. A customizable mapping service supports OpenLayers/OpenStreetMap in addition to Google Maps, Microsoft Virtual Earth, and Mapstraction (which provides mapping support for MultiMap, Map24, MapQuest, and more). It supports GPS trackers from a variety of vendors, from low- cost models to high-end quality brands (Traccar, 2019). The implementation of Traccar in the TMS allows the constant monitoring of the location of the different autonomous transport boxes in real time. Also, as can be seen in Figure 7, the Traccar architecture is similar to the general architecture proposed by us, which makes it perfect to meet our requirements, fulfilling the objective of using open source software for the development of the system. Following the architecture of Traccar, in our use case the tracking devices are the autonomous transport boxes and the small hybrid or electric vehicles, the persistent storage is a MySQL database implemented on the TMS and the Web application is for managing users, devices and other entities.
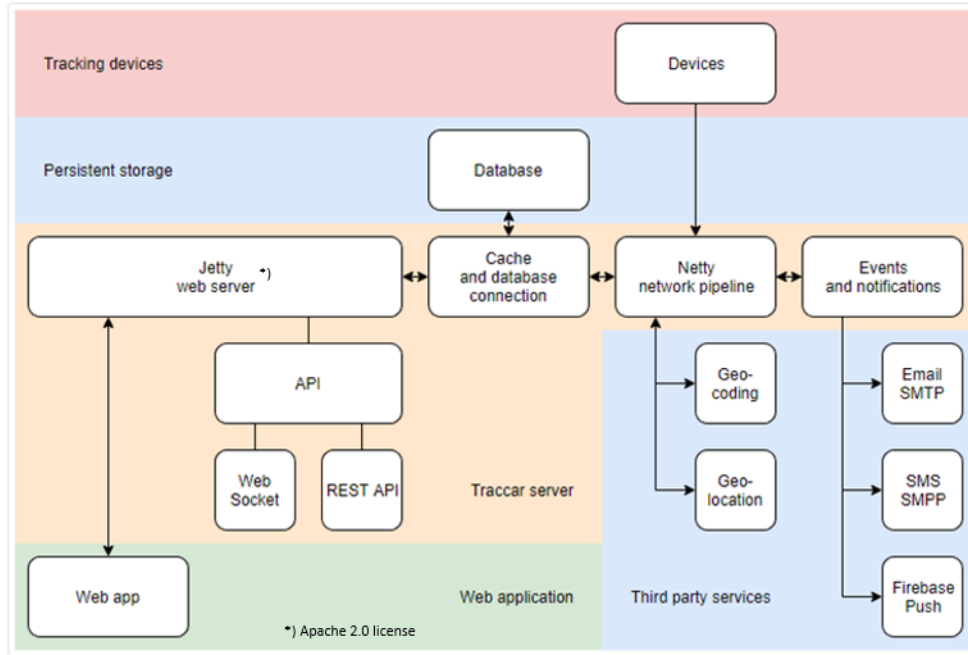
Figure 7: Traccar architecture (Traccar 2019).

b.   SMS Gateway-Jasmin

Similarly to the autonomous transport box, the TMS includes a software application called Jasmin (Jasmin, 2014) that works as a framework to use the python SMS-Gateway that is available in the DC. Through the HTTP protocol communication with the autonomous transport boxes is established. In addition the API makes it possible an intelligent routing to connect in an efficient way to the autonomous transport boxes and the transport vehicles.

6. Conclusion

In this work we proposed an alternative way to transport packages or mail based on a multi-agent autonomously controlled system, explaining in a general way the architecture of the system designed; making special emphasis in the design of the hardware and software components of a prototype for autonomous transport boxes. A description of the implemented transport management system in the DC completes the work.

One of the main objectives of this work was to implement the prototype of the autonomous transport box to test it in real conditions. To achieve this goal we also developed the required software. After testing the platform regarding communication and monitoring tasks (servers, SMS gateways and GPS software) to detect potential conflicts, we concluded that the trial communication with the distribution center ran seamlessly.

Future work will address a more sophisticated system that will be evaluated in various scenarios including other road users.

Acknowledgment

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Automated delivery of shipments in urban areas

Franz Kopica, Walter Morales-Alvarez and Cristina Olaverri-Monreal
Chair for Sustainable Transport Logistics 4.0

JXU
JOHANNES KEPLER
UNIVERSITÄT LINZ

Introduction

Urban agglomerations are continuously growing, testing the limits of transport and infrastructure resources and causing extremely congested traffic areas in cities. As a consequence, travel time increases, which results in higher CO_2 emissions.

Fuel consumption and CO_2 emissions reduction requires new vehicle concepts as well as efficient transportation systems. The expansion of fully electric vehicles into the market provides opportunities for sustainable mobility and a new technological era while also presenting a promising alternative to vehicles with internal combustion engines for urban goods mobility demands. In addition, time-critical deliveries can hardly be realized if the vehicles have to charge for hours in the middle of the delivery process, or are subject to an insufficient charging infrastructure. Therefore, small hybrid or electric vehicles are an optimal approach for the urban area. In line with this, we contribute to the "last mile and city logistics" topic by proposing a case study describing the application of an autonomous logistics system for delivering packages and mail. By using delivery hybrid- or electric vehicles that contain standardized autonomous transport boxes with electronic labels it is possible to optimize delivery cost and times. They drive from a strategically located logistic or central operating platform (distribution center or hubs) to a predefined destination where their load is distributed according to the information that they receive.

The proposed autonomous system for transport logistics relies on a multi-agent architecture. The different entities in the architecture are interconnected through mobile networks for the internal exchange of information (e.g. the state of the processes of each unit or its location) or for external communication to acquire data related to the surrounding road users or customer information to which the delivery is scheduled.

System General Architecture
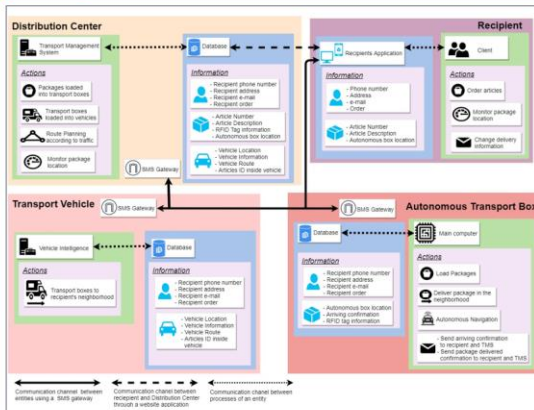
System Communication

For the communication between the entities in our system, a transport management system in the hub DC includes additional communication capabilities through GPS and short message service (SMS). This communication is achieved thanks to the fact that on the autonomous transport box side there is a SIM7000E device that works as a GSM module and that together with the program SMS Server tools generates an SMS Gateway that connects with the DC's SMS gateway. The SMS gateway is an interface for communication that uses mobile networks between smart entities. It offers a framework to process the messages transmitted between the devices and it can handle the data acquire through the HTTP protocol from the network or the email to SMS functionality.
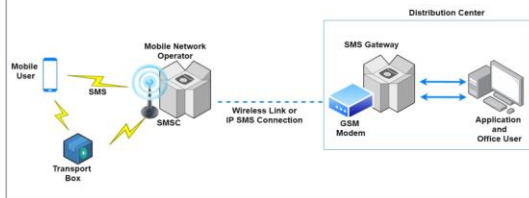
Use Case

The goods are unloaded from the carriers in the distribution center into a hybrid or electric van that drives to a target destination determined by the central operating platform following the information from the leading IT system. The autonomous transport boxes then receive an updated destination with new coordinates via text message (SMS) or email that is read and interpreted automatically by the box without a third party intervention, in cases where the recipient changes the destination address. In this scenario, the change is stored in the database of the transport managing system and sent to the autonomous transport box through the communication channels mentioned.

After the autonomous transport boxes have left the delivery van they drive towards the destination. A confirmation that the destination has been reached and the box can take a parked position is made through the RFID tag located inside the transport box where a customer ID is stored. This information is transferred to the database application in the box and triggers the transmission of an SMS message with the delivery time information to the package's recipient (as listed on the database). The operator receives the same information. Eligible receivers are smartphones with RFID/NFC functionality that can confirm the receipt.

(a) The leading IT system
(b) The transport vehicles
(c) The autonomous boxes traveling
(d) Taking their parked position
(e) The delivery of the message to the database
(f) The delivery of the message to the recipient
(g) The smartphone to unlock the box
(h) The confirmation of the delivery

Proposed Prototype

The prototypes proposed are equipped with all the required technology for a smooth autonomous operation. They are capable of simultaneous localization and mapping (SLAM) by constructing and/or updating a map of an unknown environment while simultaneously keeping track of their location through GPS. They are also able to perceive their surroundings through several active and passive mounted sensors. All units communicate changes in the delivery plan or schedule with the parent system. In addition, the autonomous transport boxes are equipped with a GPS module for localization and a global system for mobile communication (GSM) module that acts as a mobile communication modem for sending and receiving messages from the hub.

A RFID reader/writer unit is installed in the autonomous transport box. The goods are equipped with a RFID-tag that contain a microchip to store and retrieve the information from the inventory database records in the central operating platform. Through this technology, the autonomous boxes are also labeled with unique identifiers that can contain a large amount of information and make inventory tracking a faster process. To complete the system, the boxes have a embedded computer that stores and processes the information, enabling communication between all the peripherals and processes explained above.

Recipients are able to open the box through the use of radio waves to read and capture information stored on the tag attached to the box using a previously installed mobile device application. This application makes it possible to operate NFC as RFID tags.

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FFG · **bmvit** · **automotive engineering iav** · **Post** · **FH TECHNIKUM WIEN** University of Applied Sciences
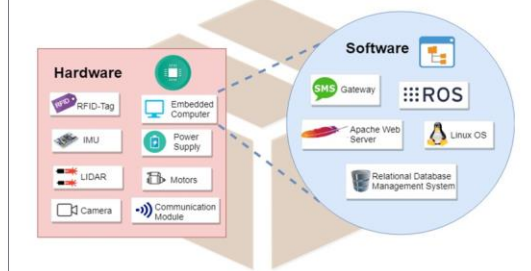
Ports and Hubs as the PI Cornerstone - 9th July 2019 13:30 – 15:00

Sustainable port development: towards the Physical Internet concept

Amalia Nikolopoulou[1], Angelos Amditis[1], Georgios Tsimiklis[1], Athanasia Tsertou[1], Evangelia Latsa[2], Eleni Krikigianni[2], Meng Lu[3], Alexandr Tardo[4], Carles Pérez Cervera[5], Ioannis Kanellopoulos[6], Ville Hinkka[7] and Allister Slingenberg[8]

1. Institute of Communication and Computer Systems, Athens, Greece
2. SEAbility Ltd, Piraeus, Greece
3. Dynniq, Amersfoort, The Netherlands
4. CNIT, Pisa, Italy
5. Fundación Valenciaport, Valencia, Spain
6. Piraeus Container Terminal, Piraeus, Greece
7. VTT Technical Research Centre Of Finland LTD, Espoo, Finland
8. Deltares, Delft, The Netherlands

Corresponding author: anikolop@iccs.gr

Abstract: *European ports are currently facing the challenge of adapting to the current trends in global trade and efficiently handling the increasing volumes placed on them. The aim of this paper is to present an innovative framework supported by disruptive technologies for cargo ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. The innovations to be implemented within the proposed framework will contribute to the Port of the Future objectives regarding reduction of port's total environmental footprint associated with intermodal connections; the improvement of operational efficiency, and increase of data sharing and information visibility; and the promotion on the innovation in the port-urban context. Among the solutions presented, the model-driven tool for Real-time Control of port operations, the advanced Truck Appointment System and the Cargo Flow Optimization tool, aim to pave the way into interconnected port systems with information at various steps of the transportation flow. Overall, the proposed framework aims to develop models and tools which can support ports to improve their efficiency and gradually participate in a Physical Internet network.*

Keywords: *port of the future, container terminal management, sustainability, internet of things, data analytics, 5G networks*

1 Introduction

With the ongoing growth in economic activity and the trend towards increasing globalisation, transport infrastructure has to accommodate ever larger numbers of cargo flows. Extended transport capacity from building new transport infrastructure is often increasingly rapidly fully

absorbed, due to ever increasing demand for freight transport. In order to sustain an efficient functioning of the economic system and preserve quality of life, new solutions for the future ports need to be found.

In Europe, ports face the challenge of adapting to the trends in global trade and efficiently handling the increasing volumes placed on them. This challenge is further magnified by the restrictions in available land use, the environmental impact in the vicinity of the port area as well as the complexities of the hinterland connection between the port and the urban environment. These concerns increase the need for technological development and advanced logistics concepts to propose sustainable, yet economically competitive solutions for European ports (Prokopowicz and Berg-Andreassen, 2016).

The Physical Internet (PI) term has been recently used and targets sustainable logistics and supply chain management. The basic concept is an open global logistics system based on the physical, digital and operational interconnectivity enabled by smart modular containers, interfaces and protocols for increased efficiency and sustainability (Montreuil, 2011). In other words, PI intends to provide universal interconnection of logistics services, and substantially increase efficiency.

This paper presents an innovative conceptual framework supported by disruptive technologies, including internet including Internet of Things, data analytics, next generation traffic management and emerging 5G networks for cargo ports to handle upcoming and future capacity, efficiency and environmental challenges. The innovations will be implemented and tested in real operating conditions in five Living Labs (LLs), associated with five European ports: Port of Livorno, Port of Piraeus, Port of Valencia, Port of Haminakotka, and Port of Antwerp.

In this work, we present selected innovations of the proposed framework to be adopted by the ports that will serve as enablers for driving ports of the future to be ready to a PI environment, though optimisation, integration, and massive connectivity. The innovations examined in this work can be viewed as complementary to understanding the benefits of the PI. In addition, the proposed technologies exhibit innovation potential. At first, the use of predictive analytics for implementing dynamic asset management is a major step towards resource and land-use efficiency. Current asset management tools, e.g. SAP, only perform static preventive maintenance. Another novel application of predictive analytics based on rail/barge/vessel ETAs are cargo flow prognoses in order to support port operators and urban planners foresee required infrastructure changes and upgrades in the medium-/long-term so as to accommodate increased flows. Finally, truck appointment systems minimise trucks' waiting time by offering different time windows to enter the port. The Truck Appointment System presented in this work will provide a more collaborative and dynamic approach making use of an IoT environment that will link different platforms and IT sources of the logistics supply chain actors' with real time information from the urban Traffic Management Center. The system will be supported by a machine-learning module based on real-time information and traffic flows forecasting (both entering and leaving the port).

The paper is structured as follows: Section 2 provides an extensive literature review, and introduces port-driven technological innovations. Section 3 presents an approach for establishing a framework for sustainable development of the port of the future. Section 4 provides an overview of the framework implementation through the Living Labs and highlights the expected impact from the implemented technologies. Finally conclusions are drawn in Section 5.

2 Physical Internet and sustainable port development

2.1 Literature review

Very recently, the concept of the Port of the Future has been introduced, as the one that has 'no negative impact on the ecosystem and recognises environmental systems as a mix of elements that interact with each other' in the maritime environment (Schipper et al., 2017). However, as this 'no-impact port' term refers to an ideal situation in practice, the Port of the Future can be better described as the port which has achieved and is maintaining a balance in economic, environmental and social extent for the surrounding local region[15][16]. Moving to such a definition and considering that ports are strong catalysts for regional development, their optimisation, integration and seamless connectivity with the surrounding socio-economic area are key requirements.

To this end, and according to Deloitte Port services (2017), the Port of the Future has three considerable characteristics, which can provide the port of the future with the level of adaptability required to the increasingly changed (physical, economic and social) environment, namely the cooperation in both horizontal and vertical level, the innovation and digitalization and the sustainability. Having embraced the above, the vision of the Port of the Future ecosystem is twofold: on the one hand it is substantially increasing and extending the range of innovation possibilities and it is providing opportunities across the entire value chain (from seaside to port and landside) and on the other hand the desirable seamless infrastructure, port ecosystem connectivity and data handling can be more proactively come true toward a more sustainable and interoperable future.

Whilst ports are ripping for disruption in optimization processes, seamless connectivity and data handling and although disruptive technologies (such as IoT, 5G networks etc.) are considered as major driving forces, some of the already matured technologies and processes are not fully-fledged drive towards the Port of the Future vision, according to Trelleborg Marine systems (2017). For achieving a step closer to this vision, the PI is a newly introduced concept in port logistics, with the aim to provide the principles for making disruptive and emerging models more dynamic, towards improving the transportation of goods both environmentally, economically and socially speaking. The paradigm of the PI intends to substantially increase the flow of physical goods through open networks, protocols and the encapsulation of goods (Montreuil et al., 2012).

Under the PI vision, a large scale optimization process along with the development, customization, and deployment of proper emerging technologies can radically replace the deficit of efficiency in networks interoperability and operations with tangible positive effects on prices, time, urban congestion, pollution etc. (Crainic and Montreuil, 2016). To this end, PI can be considered a mean to improve the sustainability of logistics by fostering the seamless movements of goods in and out of ports and across the cities towards the Port of the Future vision[17].

2.2 Port-driven technological innovations

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[15]Port of the future: Explanatory Study, Deltares & WWF (2015)
https://www.deltares.nl/app/uploads/2015/12/Port-of-the-Future-report.pdf
[16] PIANC - IAPH EnviCom WG150, Sustainable Ports, A Guide for Port Authorities (2014)

[17] https://www.port-montreal.com/en/physical-internet-aut2015.html

A challenging task for port operators, is to make decisions regarding freight movement and other related matters such as asset management, without having information on how their choices may affect the entire transport system. There have been numerous efforts in the past to enhance information sharing and collaboration on vertical as well as on horizontal level, in order to increase operations efficiency. Today, collaboration enabled by new technological solutions, new logistics paradigm as provided by the PI as well as new business models, are creating a new business reality paving the way for well-coordinated and networked port logistics operations (Montreuil B., 2011).

The proposed framework comprises a set of port-driven technological innovations, which are expected to lead to an increased understanding of port and terminal requirements in order to be able to move towards a physically connected world. These innovations include:

i. The Truck Appointment System: This system aims to enhance the hinterland connectivity of the port with the surrounding urban space as well as optimise the use of trucks within the container terminal area. The aims are achieved by using developed solutions to increase data sharing and visibility between supply chain actors, which is one prerequisite in PI.

ii. The PORTMOD Module: This is a modelling tool focusing on operational efficiency. It will help port operations to plan container yard layouts such as optimal length of container rows and stacking heights. The tool uses historical data of container movements, and when the port operates with intelligent PI containers, the simulation model will benefit from accurate data.

iii. The RTPORT Module: It is a model-driven tool for real time control of port operations, and it uses emerging technologies in mobile communications (4G/5G) and Internet of Things. The module relies on availability of supply chain data of intelligent PI-containers and fast data processing, which enables improvements in container ground handling and helps to avoid inefficiencies.

iv. The Cargo Flow Optimiser Module: This module aims to minimise containers' waiting times at the port and improve current land infrastructure use by multiplexing vessels' estimated time arrival with data from the rail operators. This data sharing of different actors is a step towards open supply chain data in port, where PI relies.

v. The Predictor – Asset Management Module: This module will realise a powerful predictive analytics task by analysing the monitored data of port handling equipment. It will enable cost-efficient maintenance models for the handling equipment and prevent disturbances of operations.

3   Methodology

The proposed methodology will be implemented in three distinctive yet complementary phases. A stakeholder driven approach will be initially followed, considering the ports' and port-cities' main challenges.

3.1   Scenarios and requirements phase

The first phase of the approach will produce a classification of the port of the future stakeholders through a two-staged iterative participatory method: in the first stage, the 'Tier 1' stakeholders will be identified and classified, comprising the core port personnel, city authorities and logistics organisations immediately collaborating with the port. Next, the 'Tier 2' stakeholder list will be identified, namely an extended and comprehensive list of people and organisations involved and influencing the smart port-city ecosystem. By mapping and prioritising the stakeholder list, a set of personas will be identified, representing persons/roles that have a direct impact to or from the port-city operations within the surrounding urban space. Around those representative personas, the scenarios describing the implementation of the proposed modules in the LLs will be created via a two-stage process of scenario co-creation and description a) a hands-on, scenario co-design iteration implemented during local focus groups, organised in each LL, and b) a second iteration, that aims to enhance, refine and consolidate/document the co-designed scenarios produced during the first iteration. Phase I will conclude with deriving port requirements (technical, operational, societal, environmental, legal, security and other relevant) that will stem from the defined scenarios.

3.2 Technical design and development phase

This phase will cover the technical design and development and will implement the technical and societal innovations piloted and assessed in the LLs. Phase II will start with producing detailed technical specifications. The mapping will be reflected in a requirements-specifications traceability matrix that will clearly demonstrate the priority level for each specification and the components involved. The design and development of the components/innovations will be done in two iterations: i) The first iteration involves the implementation of proof-of-concept alpha versions of the technical components in a protected environment (the definition of alpha version per component will be included in the scoping documents). In parallel, this phase will produce a set of KPIs/metrics to be measured and assessed within each LL. ii). During this iteration, any tools, devices or components that are necessary for the final testing of the innovations in each LL will be deployed and full integration with existing IT infrastructure in each port will be implemented in real-life operating conditions.

3.3   Full-scale implementation phase

During this phase, real-life implementations will take place in each local LL setting described in section 3.1. Initially, a full set of solutions will be ready to be deployed, allowing complete testing, demonstration and results evaluation in the target operational environment.

The proposed methodology, follows a stakeholder driven approach, considering the ports' and port-cities' main challenges, in view of the major changes brought by ocean carriers and the shift to Industry 4.0 era. Within this approach, the innovations will be co-created with the ports after prioritising the port requirements and needs. The three complementary phases are expected to create better systems, taking into account the specific challenges faced in each local setting, related objectives of each port and the port's anticipated benefits.

4   Implementation approach

4.1   Living Labs

4.1.1 Port of Livorno

The Port of Livorno is a mid-size port, which is an ideal reference for implementing ICT solutions oriented to sustainable growth. It is taking part in the digital revolution around the maritime transport. The Port of Livorno, with CNIT of Pisa, is leading a deep digital revolution, making port industrial activities more efficient and safer. The main goal is to achieve a complete digitalization of port operations, through R&D and technology transfer.

The focus of the Livorno LL is represented by the implementation of a general cargo management system called RTPORT (Model Driven Real Time Control Module), based on the usage of disruptive and pervasive technologies (5G). This innovation proposes a complete and optimized system for managing the general cargo in relation to the vehicles available on the yard. The optimization that will be achieved, will concern: 1) loading/unloading phases of the general cargo, 2) distribution of the cargo into the storage area and its handling during loading phases on the ship, and 3) the choice of the most appropriate forklift for handling the cargo.
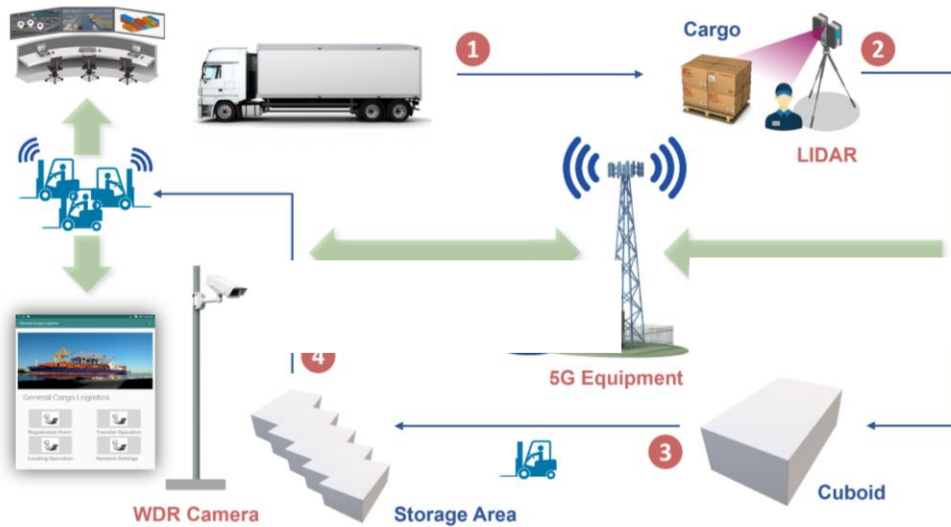
Figure 4: Flow Diagram.

The RTPORT tool, consists of a mobile network (5G), connecting smart sensors with cloud resources for optimized handling of general cargo compared to traditional human-driven communication. IoT devices such as HDR cameras and LIDARs will be used for cargo size measurement as well as goods localisation. In particular, the area where goods are stocked will be monitored by a set of cameras. Specific software will then be used to identify each object and its position. Local processing will be applied to run the distributed applications needed for image processing and pattern and context recognition while Artificial Intelligence processing, will support workers' activities to guide drivers and workers with real time Augmented Reality info.

The implementation of RTPORT provides a high level of automation for the general cargo management process that is an indispensable requirement to increase the visibility of the cargo in the intra-terminal operations. This is expected to be a fundamental part of the full visibility concept throughout the supply chain.

4.1.2 Port of Piraeus

Piraeus Container Terminal (PCT S.A.), is managing Piers II & III of the container terminal in Piraeus. The Company's main activities are the provision of loading/unloading and storage services for import and export containers handled via the Port of Piraeus, including cargos which use Piraeus only as an intermediary station of transport (transhipment cargo). The strategic location of Piraeus makes it an ideal port to be used as a hub for destinations in the Central and Eastern Mediterranean, as well as the Black Sea. The Piraeus container terminal is currently ranked 6th in terms of annual throughput among European container terminals.

The focus of the Piraeus LL will be on the Predictor tool which focuses on the development of a predictive maintenance tool for yard equipment in order to achieve Just in time (JIT) spare parts inventory. The Predictor tool will dynamically predict anomalies in port operations and reduce the total life-cycle cost of port assets, increasing its accuracy over time. To do this, an Artificial Intelligence model will be developed for predictive maintenance of the ports' assets. The model will aggregate similar data from different assets to determine recurring phenomena; calculate the impact of asset state changes on port inventory and compare events with patterns to detect anomalies. This learning approach helps to comprehend interactions of port agents and accurately estimates control measures' impact to operations. Coupled with advanced heuristic optimization algorithms to calculate nearly optimal control measures in quasi-real time, it will enable a Just-In-Time inventory and longer (re)use of port assets. At first, pre-processing of data and training of the AI model takes place. Then, using the network infrastructure, this data is transmitted and utilized to predict assets' breakdowns.

JIT inventory is one of the main methodologies used to enhance competitiveness through yard equipment availability, life-cycle extension and lead time reduction. However, implementing JIT has some challenges, e.g. lack of required information sharing or communication between stakeholders, insufficient sound action or planning system etc. Achieving JIT will enable the port to take advantage of Internet of Things (IoT) technology which has the potential to be used for acquiring data and information in real time to facilitate dynamic yard equipment planning and repairs. In addition, by better estimating the resources and the maintenance time the module will contribute to a fully interconnected system with better estimations between the relevant logistic entities, closer to the vision of PI.

4.1.3 Port of Valencia

The Port of Valencia, is the first port of the Mediterranean Sea in container cargo with an annual throughput in 2018 of 5.18M TEU. The Port of Valencia is considered as a mixed hub with balanced transshipment and gateway traffics and it is the first port for import/export container cargo in Spain with more than 2.35M TEU[18]. This figure of gateway traffic is translated into a huge pressure for its hinterland, which is mainly connected by road transport (approximately 93% of the container cargo) while the rail transport represents only the remaining 7%. To tackle this unbalanced hinterland connectivity, the LL of the Port of Valencia will focus on the implementation of new solutions to improve the efficiency of the road transport as well as boosting the railway transport for inland cargo.

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[18] https://www.valenciaport.com/wp-content/uploads/Bolet%C3%ADn-Estad%C3%ADstico-Diciembre-2018-PBI-1.pdf

The implementation of an advanced Truck Appointment System (TAS) to increase the efficiency of the delivery and pick-up container operations in the port terminals will be assessed in the Valencia LL. This Advanced TAS will count with predefined slots to perform operations at the container terminals but will also calculate in real time the Estimated Time of Arrival of the trucks to the port premises, increasing the information available for the stakeholders of the container supply chain. The ETA component relies on a machine learning model that learns the patterns in the recent location data from the trucks (e.g. peak hours, congestion, weather impact) and infers the arrival time at the port with a high accuracy.

In addition to the Estimated Time of Arrival of the trucks is computed dynamically offering a rescheduling capability to the system. By sharing information about available capacity for the port in real time it can improve the load rate of the trucks, reduce the waiting time and contribute to an interconnected system. The utilization of the system promotes multimodal solutions on one hand while on the other hand the efficiency of operations is increased. The system brings one step closer the vision of PI for an interconnected system with information about the capacity at various steps of the transportation flow.

4.1.4 Port of Haminakotka

Kotka Container Terminal (KCT) handles about 650.000 TEUs a year, one half of which are export containers (paper, pulp, sawn timber). Outbound products are transported mostly by rail to the stuffing warehouses located at the port, but significant share of cargo comes also by trucks from paper, pulp or sawn timber mills. In the stuffing warehouses, the products are stuffed to containers and shipped with feeder container ships to the main ports of North Sea. Therefore, in addition to moving containers, modularity questions of containerized cargo are integral parts of operations..

The aim of HaminaKotka LL is to define a roadmap to increase automation in a medium-sized port. Important part of this aim is to increase data sharing between different stakeholders and improve the use of the data. To achieve this aim, the PORTMOD simulation tool will streamline container handling operations in the container field. The tool is expected to evaluate the benefits of different container yard layout alternatives, especially for the cases where the port has major changes in its cargo flows.

The purpose of TAS tests is to link physical transports with information flows by increasing cargo data sharing between transport company and port operator. Adoption of TAS will improve visibility of pulp, sawn timber and paper transports between mills and stuffing warehouses, which simplifies port operator's ability to balance work force needs between different warehouses. This supply chain data sharing is also one step towards PI supply chain and hub in HaminaKotka LL.

4.1.5 Port of Antwerp

As the second largest port in Europe, the Port of Antwerp is an important transit port in Europe handling great volumes of international maritime freight. Antwerp is the biggest port area in the world. The central position of Antwerp provides its customers a vital link among biggest maritime and to Europe's centers of production and consumption. The Antwerp Port Authority seeks to achieve a better balance among the various modes of transport by switching to more

sustainable options: rail and inland shipping, where further growth is anticipated. Main problems/weaknesses existing in the port-city context include i) sub-optimal organization of pickup and delivery of containers due to schedule changes or delays of both ocean vessels or inland means of transport, ii) road congestion around the port and city area and at the CT gates, and iii) delays regarding discharging cargo and late booking of necessary equipment.

The Antwerp LL will be focused on demonstrating the advantages of the Cargo flow optimizer. Automatic Identification System (AIS) data from the Port of Antwerp management system, data from barges schedules at national level, data from railway operators in Belgium and the Netherlands, and contextual information, e.g. weather, will apply Big Data based advanced predictive and descriptive analytics coupled with optimization techniques, in order to perform cargo flow optimization and prognoses. The AIS data will be multiplexed with (big) data from an Automatic Number Plate Recognition (ANPR) network, the rail operators and barges ETAs so that cargo flows are streamlined aiming to minimize containers' waiting time at the port. Cargo flow prognoses for short-, mid- and long-term will be implemented for urban planners to optimize their infrastructure investment planning.

4.2   Expected impact

In terms of sustainable port development, the proposed framework aims to improve the terminal operations efficiency, maximize the use of the infrastructure and equipment and decrease operational costs as well as external costs derived from congestion, waiting and idle time. This will be primarily achieved via the Cargo Flow Optimization module, the TAS and a high-capacity mobile network, following forthcoming 5G standards. A significant increase up to 15% in service times for shipping companies as well as an increase of 10-15% in operational efficiency is expected. Furthermore, the PORTMOD and RTPORT modules, are expected to lead to a 5% reduction in the empty container runs, 10-20% reduction of operational and maintenance costs of the port spare parts as well as 30% reduction in the trucks and yard equipment idling. Regarding the data-driven opportunistic replacements of assets proposed by the Predictor module, more than 10% cost-rate improvements can be achieved compared to the classical failure-based or naïve age-based equipment replacement methods. In addition, the proposed framework aims for a lower environmental impact of port operations. In particular, a decrease of 15% in CO_2 emissions is expected as well as up to 10% reduction in the noise generated by trucks calling in the port to pick up or deliver containers. This will be achieved via the advanced TAS that is expected to improve links with the road traffic in the port vicinity by scheduling truck arrivals and reduce trucks' dwelling time before entering the port.

Furthermore, the innovations examined in this work can be viewed as complementary to understanding the benefits of the PI. The framework primarily aims to lead to an increased understanding of port and terminal requirements in order to be able to move towards a physically connected world. The framework is expected to raise awareness of the types of possibilities that PI may have on future transport logistics, and further assist port operators into understanding the potential benefits of PI applications for their business.

5   Conclusions and further research

The proposed framework aims to improve the terminal operations efficiency, maximize the use of the infrastructure and equipment and decrease operational and external costs derived from

congestion, waiting and idle times. A lower environmental impact of port operations is also expected to be achieved. Finally, the framework aims to improve links with the road traffic in the port vicinity as well as increase the modal split to greener transport modes, such as rail and inland waterways.

The innovations to be implemented within the proposed framework will contribute to the Port of the Future objectives regarding reduction of port's total environmental footprint associated with intermodal connections; the improvement of operational efficiency, optimization of yard capacity and increase of data sharing and information visibility; and the promotion on the innovation in the port-urban context. Some of these technologies, and in particular the RTPORT tool, the advanced TAS and the Cargo Flow Optimiser tool, aim to pave the way into interconnected port systems with information at various steps of the transportation flow. The interoperability between networks and IT applications for logistics represents the first step to follow in order to achieve the ambition of the PI concept: set up an open global logistic system founded on physical, digital and operational interconnectivity, enabled through encapsulation of goods, standard interfaces and protocols. The adoption and integration of smart infrastructures such as IoT devices and new disruptive technologies (5G) in supply chains will allow increasing the efficiency, effectiveness and control of supply networks.

Acknowledgements

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Big Data and Data Analytics for Ports of the Future, COREALIS

Georgios Tsimiklis[1] , Amalia Nikolopoulou[1] , Carlos Morillo[2], Jihed Khiari[3], Angelos Amditis[1]

Introduction

COREALIS proposes a strategic, innovative framework, supported by disruptive technologies, including IoT, data analytics, next generation traffic management, for modern ports to handle future capacity, traffic, efficiency and environmental challenges. Through COREALIS, the port will minimize its environmental footprint to the city, it will decrease disturbance to local population through a reduction in the congestion around the port. COREALIS proposes a bunch of solutions for the ports based on big data analytics: i) a predictive model for maintenance for the port of Piraeus   ii) a cargo flow optimizer based on historical and current data for hinterland connection applying at the Port of Antwerp iii) an optimized Truck Appointment System based on an Estimated Time of Arrival through real time data.

The solutions are contributing to the digitization and smart objects creation , the movement of containers and their interconnectivity and the creation of a multimodal transfer system , bringing one step closer the vision of Physical Internet for logistics .

This research has been conducted as part of COREALIS which has received funding by European Union's Horizon 2020 research and innovation programme under Grant agreement No. 768994.

Objectives

- Reduce the port's total environmental footprint associated with intermodal connections and the surrounding urban environment for three major transport modes, road/truck, rail and inland waterways
- Embrace circular economy models and Improve operational efficiency without additional infrastructural investments
- Identify synergies between Physical Internet and synchro modality for the movement of freights by inducing a positive modal shift from roads to rails and inland waterways

Predictive maintenance

- **Predictive Maintenance (PdM)** relies on data about the equipment (e.g. status and past breakdowns), e.g. the trucks and cranes in a port, to predict when maintenance should be performed. Using the network infrastructure, this data is transmitted and utilized to predict assets' breakdowns.
- The figure below describe the workflow of predictive maintenance for the ports' assets.

Equipment Data

Maintenance Data

PdM. Schedules

Overview of Assets

Optimizing Purchases

Collecting and Transmitting Data   Preprocessing Data and Training of AI Model   Predicting Breakdowns   Utilizing Predictions
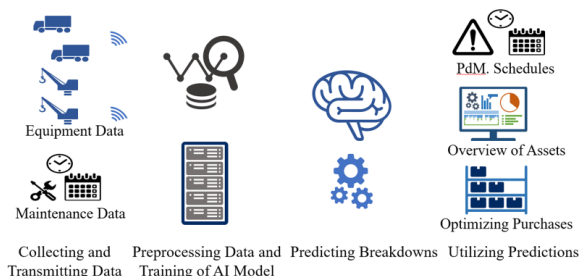
- Contrary to preventive/routine maintenance, predictive maintenance provides the *"right information at the right time"* which allows:
  - ❖ Cost reduction of routine maintenance
  - ❖ Reduction of loss of service and its cost, i.e. higher reliability
  - ❖ Productivity Improvement
  - ❖ Smarter Inventory Management

By better estimating the resources and the maintenance time it contributes to a fully interconnected system with better estimations between the relevant logistic entities , closer to the vision of Physical Internet.

Cargo Flow Optimiser

Terminal input

- Terminal occupancy
- Containers arriving / leaving time stamp
- Inland mode of transport expected

Current transportation environment

- Current inland connections
- Capacity of transport connections

- Prediction availability of inland transport routes according to:
  - -Transportation time
  - -Cost of the route

Optimization model

- **Proposition of new transport shared services on-demand**

The ambition of the European Commission aim is to shift 30% of road freight transport by 2030 to environmentally friendlier modes that have lower societal impact, such as rail and inland waterways . This shift should reach 50% by 2050. Therefore, it is necessary to introduce innovative solutions that would support optimal integration of different transportation modes and their cost-effective use

The Cargo Flow Optimizer (CFO) will allow to share the same transportation service for different carriers and types of goods promoting the reduction of social economic, social & environmental costs.

The Cargo Flow Optimizer is defined to promote different carriers to use the same mode of transport, issue that can be understood as one step further on the Physical Internet.

Enhanced TAS

An enhanced Truck Appointment system where the truck drivers can pre-book available slots at the ports . In addition the Estimated Time of Arrival of the trucks is computed dynamically offering a rescheduling capability to the system .

By sharing information about available capacity for the port in real time it can improve the load rate of the trucks , reduce the waiting time and contribute to an interconnected system .

The utilization of the system promotes multimodal solutions on one hand while on the other hand the efficiency of Operations is increased . The system brings one step closer the vision of Physical Internet for an interconnected system with information about the capacity at various steps of the transportation flow .

System provides the available slots based on the internal capacity.

The Truck driver books a slot in the system based on his estimated time of arrival and the availability.

Prediction of the trucks' estimated time of arrival (ETA) allows for a dynamic allocation of slots by the appointment system . The ETA component relies on a machine learning model that learns the patterns in the recent location data from the trucks (e.g. peak hours, congestion, weather impact) and infers the arrival time at the port with a high accuracy.

Conclusions

COREALIS innovations are aiming for increased economic, environmental and societal efficiency . The TAS can support hyperconnected logistics as all the trucks are identified and synergies among them are supported . The Cargo Flow optimizer is proposing a multimodal transport system which in parallel promotes the sharing of resources among the various providers by reducing the empty containers problem. Whereas all assets of the port will be continuously evaluated with a predictive maintenance system , aiming to better monitor the resources of the port . All in all the port will minimize its environmental footprint to the city and decrease disturbance to local population through a reduction in the congestion around the port.

Routing and Synchromodality - 9th July 2019 15:30 – 17:00

Conceptual Model of a Decentralized Transport Organization in the Increasingly Uncertain Transport Environment of the Physical Internet

Georg Schett[1], Georg Brunnthaller[1], Christina Hess[2] and Stefanie Kritzinger[2]

1. Fraunhofer Austria Research GmbH, Theresianumgasse 7, 1040 Vienna, Austria
2. RISC Software GmbH, Softwarepark 35, 4232 Hagenberg, Austria

Corresponding author: georg.schett@fraunhofer.at

Abstract: In recent literature, it is indicated that freight transportation via trucks is still insufficient in terms of efficiency and sustainability. Reasons for such inefficiency are poor utilization of capacities (drivers, trucks, containers etc.), high shares of empty mileage, as well as lacking flexibility when responding to an increasing market volatility. It is assumed that future transport systems will have to deal with higher urgencies and with smaller lot sizes. In course of this, the assignment of transport orders will be characterized by increasing spontaneity and an uncertain planning environment for logistics service providers.

Thus, the objective of this paper is to present a conceptual model that combines a dynamical price prediction model and an approach for the dynamical assignment of freight flows through a network of hubs. Due to a constantly changing environment (e.g. demands, capacities, and/or prices), freight assignment will be updated continuously. As a result, the operational freight flow will evolve over time and choose the most cost-efficient route through the network by dynamically bundling and unbundling itself.

After a brief introduction on recent Physical Internet (PI) research, this paper will give a description of the proposed model, for a continuous and dynamic freight flow assignment. Eventually, we will discuss the results and conclude with the implications on our research.

Keywords: capacity management, dynamic pricing, freight transportation planning, Physical Internet

1   Introduction

In recent literature, it is indicated that logistics networks are still insufficient in terms of efficiency and sustainability with respect to economical, ecological and social aspects (Montreuil, 2011). To overcome these challenges, Montreuil (2011) exploits the Digital Internet metaphor to develop the Physical Internet (PI) vision. With the characteristics of that vision, he tries to address the current challenges of the logistics system. Since these days, the idea of the PI in particular was further developed by Montreuil himself (Georgia Tech, USA), E. Ballot (Mines ParisTech, FR), T. Crainic (Université du Quèbec à Montréal, CAN) and Y. Sallez (University of Valenciennes and Hainaut-Cambrès, FR) (Montreuil, 2012; Montreuil et al., 2012a; Montreuil et al., 2012b; Sallez et al., 2015; Sallez et al., 2016; Crainic and Montreuil, 2016; Domanski et al., 2018). Since 2004, several publications have outlined the general concept of the PI; since 2013, approaches with application character have been published (Domanski et al., 2018). Main research areas are the standardization of logistical units (Ehrentraut et al., 2016; Sallez et al., 2016), the sharing of resources and the operational

handling and control of freight flows (Domanski et al., 2018). Further research interests lie in urban logistics (Crainic and Montreuil, 2016) and the design of suitable terminal infrastructure and processes (Sallez et al., 2015; Walha et al., 2016).

In our research, we focus on rising uncertainties in the assignment of transport requests in transport networks. Firstly, we will outline challenges going along with a dynamic transport environment. Furthermore, we will analyse recent PI literature on how the addressed challenges are solved. Moreover, we will give a description of the proposed model for a continuous and dynamic assignment of transport requests, followed by an exemplary application of the model. In a last step, we will give a conclusive outlook on our main findings and our next research steps.

2 Problem Statement

Due to increasing volatility in the freight transport market, the transport sector is developing ecologically, economically and socially unsustainably:

- Typically, a high share of fixed costs characterizes the cost structure of carriers (Lohre, 2007). Additionally, capital coverage (i.e. capital assets that are covered by equity and long term loans) is low. Therefore, under- and overcapacities resulting from higher probabilities of demand fluctuations directly increase the risk of liquidity shortages and/or lost sales (Wittenbrink, 2014).
- In the Austrian freight transport sector, greenhouse gas emissions (GHG emissions) have been rising more than 60% since 1990. In 2015, the transport sector was responsible for approximately 28% of the Austrian GHG-emissions, which equates 22.1 Mio. t CO2-Equivalent (Umweltbundesamt, 2017). Especially road freight transportation contributes to that significant rise. Since 1990, GHG-emissions in road freight transportation have been rising to 128%; between 2014 and 2015, they still rose for more than 1.4%. In 2015, road transportation was responsible for 27.7% of total GHG-emissions. Specifically, road freight transportation contributes to 12.1% to Austrian GHG-emissions (Umweltbundesamt, 2017). Similarly, the transport sector is responsible for 33.1% of the energetic end consumption and is 80% dependent on oil products as primary energy source (BMWFW, 2015). In a dynamic transport environment, logistics service providers tend to use the road instead of the more ecologically friendly rail due to high flexibility requirements (Bühler, 2006; Wittenbrink, 2014, pp. 9–10). Additionally, these means of transport are still utilized in an insufficient way (Bundesamt für Güterverkehr, 2017). As modal shift and the high use of transport capacities directly influence ecological efficiency (Keller and Helmreich, 2011), an increasingly dynamic transport environment contradicts such development.
- The availability of handling and driver personnel is essential for efficient freight transportation. Many transportation and logistics service providers find it increasingly difficult to fill open positions with appropriate staff (Wittenbrink, 2014). Furthermore, logistics service providers find themselves in a public debate over low pay and poor working conditions. Low pay and a high number of on-call hours are unattractive especially for truck drivers (Lohre et al., 2015). Uncertainties in necessary deployment, poor personnel-planning and high flexibility requirements for the staff contribute to a reduction of normal working relationships, enforce precarious employment situations and thus lead to personnel shortage (Lohre et al., 2015).

SteadieSeifi et al. (2014) also indicates an ongoing trend of higher flexibility and increasing delivery urgencies in the logistics service sector. Additionally, a concept asking for high flexibility from transport service providers is Sharing Economy. From a microeconomic point

of view, companies acting in such an environment have business concepts characterized by the shared and temporary use of resources that are not permanently required (Puschmann and Alt, 2016). Therefore, carriers can apply for desired transport orders and shippers can bid for available resources without having to make long-term contracts. This leads to a highly dynamic and hardly predictable environment within the concept of PI (Qiao et al., 2016). Additionally, increasingly dynamic and digitized value chains place new requirements on logistics operators. Due to the digitization value creation, networks will be more segmented, freights-sizes are decreasing and quality requirements (e.g. punctuality, speed) are increasing (BMVIT, 2016; Scheucher, 2014). Another trend having effects on the freight transport sector is a visible shift of the structure of freight. Freight is increasingly becoming of high value, high quality, low volume and rather low weight (König and Hecht, 2012). Consequently, future transport systems will have to deal with higher urgencies of shipments (higher value of goods, same day delivery) in smaller lot sizes (individualization, lot size 1). Therefore, the assignment of transport orders is characterized by an increasing volatility and spontaneity leading to an uncertain planning environment for logistics service providers.

In summary, the mentioned changes tend to lead to economically, ecologically and socially unsustainable developments. Time consuming transport mode choices and implementations of bundling concepts are more unlikely to be implemented due to rising transport urgencies. Rising volatility of freight transportation demand leads to under- and overcapacities in means of transportation leading to lost sales and liquidity shortages at logistics service providers. Furthermore, a lack of planning competencies in an increasingly uncertain transport environment results in an unsecure work environment for drivers and logistics personnel. Our research aims to tackle the mentioned challenges by providing a solution in terms of a model that allows the dynamical planning of freight flows through a network of hubs and the constant surveillance of these freight flows. The approach helps to gain transparency over planned freight flows and helps to realize economic, ecological and social potentials.

3   Literature Review

In terms of a PI literature review, relevant publications regarding concepts of vehicle routing, routing of goods and dynamic pricing strategies in recent PI literature are considered. In general, planning problems are clustered in operational, tactical and strategic planning levels (Caris et al., 2008; Crainic and Bektas, 2007; Hoff et al., 2010; SteadieSeifi et al., 2014). A synonym for the strategic planning level is "system design" (Crainic and Bektas, 2007); long-term decisions are made, as for the number and locations of terminals and the capacity level of (transport) equipment. On tactical planning level, three essential planning domains are described: The Network Flow Planning (NFP) problem results in a plan, how goods are routed through a defined network. The Service Network Design (SND) problem defines what kind of service (type, frequency and quantity) is provided between network elements (SteadieSeifi et al., 2014). Additionally, decisions on the capacity level of labour are generally summarized on the tactical planning level (Caris et al., 2008). On operational level, the optimal means of transportation is selected for a pending transport order and the vehicle routing is made for the set of transport orders assigned to a means of transportation (Hoff et al., 2010). For the taxonomy of the analysis of the literature review, we follow the general structure of Crainic et al. (2017). We focus on the following questions:

- Addressed stakeholder: Who is the focused stakeholder of the proposed model?
- Objective: What kind of added value does the model aim for?
- Addressed objects: What are the focused objects considered within the defined model?
- Addressed modes: What transport modes are taken into account?

- Predictive modelling: Are there any forecast procedures proposed?
- Demand modelling: How is the initial data for the model defined?
- Application modelling: How do changing framework conditions influence the model?
- Period Type: Is the planning horizon discretized and how many planning periods are considered?

Two papers related to dynamic pricing in the PI are identified. Qiao et al. (2016) investigate how bidding prices for requests based on an auction mechanism should be determined by carriers regarding less than truckload orders in the PI. Thus, two pricing strategies for a one-leg problem are taken into consideration: a unique bidding price and a variable bidding price. The objective of each of these strategies is to maximize the carrier's profit. They use a dynamic programming model. After all, they conclude that both strategies could be used as a decision making tool, especially since the two approaches both lead to very comparable results. This research issue is further studied by Qiao et al. (2017). They extend the work mentioned earlier by taking a multi-leg problem and corresponding routing of vehicles into account. Furthermore, besides request selection and pricing strategies for less than truckload capacity of a carrier, the possibility of having full capacity to load is investigated. Again, the objective of the strategies is to maximize the carrier's profit. However, restrictions of the model are that a carrier could only select one type of request to bid for as well as static request quantities in the hub. They compare two scenarios – on the one hand taking full capacity and on the other hand partially loaded vehicles into account. Altogether, they concluded that the main difference of these scenarios is the way future request information is taken into consideration. Regarding carriers with fully utilized capacity, only the hub the carrier will arrive next is considered, while all hubs between the original and destination hub of an LTL utilized vehicle are taken into account. A limitation of the paper is that the request quantity emerging in each hub is static and not dynamically solved. Thus, the very dynamic environment of logistics services is not fully described by this model.

The remaining results of the literature research are related to routing of either vehicles or goods in the Physical Internet. In the course of the study by Montreuil, Hakimi et al. (2012) a mobility web simulator was developed. The purpose of this simulator is to plan various tasks of the supply chain manager, transport agent and routing agent. Thus, it is realized via a multi-agent based model. Furthermore, the task of a routing agent in the simulator also includes vehicle routing of trucks and trains. This vehicle routing problem is approached via a simple two-step method. First, fixed costs are assigned to each route between nodes. Second, a shortest path algorithm is executed from origin to final destination. Altogether, they come to the conclusion that the implemented PI-scenario results in shorter but yet more hopping trips as well as a significantly lower overall travel distance compared to the current logistics network. The paper of Furtado (2013) deals with a simulation for a decentralized transport planning and thus vehicle routing within the PI. Since the network is decentralized, each hub plans the route for a vehicle to the next hub. The trucks are linked to single hubs and hence have to travel back to those after delivering. In terms of vehicle routing optimization, the objective function is to minimize the total costs. Additionally, the possibility of container consolidation was also taken into account. From the obtained simulation results they concluded that consolidation reduces overall costs of logistics network and leads to an increase in efficiency regarding empty mileage as well.

Sarraj et al. (2014) is currently the most cited article related to PI. It deals with the definition of transportation protocols with respect to the Physical Internet, which includes the definition of new container loading, routing and consolidation protocols in that context. Regarding the container routing not only trucks, but also trains were considered. Moreover, the objective function of the routing algorithm is to minimize besides the costs also the time and environmental impact. Furthermore, in terms of solving the vehicle routing problem the A*

heuristic for calculating the shortest path for each destination at each hub is used. From the obtained results, they deduced that the fill rate of transportation capacity has significantly increased. Moreover, the implementation of the PI concept into the observed network leads to a CO_2-emission reduction of 60% due to a significant share of rail transportation. Consequently, also the costs are lower than in the current logistics networks.

Moreover, Yang et al. (2017) investigated the resilience of freight transportation – trucks and trains are considered – with respect to the Physical Internet. Thus, they implemented a VRP regarding the hub disruptions with the help of dynamic and resilient routing protocols. The objective function of the VRP does not only imply cost minimization, but also reduction of CO_2-emissions and the overall travel time of the goods. Again, a multi-agent simulation model was implemented as well as the A* heuristic for solving the VRP. Overall, Yang et al. deduce from their simulation results (4.3% of additional costs, an increase of 9.6% of CO_2-emissions and 1.83 hours of delay in the worst considered case of disruption), that PI can be seen as a resilient transportation system. Other PI literature is not described in this literature review as it does not fit into the problem statement or the taxonomy described above.

Table 1: Other reviewed PI Literature

Author	Title
Ballot and Montreuil (2012)	Analysis of the Physical Internet vs. supply chains
Meller et al. (2013)	Functional Design of Physical Internet Facilities: A Road-Rail Hub
Oktaei et al. (2014)	Designing Business Models for Physical Internet Transit Centers
Rouges and Montreuil (2014)	New interconnected business models to reinvent delivery
Montreuil et al. (2015)	Modular Design of Physical Internet Transport, Handling and Packaging Containers
Pan et al. (2015)	Perspectives of inventory control models in the Physical Internet
Crainic and Montreuil (2015)	Physical Internet Enabled Interconnected City Logistic
Gasperlmair et al. (2016)	Go2PI - Practically proved steps to implement the Physical Internet
Maslarić et al. (2016)	Logistics Response to the Industry 4.0. The Physical Internet
Colin et al. (2016)	A proposal for an open logistics interconnection reference model for a Physical Internet
Ounnar and Pujo (2016)	Holonic Logistics System: a novel point of view for Physical Internet
Pan et al. (2016)	Physical Internet and interconnected logistics services
Venkatadri et al. (2016)	On Physical Internet logistics: modeling the impact of consolidation on transportation and inventory costs
Fazili et al. (2016)	Physical Internet, conventional and hybrid logistic systems. A routing optimisation-based comparison using the Eastern Canada road network case study
Pal and Kant (2016)	F2π: A physical internet architecture for fresh food distribution networks
Simmer et al. (2017)	From horizontal collaboration to the physical internet - a case study from Austria

Zhong et al. (2017)	Big Data Analytics for Physical Internet-based intelligent manufacturing shop floors

Overall, the main part of the papers regarding concepts of vehicle routing, routing of goods and dynamic pricing strategies in the PI focus on modelling and solving vehicle routing problems. Additionally, two research papers deal with pricing strategies of freight transportation in the PI regarding not only a one-leg but also a multi-leg problem As a result, to the best of our knowledge, there is no modelling approach for a dynamical and continuous assignment of transport requests in the context of the PI. We have not found a model that allows a continuous surveillance of freight assignments to carriers and a dynamical update of these assignments under consideration of changing framework conditions. Therefore, freight forwarders are not able to identify available capacities within the network and do not continuously rearrange the assignment of freight due to a constantly changing transport environment (e.g. demands, capacities, and/or prices). Finally, they are not able to constantly bundle and unbundle freight transport orders, which leads to poorly utilized transport capacities, unsustainable transport mode choices, under- and overcapacities as well as spontaneous and socially unsustainable working conditions.

4 Conceptual Model

We introduce a conceptual model for dynamically and continuously (re-)assigning transport requests to carriers within an abstract network of origins, destinations and hubs. The objective is to reduce costs and GHG emissions by dynamically bundling transport requests and fully utilizing transport capacities. More specifically, the underlying problem can be described as the following: Given a transport network consisting of a set of customers and an arbitrary number of transshipment points, a set of transport requests has to be assigned to transport routes such that all goods are picked up at their origin and delivered at their destination at minimal costs.
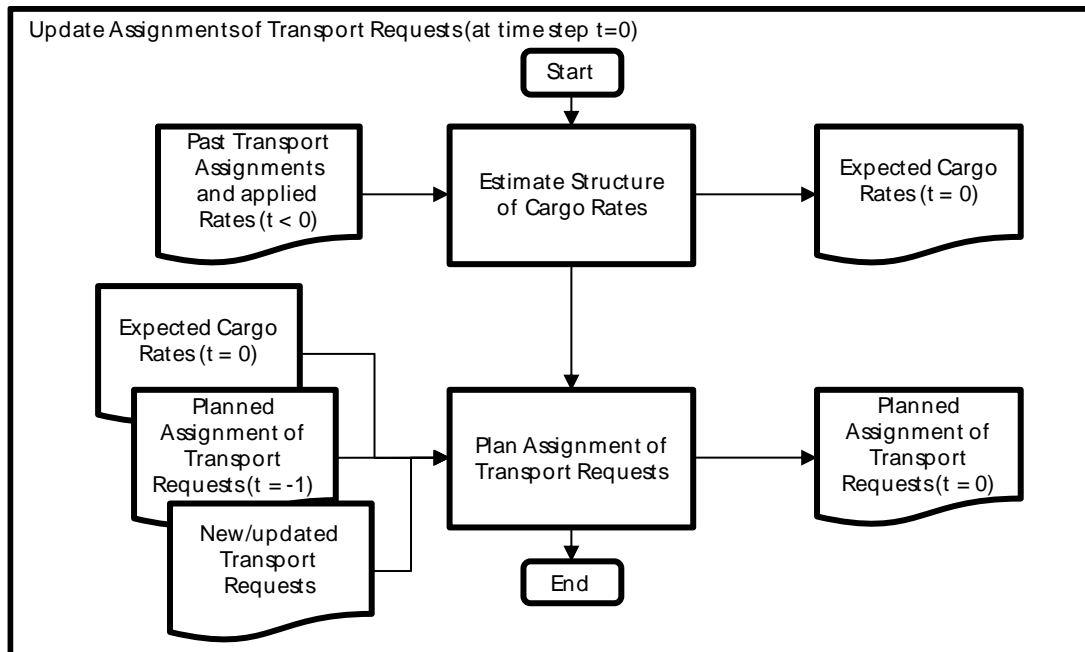
Figure 5: Approach to update planned assignments of transport requests continuously

Thereby, the assigned carriers have to service each customer within the given time windows and the cargo may not exceed the maximal transport capacity of the carriers. In addition, new requests are dynamically added to the system and framework conditions (e.g. time windows) are changed. As a result, the assignment has to be updated continuously. The approach should

help to fully utilize available capacities, reduce GHG emissions and to minimize the overall transport costs. The proposed model is defined as a multi-step approach. It consists of a model to estimate the structure of expected freight rates within a transport network, a model to (re-)assign transport requests and a model to continuously update the planned assignment of transport requests. Schematically the approach is depicted in Figure 5.

The continuous application of the model results in an updated plan of assignment of transport requests. The following components of the model are described in this chapter:

- Estimate structure of cargo rates: A pricing model evaluates the expected costs of different transport variants between origins, destinations and hubs in an abstract transport network.
- Assign transport requests: A routing model optimizes the assignments of the transport requests in order to generate cost minimal freight flows through the network.
- Update assignments of transport requests: A planning algorithm continuously updates the transport routes of all requests when new transport requests are added or framework conditions are changed (e.g. time windows).

4.1 Estimate Structure of Cargo Rates

The first component of the model is a transport-pricing model. To optimize the assignment of transport requests, we want to estimate expected transport costs for each request. In order to do so, a model describing expected freight rates of transports between all relevant locations (e.g. origins, destinations, hubs) as well as individual framework conditions (e.g. type of freight, fill rate, urgencies) is needed. Depending on the respective use case, a suitable pricing model has to be developed. Several formulations can be found in literature:

Zhang et al. (2015) consider the case of a third-party-logistics provider that provides warehousing and transportation services. They developed a stochastic nonlinear programming model to find the optimal freight rates for different delivery dates considering the provider's holding cost and available transportation capacity.

Budak et al. (2017) developed a model for forecasting the spot market prices. They introduced two methodologies, a quantile regression model and an artificial neural network, to estimate the transport costs between two locations depending, among other things, on the distance, the freight type, the possibility of a return load from the arrival town and the tonnage.

In section 5.2, we present a two-stage regression model for the use case of a freight forwarder, specialized on arranging transports from Scandinavia to South-East Europe. Thereby, we use similar parameters as Budak et al., but introduce a new way tonnage is included in the model.

4.2 Plan Assignment of Transport Requests

The second component of the model is the optimized assignment of transport requests to carriers in a given network under consideration of the estimated cargo rates. Given is a set of customers and a list of transport requests from origins to destinations. The objective is to find cost minimal freight flows, in order to fulfil all transport requests under consideration of a certain transport demand for each request. Therefore, the set of transport requests is assigned to a set of carriers. The cost of each transport is determined by a transport pricing model of section 4.1.

For each customer, time windows are given determining pickup and delivery times. It is possible to transport multiple requests by the same carrier, if the transport capacity of the carrier is sufficiently large. It is also possible to transship the cargo at certain transshipment points as well as to organize groupage or distribution traffics.

The problem described can be classified as Pickup and Delivery Problem with Transshipment (PDPT). Cortés et al. (2010) introduced a mixed integer-programming formulation of the problem, but as the problem is NP-hard (Rais et al., 2014), finding the optimal solution is computationally not efficient.

Therefore, heuristic approaches were developed for finding a reasonable good solution within acceptable time limits. Qu and Bard (2012) and Masson et al. (2013) proposed Large Neighbourhood Search (LNS) algorithms to solve the problem efficiently. Danloup et al. (2018) extended their idea and introduced a Genetic Algorithm (GA).

4.3 Update Assignment of Transport Requests

The third component of the model is an algorithm to continuously update the planned assignment of transport requests to carriers. Therefore, the estimation of cargo rates as well as the planned assignment of transport requests is continuously re-evaluated. Whenever a new transport request is added to the existing plan of freight flows or other framework conditions change (e.g. time windows), the planned assignments are updated. Past requests as well as new requests are recalculated under consideration of relevant constraints (e.g. fixed time windows) and expected cargo rates (see section 4.1).

The model enables the freight forwarder to evaluate the transport costs of newly added requests and changing framework conditions (e.g. time windows) by comparing the overall costs of different transport bundling and unbundling alternatives:

- Variants of combining the newly added transport request with past transport requests.
- Variants of using one or more transshipment points as well as implementing groupage (collecting one transport order after another) or distribution tours (delivering one transport order after another).
- Variants of alternative time windows at the origins and/or destinations.

5 Application of the Model

In the upcoming section, we apply the proposed conceptual model to a use case of a freight forwarder, specialized on arranging transports from Scandinavia to South-East Europe with a central transshipment point (hub) in Budapest, Hungary.

5.1 Case Study: General Classification of the Available Data Set

The available data set consists of 8 158 full truckload (FTL) and less than truckload (LTL) transport orders between the years 2015 and 2017. It contains information about the carrier selected, assigned transport orders to each transport, pick-up and delivery due dates and locations as well as the type of cargo. Additionally, past transport costs per transport order are given.

To generalize and abstract the model, we cluster each location to its corresponding NUTS3-region (French: "Nomenclature des unités territoriales statistiques"). NUTS is a geocode standard from the European Union for abstracting European countries into smaller regions for statistical purposes. For countries like Bosnia-Herzegovina or Serbia, which are not member of the European Union, we define these regions manually. As an estimate for the travel distance we use the distance between the centers of the corresponding NUTS3-regions.

For clustering the types of cargo, we used the NACE classification of the European Union (French: "Nomenclature statistique des activités économiques dans la Communauté européenne"). According to NACE the transport orders are associated with the categories C17 (Manufacture of paper and paper products) and C24 (Manufacture of basic metals). Depending on the type of goods, either the length or the weight is the restricting factor regarding the

maximal transport capacity. Products from the metal industry sector are usually restricted by their weight, while for paper products usually the size of the products restricts the maximal transport capacity.

According to the type of goods, we defined a degree of loading per transport order. The degree of loading is described by the percentage of the restricting factor related to an FTL transport order. Based on that definition, we call a transport order a FTL transport order, if the degree of loading is greater than or equal to 95 %. If the degree of loading is less than 95 %, it is defined as a LTL transport order. The considered data set contains 1726 LTL transport orders, what corresponds to 21.2% of all transport orders.

5.2 Estimate Structure of Cargo Rates: A Two Stage Regression Pricing Model

Based on the data set and the defined classifications, we developed a regression model to estimate cargo rates for the assignment of transport orders to carriers. For the estimation of cargo rates we identify significant attributes similar to Budak et al. (2017).

We propose a two-stage regression model. Firstly, we fit a regression model with using FTL transport data and their significant attributes only. After that procedure, in a second stage, we take the degree of loading for LTL transport orders into account. In this way, we overcome the problem that some interaction terms of the degree of loading with other attributes (e.g. distance) have a significant effect on the cargo rates.

5.2.1 First Stage: Cost Model for FTL transport orders

The first stage of the regression model for estimating the cargo rates of FTL transport orders includes the following significant attributes:

- Year and quarter variables: Dummy variables for the year and the quarter in which the transport has taken place to account for the overall seasonal and annual change of transport costs.
- Cargo type: Dummy variables indicating the type of the cargo (see NACE classification).
- Truck driver's country of origin: Two dummy variables indicating whether the country of origin of the truck driver matches the country of the start respectively the endpoint of the tour. This is something we were told by experts working in the transport sector that it might have a significant effect on the transport pricing.
- Transshipment: Dummy variable, which is equal to 1, if the freight was transshipped.
- Way stops: Number of way stops of the tour other than a transshipment point.
- Distance between NUTS regions: Estimated travel distance using distance between the center points of the NUTS regions.
- Distance between NUTS regions squared: Square of the estimated travel distance.
- Start and end region: Dummy variables for each NUTS region indicating in which region the start and the endpoint of the tour is. These variables are used to account for the fact that transports to or from certain regions may defer in price due to the lack of return loads or due security reasons.

The coefficient of the travel distance is significantly positive while the coefficient of the squared distance is significantly negative. This implies that the impact of the change in distance on the transport costs becomes smaller the larger the travel distance is. Finally, the country of origin of the truck driver has an effect on the cargo rate: If it matches the country of the start respectively the endpoint of the tour, the transport costs become significantly lower. Obviously, carriers are willing to transport goods for a lower rate, if they have the option to start the tour at home or to return home.

Resulting from our analysis, neither the weekday of pickups or deliveries nor the transport duration has a significant effect on the cargo rates: The duration may be described by the distance assuming the average speed is similar on different routes. The fact that weekdays of pickups and deliveries have no significant effect on freight rates may coincide with the fact that customers do not have a clear preference regarding these weekdays. A fact, confirmed by the logistics experts of the application partner as well.

5.2.2 Second Stage: Accounting for the Degree of Loading

As we have little options, when it comes to bundling and unbundling FTL transport orders, we are interested in the LTL transport orders in the data set. These transport orders may be carried out as direct deliveries (direct transport from origin to destination), they may be collected in groupage tours (collect one transport order after another) and delivered in distribution tours (deliver one transport order after another) or they may transshipped at the transshipment points (unload and load transport orders).

We generalize cargo rates for LTL transport orders by performing a second regression analysis on the actual cargo rates using the following attributes:

- Predicted FTL costs of the first stage multiplied by the degree of loading
- Predicted FTL costs of the first stage multiplied by the square of the degree of loading
- Distance (between NUTS regions) multiplied by the degree of loading
- Distance (between NUTS regions)

The analysis is performed using the data set of LTL and FTL transport orders resulting in the coefficients shown in Table 2.

Table 2: Coefficients of LTL Model (Second stage)

pred. costs * degree of loading	pred. costs * degree of loading²	distance * degree of loading	distance
1.4078	-0.4066	-0.0820	0.0825

These results are consistent as the estimated costs of LTL transport orders (second stage model) converge towards the estimated costs for FTL transport orders (first stage model) when the degree of loading approaches 1. As the coefficient of the predicted costs times the square of the degree of loading is negative, the marginal costs for an LTL transport become lower with an increasing degree of loading. Furthermore, the predicted costs increase with a longer travel distance. However, this effect diminishes with an increasing degree of loading.

The results of the case study are promising: The median absolute prediction error for the whole data set, estimated by cross validation, is 3.42 %; the third quartile of the absolute prediction errors is 7.08 %. The median absolute prediction error for LTL transport is 10.27% compared to 3.04% for FTL transport orders. A test calculating the second stage separately for LTL transport orders did not significantly improve the results.

5.3 Plan Assignment of Transport Requests: Solving a Pickup and Delivery Problem with Transshipments

To determine the most cost efficient way to assign transport orders to a set of carriers, we solve a pickup and delivery problem with transshipments (PDPT) proposed by several authors in chapter 4.2. However, since the derived cost function of chapter 5.2 is cubic (the travel distance as well as the degree of loading of a truck depends on the route of the truck), exact algorithms cannot be applied to solve the problem efficiently. Therefore, we integrated our pricing model

into the genetic algorithm proposed by Danloup et al. (2018). Schematically, the approach is depicted in Figure 6: Three transport orders are planned to be shipped directly from several origins to several destinations. (Request A from location 1 to location 2, request B from location 3 to location 4 and request C from location 5 to location 6). Furthermore, each transport order's time windows are defined, describing pickup and delivery due dates. Two options for transshipments are labeled with "T".
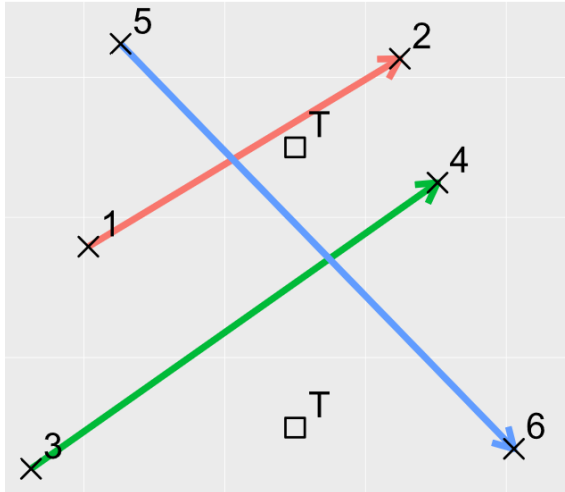
Figure 6: Illustration of the initial scenario

Solving the PDPT initially, each transport order is assigned to a direct delivery transport, as their framework conditions do not allow any other solution. (Request A by carrier "Red", request B by carrier "Green" and request C by carrier "Blue")

5.4   Update Assignment of Transport Requests

However, as framework conditions and the number of requests in the system is constantly changing, the sequence of modelling cargo rates and assigning transport requests is applied iteratively. By updating the assignment of transport orders, the freight forwarder is able to quantify the costs of a new request. Furthermore, the forwarder is able to evaluate changing time windows. As a result, he can generate a discount for altering or changing the time window of pickup and delivery due dates; new options for bundling and unbundling are occurring and he can carry out the transports more efficiently. The total travel distance of the used means of transportation decreases and their utilization increases.

In Figure 7 a schematic example of a changing number of transport requests and changing framework conditions (time windows) is shown. In figure 3a, only three transport requests need to be fulfilled. As indicated earlier, the best solution is, to carry out all transports separately. The estimated overall transport costs at this are 25.36 (for demonstration purposes, in this schematic example all cost figures are represented by the sum of the overall travel distance).

Next, a new transport request is added to the system and the assignment of all transport requests is updated. The result is shown in the figure 3b: Two trucks pick up requests from location 5 and 7 and deliver it to a transshipment point. From there, a single truck delivers these requests to their respective destinations 8 and 6. Due to the bundling, the transport costs are reduced to 31.90, compared to 32.93 if all transports would be carried out separately.
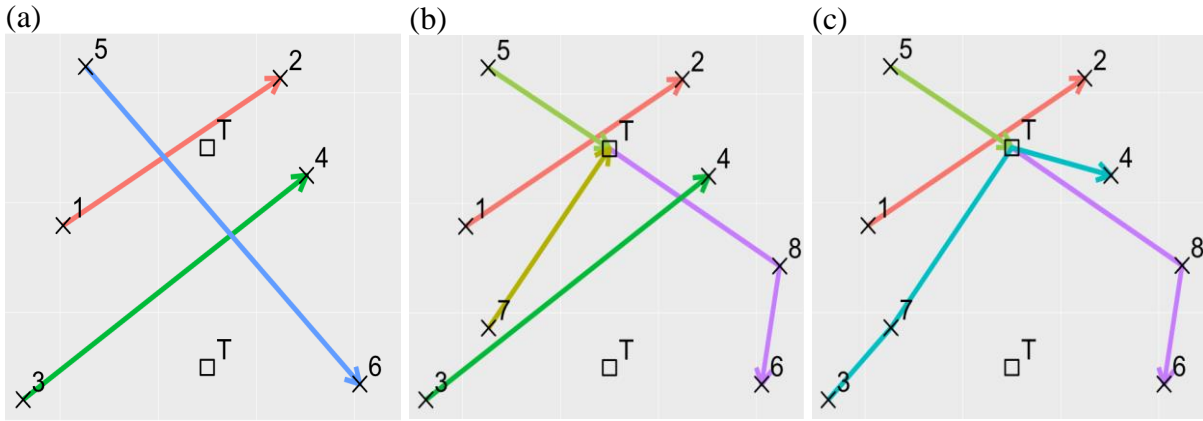
Figure 7 (a, b, c): Illustration of optimal assignment of transport orders in different scenarios

However, the total cost can be reduced to 27.95, if the given time window at location 7 is extended by one day. The freight forwarder is able generate a significant smaller transport price, while decreasing GHG emissions due to the shorter travel distance. The resulting routes are shown in the figure 3c.

6   Conclusion

In this paper, we introduced a conceptual model for a dynamical and continuous planning procedure for the assignment of transport request in the context of the PI. We developed a model that allows the continuous planning of freight flows through a network of hubs and the constant surveillance of freight assignments to carriers. Therefore, freight forwarders will be able to identify available capacities within the network and are able to rearrange the assignment of freight. Finally, they are able to bundle and unbundle freight transport orders, which leads to better utilized transport capacities, lower costs and fewer GHG emissions.

The model consists of three components building up on each other: A model to estimate cargo rates, a model to assign transport requests and a planning algorithm that continuously updates the expected assignments of transport requests. We introduced a use case of transport requests from Scandinavia to South-East Europe. The results of the developed model for the estimation of cargo rates are promising as the median absolute prediction error is only 3.42%. Furthermore, we demonstrated the feasibility of our approach as it is possible to quantify the costs caused by additional transport requests and changing time windows. Dynamic bundling and unbundling enables freight forwarders to generate lower costs per transport request. Our next steps are to evaluate the overall bundling potential of our conceptual model for the presented use case and to show the generated economic, ecological and social potential.

7   Acknowledgements

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Decision making in a Dynamic Transportation Network: a Multi-Objective Approach

M.R. Ortega del Vecchyo[1, 2], F. Phillipson[2] and A. Sangers[2]

1. Delft University of Technology, Delft, The Netherlands
2. TNO, The Hague, The Netherlands

Corresponding author: frank.phillipson@tno.nl

Abstract: Multiple different attributes are important in the container-to-mode assignment in a transportation network. This paper proposes an interactive multi-objective optimisation approach for planners of those transportation networks. This approach offers a range of solutions according to her/his preferences, and offers the opportunity to seek for new ones if the planner is not satisfied with the solutions found so far.

Keywords: Container Logistics, Minimum cost multi commodity flow, Space-time graphs, Multi-objective optimisation, Robustness, Flexibility

1 Introduction

In this paper we look at a transportation system where logistic units (e.g., containers) travel freely through this network. Decision makers here can be logistic service providers, clients controlling the stream of their containers, intelligent containers or other smart logistic units themselves. This occurs in Physical Internet (PI) and in Synchromodal or Intermodal networks. For an overview of those concepts and differences we refer the reader to Ambra et al. (2019). Many transportation planning problems are solved via a deterministic optimisation-based tool where the lowest cost solution is chosen (Caplice and Jauffred (2014)). However, the used forecasts of the demand and transportation times can be very inaccurate and realisations may lead to drastically changed, or even infeasible plans. This changing of plans will become an important issue in realisation of synchromodal transportation networks. The Platform Synchromodality (www.synchromodaliteit.nl) provides the following definition: 'Synchromodality is the optimally flexible and sustainable deployment of different modes of transport in a network under the direction of a logistics service provider, so that the customer (shipper or forwarder) is offered an integrated solution for his (inland) transport.' Synchromodality is based on the usage of various transport modes available in parallel to provide a flexible transport solution, the entrustment to the logistics service provider with the choice of transportation mode and the possibility to switch in between transportation modes in real time, as can be seen in Agbo and Zhang (2017), Bahdani et al. (2016), and De Juncker et al. (2017). Especially the real time aspect, in combination with the need to make (some sort of) general planning, gives need for robust and flexible plans, where costs and customer satisfaction keep their importance.

In this work, we propose an interactive approach based on multi-objective optimisation, which is meant to be used as a decision support tool for a transportation planner. In most papers cost of the operation and service time are still the only used objectives, and other attributes are neglected (SteadieSeifi et al. (2014)). In Ishfaq and Sox (2010) it is proposed that cost, service,

frequency, service time, delivery reliability, flexibility and safety are all performance indicators. The work in Ramezani et al. (2013) takes customer responsiveness and quality as objectives next to costs. We propose Robustness, Flexibility and Customer satisfaction as alternative objectives next to costs in the multi-objective approach.

The mathematical framework we use as basis in the approach is the *Multi-Commodity Flow problem* (Crainic (2000)), to model the sychromodal planning problem. In the case where only cost is considered, it can be modelled as a Minimum Cost Multi-Commodity Flow (MCMCF) problem. Flow of goods on a synchromodal, intermodal or multimodal network can be modelled via a multi-commodity flow problem on a special kind of graph called spacetime network (STN) or space-time graph. This kind of networks consider the schedule of the transportation modes. On this model we build an interactive multi objective analysis method, inspired by Miettinen et al. (2008). As objectives we use the objectives proposed in Ortega Del Vecchyo et al. (2018) to get a robust and flexible planning to be used in the synchromodal environment.

The remainder of this paper is organised as follows. In Section 2 we present the MCMCF problem, and propose and define the new objectives. Then we present the interactive approach and illustrate this by applying it on an example. Finally, in Section 5 we will present the conclusions and give directions for further research.

2   Multi-objective analysis

In this section, we present the MCMCF problem and the Multi Objective Approach. Also we propose and define the new objectives.

2.1   Minimum cost multicommodity flow on space-time graphs

In this section we introduce a modelling framework and notation used, that we need in the remainder of the paper: minimum cost multicommodity flow on space time graphs, based on Crainic (2000). On a graph *(G, A)* with n nodes and m arcs, where each arc *(i, j)* has capacity $u_{ij} > 0$, the multicommodity flow problem is a network flow problem with k commodities of d_k demand of flow between different source nodes s_k and sink nodes t_k. The goal here is finding a minimum cost feasible flow.

A formulation of the MCMCF problem is as follows. Let *P(k)* be the set of all directed simple paths on G from s_k to t_k, C(P) the cost of the path $P \in \cup_k P(k)$, that is, the sum of all the costs of arcs *(i, j)* $\in P$. Then the MCMCF problem can be formulated as

$$\min \sum_k \sum_{P \in P(k)} C(P) x_P \tag{1}$$

$$\sum_k \sum_{P \in P(k)} x_P \, \delta_{ij}(P) \leq u_{ij} \qquad \text{for all } (i,j) \in A \tag{2}$$

$$\sum_{P \in P(k)} x_P = d_k \qquad \text{for all } k \tag{3}$$

$$x_P \geq 0 \qquad \text{for } P \in \cup_k P(k) \tag{4}$$

$$\delta_{ij}(P) = \begin{cases} 1 \text{ if } (i,j) \in P \\ 0 \text{ if } (i,j) \notin P \end{cases} \tag{5}$$

Here, we have one decision variable x_P for each path between an Origin-Destination (OD) pair, for each OD pair.

The MCMCF can be applied to a space-time graph. The idea behind a space-time graph, as its name suggests, is that every node represents a location at a specific time, and arcs represent a

change of state. They are meant to show the characteristics of an underlying graph G with node set S as time changes discretely from 1 to T where each of these discrete times is referred to as a time-stamp.

Formally, we say that a graph G is a STN (or space-time graph) if its node set is of the form $S \times \{1,2,...,T\}$ for some $T \in Z^+$ and some set S and every arc $((a, p),(b,q)) \in A(G)$ satisfies $p < q$. We refer to the node (a, p) as location a at time p, and to T as the time horizon of G.

2.2 Objectives

Instead of only minimising costs, now multiple objectives are proposed as defined in Ortega Del Vecchyo et al. (2018). These objectives were constructed using the definitions:

- Robustness is the capacity of a plan to overcome delays in travel times and handling times on terminals and still be carried on as planned.
- Flexibility is the capacity of a plan to adapt to delays in travel times and handling times on terminals when these force the plan not to be able to be carried on anymore.
- Customer satisfaction indicates how satisfied the customer will be if his order arrives a certain time after the due date.

We will give a short derivation of the mathematical definitions of those objective here.

Let $t_0, t_1, t_2 \in Z^+$, $t_0 < t_1 < t_2$. For a given path P on a space-time graph, we say that $e = ((A,t_0), (B,t_1),(B,t_2))$ is an **event** of the path P if the path $((A,t_0),(B,t_1),(B,t_1+1),...,(B,t_2),(C,t_3))$ for some C, B and A is a sub-path of P, and the resource of the trip $((A,t_0),(B,t_1))$ is a different resource than the one of trip $((B,t_2),(C,t_3))$. Also, $e = ((A,t_0),(B,t_1),(B,t_2))$ is an event of P if the path $((A,t_0),(B,t_1), (B,t_1 + 1),...,(B,t_2))$ is a sub-path of P and (B,t_2) is the last node on P. If the event is of the latter form we refer to it as the **last event** of P. We use the short notation $e \in P$ to denote that the event e is an event of the path P. For a path-based multi-commodity flow problem Pr on a space-time graph, we say that e is an event of the problem Pr if it is an event of a path P of an OD pair in Pr. We use the short notation $e \in Pr$ to denote that the event e is an event of the problem Pr. If x_P is the flow variable of a path P, and F is a solution to Pr, the flow on an event $e = ((A,t_0),(B,t_1),(B,t_2))$ is defined as $F_e = \sum_{P \in P(e)} x_P$ where $P(e) = \{P \in \cup_k P(k)/((A,t_0),(B,t_1)) \in P\}$.

Let F be a solution flow for a path-based multi-commodity flow problem Pr on a space-time graph and the robustness measure $r'(f,t) = e^{-\lambda f/t}$, with $\lambda > 0$ a parameter to be specified depending on the units that represent each timestamp. By defining the robustness measure of an event $e = ((A^e,t_0^e), (B^e,t_1^e), (C^e,t_2^e)$ as $r(e) = r'(F_e, t_2^e - t_1^e)$, we introduce the **geometric mean robustness** of the solution $MR(F)$ as $MR(F) = (\prod_{e \in Pr} r(e))^{\frac{1}{|\{e \in Pr\}|}}$.

Definition 1. The geometric mean robustness is minimised by minimising the log of the geometric mean robustness of the solution, calculated by

$$\log MR(F) = \frac{\log \prod_{e \in Pr} e^{-\lambda \frac{F_e}{t_2^e - t_1^e}}}{|\{e \in Pr\}|} = \frac{-\lambda}{|\{e \in Pr\}|} \sum_{e \in Pr} \frac{F_e}{t_2^e - t_1^e}. \tag{6}$$

For a path P on an STN and an event $e = ((A,t_1),(B,t_2),(B,t_3))$ on the path, we define the subpath P_e with respect to e as the subpath of P that contains all the nodes from (B,t_3) onward. Also, for a solution F of a multi-commodity flow problem on a STN G, we denote by $G \backslash F$ the STN G whose arcs' capacity have been lowered according to the flow of F, that is, the capacity of an arc in $G \backslash F$ is the capacity of the arc on G minus the flow passing through that arc on F. Next, for a pair of nodes (A,t_1) and (B,t_2) on a space-time graph G and a positive real number r, we

denote by *mincost((A,t₁),(B,t₂),r)_G* the cost of the optimal solution of the minimum cost flow problem with source node *(A,t₁)*, sink node *(B,t₂)* and flow *r* in *G*. For a path *P* with flow x_P of a solution *F* of a multi-commodity flow problem on a STN *G* and an event *e* = *((A,t₁),(B,t₂),(B,t₃))* on the path, we define the anti-flexibility $\varphi_{G \setminus F}(e, x_P)$ of the event as the least cost that would be incurred if the trip scheduled from *A* at time *t₁* to *B* at time *t₂* would arrive one timestamp after time *t₃* to *B*. That is, $\varphi_{G \setminus F}(e, x_P)$ = *mincost((B,t₃ + 1),(S_P,t_P), x_P)_{G \setminus F}* − *C(P_e)x_P*. Here, *C(P_e)* is the cost of the subpath *P_e* and *(S_P,t_P)* is the last node on *P*. Notice the dependency of the min-cost algorithm on the solution flow *F* as well as on *G*, that is, the capacity of the arcs on *G* are lowered corresponding to the flow *F*. We call the above anti-flexibility because $\varphi_{G \setminus F}(e, x_P)$ decreases as the flexibility of the event increases, according to our definition of flexibility.

Definition 2. For a solution flow *F* of a path-based multi-commodity flow problem on a space-time graph *G* and a robustness function *r*, we define its anti-flexibility

$$\Phi_G(F) = \sum_{P \in F, x_P > 0} \sum_{e \in P} \varphi_{G \setminus F}(e, x_P)\big(1 - r(e)\big). \tag{7}$$

Definition 3. For a solution flow *F* of a multi-commodity flow problem *Pr* on a space-time graph and a family of numbers w(o) ∈ [0,1] such that $\sum_{o \in Pr} w(o) = 1$, we define the customer satisfaction as $\left(\sum_{o \in Pr} s(o, t_o) w(o)\right)^2$, where to is the delay in number of timestamps of order *o*.

Definition 4. As last objective we define Cost as $\sum_k \sum_{P \in P(k)} C(P) x_P$.

2.3   Multi Objective Approach

First we use a lexicographic method to obtain a Pareto solution. For the lexicographic method we need to rank the objective functions in order of importance. The lexicographic method can be very stiff in some problems, since it doesn't allow for any decrease in value from the top ranked objectives to increase less important objectives. For this reason, we also consider a slight variation of the lexicographic method: when optimising cost, look at the value of number of trucks and constraint the problem with the respect to this number of trucks instead of cost. Notice that, strictly, with this procedure we cannot guarantee that the solution obtained is a Pareto optimal solution, therefore, if a Pareto optimal solution is needed, then one should use the usual lexicographic method. We propose several different orderings for obtaining the (Pareto) solutions, see Table 1.

Table 1: Three lexicographic orders

First	Second	Third
Cost	Cost	Cost
Linear anti-flexibility	Mean Robustness	Customer satisfaction
Customer satisfaction	Customer satisfaction	Linear anti-flexibility
Mean Robustness	Linear anti-flexibility	Mean Robustness

The first order minimises costs and possible unforeseen costs, the second minimises costs and the need to change the plan and the third minimises costs and maximising customer satisfaction. Each of these orderings emphasises on one of the attributes constructed. The solutions provided by the lexicographic methods proposed will serve as a starting point for our interactive method.

Perhaps the most interesting methods of multi-objective optimisation for our case are the interactive methods. On these methods, the user is expected to have input on the algorithm to

explore the solutions that are of interest. In Miettinen et al. (2008) the main steps of an interactive method in multi objective analysis are explained in the most general sense. Briefly, these steps are:

1. Provide the Decision Maker (DM) with the range that the different objectives can take, when possible.
2. Provide a starting Pareto optimal solution(s) to the problem.
3. Ask the DMP for preference information.
4. Generate new Pareto optimal solution(s), show them and other possible relevant information to the DM.
5. Stop, or go back to 3.

The purpose of the first two steps is to get the DM to be acquainted with the possibilities and limitations of the problem at hand. The last three steps will also provide further insight to the DM, but are mainly geared towards finding the best Pareto optimal solution with respect to the DM preferences. These kind of methods have some nice benefits. The expertise of the DM is used as input on the method, which should give more satisfactory results from the point of view of the DM. The expert stirs the solution with respect to her or his preferences, and the method provides a solution towards these desired goals. Thus in this method the DM plays a very important role. Next, the decision maker does not need to know in advance the limitations of the problem with respect to the objectives. Rather, she or he learns from the problem at each iteration. Other benefits are that a variety of solutions will be provided, which is a desired feature for our case and that there is no need to have preference for objectives in advance.
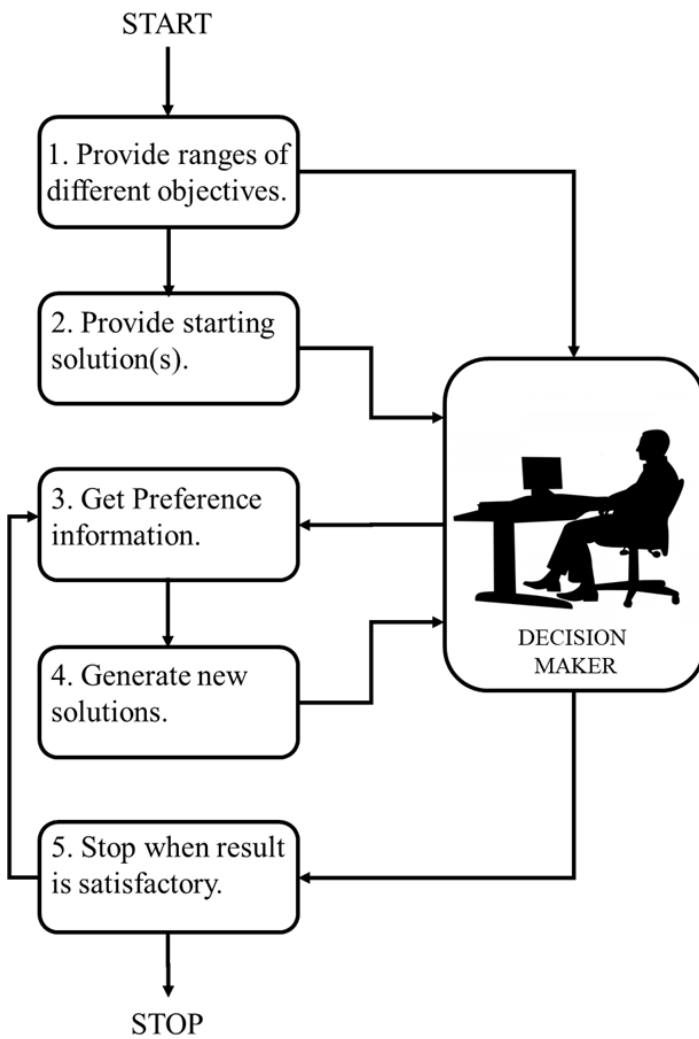
Fig. 1: Proposed approach in flowchart.

3   Proposed Approach

The steps in the planning setting we propose are (see Fig. 1):

1. Provide the decision maker with the range that the different objectives can take, when possible.

2. Provide a starting solution(s) to the problem.

We do not require the starting solution to be a Pareto optimal solution. However, a Pareto optimal solution can provide a valuable insight. The information of these solutions is gathered and kept for further assessment. Additionally, it is useful to build one optimal solution for a scalarisation of each objective (other than cost), that is, the optimal solution of the scalarisation of optimising one objective if cost is allowed a 1% increase with respect to the optimal cost (or, if more margin is given, a greater percentage).

3. Ask the decision maker for preference information.

In this step the influence of the decision maker is crucial. The information available from the solutions of the problem found so far, must be assessed and used to make decisions. This information may include, but is not limited to: (1) The value of the objectives of the solutions obtained so far, for example, the value of the base solution F1 and the influence of achieving this cost in terms of the values of other attributes (obtained from the lexicographic methods); (2) A better assessment of the range of values from the objectives done in step 1, that is, the limitations of the values of attributes; and (3) the approximate time for obtaining a solution, and given the time left for using the method, the number of solution extra we can expect to obtain. From this information the following questions need to be answered:

- What objective to optimise next?
- What range to restrict the rest of the objectives to?
- Is there a minimum capacity needed for owned transport? If so, what percentage?
- Is there a specific arc whose capacity should be updated?
- Is there a path whose value should constrained?

The last question includes whether some trip should not be used, some path must be fixed, some departure time of an arc must be fixed, etc. This characteristic allows the solver to process new information, and therefore, make it more synchromodal. When implemented, instead of building linear programs from scratch, the code modifies the existing linear program to optimise the required objective and satisfy the constraints selected, thus saving computational time.

4. Generate new solutions, show them and other possible relevant information to the decision maker.

A new LP is solved based on the questions obtained from the last step. The information of this solution is gathered and kept for further assessment

5. Stop, or back to 3.

Depending on whether a satisfactory solution has been provided, and on the time available, we either stop the method or reassess.

4   Example

We illustrate the functioning of the interactive method proposed by showing a use case. This method is meant to be used by a decision maker (which in this case is a planner) whose choices will stir the method in a certain direction, thus the method will give different solutions depending on the DM's preferences. Therefore in this example we consider the presence of a hypothetical planner and conjecture the choices that this fictional DM may make.

Instance. We generate the problem by constructing the space-time graph and the orders to be dispatched on it with the following parameters: 15 terminals (A to O) with infinite capacity, Time Horizon of 200 time units, 400 orders (OD pairs uniformly randomly generated) 16 journeys of transport resources (divided in owned transport and subcontracted transport, other than trucks), and an allowed delay of 10 time units. Handling costs are assumed 0.
Next, we assume the capacity of owned transport within the system 154 and the capacity of a subcontracted transport uniformly distributes between 50 and 55. The number of containers per order can vary between 1 and 30. We assume a Truck price of 40 and the price per container in other transport uniformly distributed between 2 and 4.

To generate the values required for Customer satisfaction, we generate the random values $s(o,t)$ $\in [0,1]$ ensuring that for each o, $s(o,t)$ is decreasing with respect to t. The weights $w(o)$ are uniformly random generated by assigning $w'(o) = \text{unif}[0,1]$ to each order and then setting the weight $w(o) = w'(o)/\sum_o w'(o)$.

Interactive method on instance. After the problem has been set, we follow the steps of the interactive method in the synchromodal context. This will be done at each point in time where realisations and new information becomes available and urges the planner to replan.

1. Provide the decision maker with the range that the different objectives can take, when possible. In this case, we have the following possible values: Cost: R+, Anti-flexibility: R, Robustness: [0,1] and Customer satisfaction: [0,1].

2. Provide starting solution(s) to the problem.
We first obtain the base solution F_1 by solving the LP with respect to costs, with no constraint on the other objectives. This results in a solution F_1 with the characteristics shown in Table 2. Suppose the DM chooses to follow the first lexicographic method, then we add the constraint on trucked containers to be less than or equal to 3,420 and optimise linear anti-flexibility. From this we obtain the solution $F_{l,2}$ and, following the lexicographic method, solutions $F_{l,3}$ and $F_{l,4}$ with attribute values as shown in Table 2. These solutions show a very significant decrease in terms of anti-flexibility of 82%, a slight change in mean robustness, and barely any change in terms of customer satisfaction. Notice that neither cost nor anti-flexibility follow a strictly monotonic behaviour with respect to the solution number, despite the fact that this behaviour is expected from a lexicographic method. For the case of cost, this is a consequence of the fact that we are using a slight variation of the lexicographic method where we do not allow trucked containers to increase, instead of cost. For anti-flexibility it is not expected to have any particular monotonic behaviour since it is not constrained directly on the LP. Further analysis on the full transportation plan file corresponding to each solution reveals that despite their similarity in terms of attributes, solution $F_{l,1}$ and $F_{l,4}$ differ on the transport plan of 95 out of 400 orders.

The value of the attributes between solutions is relatively similar because the lexicographic method is quite restrictive, but the solutions provide us the insight of how much are the other attributes subject to change when the cost is (almost) rigid. Also, in this case, as it is often the case on lexicographic methods, the Pareto optimal solution $F_{l,4}$ is a very good proposal in terms of the attributes when compared to the other solutions obtained (that is because all the attributes have been optimised at some stage). This solution will serve as a good reference for the capabilities of the solutions in terms of the attributes.

Table 2: Attribute values of the solutions of the lexicographic method

	F1	Fl,2	Fl,3	Fl,4
Cost	146,387	147,812	147,695	147,653
Mean Robustness	0.8778	0.8831	0.8834	0.8836
Anti-Flexibility	2365.55	442.46	439.82	442.65
Customer Satisfaction	0.8917	0.8907	0.8926	0.8926
Trucked Containers	3420	3420	3420	3420
Linear Anti-flexibility	116.79	20.73	20.73	20.73
Computational Time (seconds)	245	65	85	70

We now calculate the set of solutions corresponding to optimising each objective (that is, scalarisation) allowing 1% increase of cost over the optimal cost. We write F_f, F_r, and F_{cs} for the solution corresponding to flexibility, robustness and customer satisfaction, respectively. The results are summarised in Table 3.

Table 3: Attribute values of solutions

	F_1	F_r	F_f	F_{cs}	F_2	F_3	F_4
Cost	146,387	147,851	147,851	147,844	146,395	146,395	148,352
Mean Robustness	0.8778	0.9056	0.8850	0.8859	0.8761	0.8812	0.8761
Anti-Flexibility	2365.55	626.40	396.84	1498.30	755.53	799.44	801.94
Customer Satisfaction	0.8917	0.9069	0.8937	0.9619	0.9060	0.9060	0.9035
Trucked Containers	3420	3435	3443	3454	3420	3420	3474
Lin. Anti-Flexibility	116.79	36.49	16.53	77.24	39.99	39.99	39.93
Comp. Time (sec.)	245	60	169	729	229.96	2128.02	215.33

From the scalarisation solutions obtained, we can see the extent to which the other attributes can be improved with as little as 1% increase on the cost: customer satisfaction can be improved 0.6 and mean robustness can be increased a bit less than 0.3. In terms of anti-flexibility, there can be a reduction of almost 2000 units. It should be noted that the computational time to derive the solution Fcs is comparatively larger than the other ones.

3. Ask the decision maker for preference information.
At this stage, the decision maker has to assimilate the information she/he has of the problem so far, provided by the previous steps. We conjecture here our fictional DM's train of thought: The values of the attributes of the solutions provide a better idea of the range of the attributes: customer satisfaction is quite cost-effective to improve. Also, from $F_{l,2}$ and F_f we see that anti-flexibility can be reduced substantially for little cost. Additionally the DM knows that for this particular problem any plan with a customer satisfaction value over 0.9 is acceptable. Therefore the DM chooses the next solution to be the solution F_2 of the scalarisation of optimising cost with a constraint on linear anti-flexibility of 40 and a customer satisfaction of 0.9.

4. Generate new solutions, show them and other possible relevant information to the decision maker.
Solution F_2 (see Table 3) has just an increase of 8 in terms of cost, and it provides a very substantial decrease on anti-flexibility, as well as an increase in customer satisfaction.

5. Stop, or back to 3.
The solution seems satisfactory, but the DM decides to try to improve the robustness of the solution without compromising the other attributes, resulting in a new step 3':

3'. The DM decides to optimise with respect to robustness, with cost, linear anti-flexibility and customer satisfaction to be at as good as the values in F_2 (similar to a lexicographic method).

4'. We obtain a solution F_3 (see Table 3). Notice that the computational time to obtain F_3 is quite long, therefore, depending on the time available, the DM may have stopped the simulation, and picked a solution from the solutions obtained so far (probably F_2). This of course depends on the importance the DM gives to improving slightly the robustness of the solution in this circumstances.

5'. Suppose the DM choose not to finish the simulation to obtain F_3 and reports F_2 as her/his solution of choice. The DM reviews the solution obtained and is informed that F_2 uses a specific trip that has been cancelled, which is represented by the arc (('K',35),('L',44)) on the space-time network used for the problem. She/he is also informed that another trip from another transport used in F_2 will not be departing at the time the plan F_2 uses it, which is represented by arc (('C',48),('I',54)). Additionally, a particular order has been specified to be served exclusively via truck, namely, order 2. The DM is therefore forced to go back to 3 again, noted by 3'':

3''. With these new constraints, the DM has to make a choice depending on the time available: Either build a solution F_4 using constraints like the ones used to obtain the best solution so far, namely, F_2, or restart from step 1 considering the problem with this new added constraints as a new problem. Assuming a decision must be taken in a short time, the DM decides for the former

4''. The new constraints are added to the LP. We then optimize cost constraining linear anti-flexibility to 40 and a customer satisfaction of .9 and obtain the solution F_4.

5''. The DM is satisfied with the attribute values and proposes F_4 as a solution.

5 Conclusions and future work

We developed an interactive multi-objective optimisation method, which is meant to be used as a decision support tool for planners. This tool provides the user the possibility to explore solutions as she/he seems fit, and provides a range of different planning solutions for the planner to choose from, which are both properties sought for in a decision support tool.

The method above proposes a hypothetical scenario where a planner uses this tool for the purpose of making a plan. However, the tool itself is an optimizing method and it could be used for other purposes, for example, given a particular problem, it can quantify the impact that certain attributes have on cost, such as the delayed delivery, or the minimum capacity on barges. This could illustrate how certain behaviours on the network are affecting the cost-performance of the network, or how some advantages are not being exploited.

In order to understand the tool, the user needs familiarisation with the concepts used, such as space-time network, optimisation, and a fair notion of the mathematics involved. Since the goal of this tool is to illustrate the benefits that can come from planners using multi-objective optimisation, it is very important to keep things simple. Therefore the command inputs proposed in this method attempt to be used and understood (as much as possible) by a non-technical user. On the other hand, when compared to other interactive solution approaches in the literature, this method requires less input from the DM, and also less technical expertise. As future work, once the value of such a tool has been acknowledged by the planners, and the planners are committed to the interactive use of the tool, the complexity and usage of the tool can be increased. If more advanced interactive methods are developed, there should always be sensitivity into the context, use and level of involvement of the DM.

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Reduction of Variables for Solving Logistic Flow Problems

K. Kalicharan[1, 2], F. Phillipson[2], A. Sangers[2], M. De Juncker[2,3]

1. Delft University of Technology, Delft, The Netherlands
2. TNO, The Hague, The Netherlands
3. Eindhoven University of Technology, Eindhoven, The Netherlands

Corresponding author: frank.phillipson@tno.nl

Abstract: *In logistic problems, an Integral Multi-Commodity Network Design Problem on a time-space network is often used to model the problem of routing transportation means and assigning freight units to those means. In Physical Internet and Synchromodal networks an interactive planning approach is preferable, meaning that calculation times of a single planning step should be short. In this paper we provide finding ways to reduce the number of variables in the problem formulation, that are effective at reducing the computation time for ILP-based solution methods.*

Keywords: *Logistic Space Time Network, Logistic Flow Routing, Synchromodality, Variables Reduction Techniques*

1   Introduction

In this research paper we look at a transportation system where logistic units (e.g., containers) travel freely through this network. Decision makers here can be logistic service providers or clients controlling the stream of their containers, or intelligent containers or other smart logistic units themselves. This occurs in Physical Internet and in Synchromodal or Intermodal networks. These types of transport networks allow for many different options of transportation. A unit can be trucked from its origin to its destination, but (part of) the route can also be done by barge, plane or train. In synchro- and intermodal networks, a logistics service provider (LSP) is responsible for managing the flow of containers from their origins to their destinations. Especially in large logistics networks, LSPs may require assistance from algorithms to make good routing choices. These algorithms can be used to reach economic and emission-reduction targets by offering decision support for optimizing the (intermodal) transport chain (Janic 2007). In Physical Internet and Synchromodal networks, a more interactive planning scheme is preferable, following the dynamic and uncertain nature of the underlying networks. Here routing decisions can (or have to) be made, each time logistic units arrive at an intermediate node, incorporating the decisions of other agents and, possibly, the uncertainty of decisions or events in the future.

In logistic (service) network planning problems Space-Time Networks (STN) are often used for the representation (De Juncker et al., 2017). On this STN a non-negative integral minimum cost multi-commodity flow problem (MCMCF) is solved to get the overall optimal solution (Crainic, 2000). Here, all terminals are modelled as nodes. Services go from these terminals to other terminals in a certain amount of time. These services are modelled by arcs. To solve these problems, constraints can

be relaxed to obtain a simpler problem. This yields lower bounds that together with heuristically found upper bounds can be combined in for instance a branch-and-bound algorithm, see, among others, the paper by Crainic et al. (2001) and Holmberg and Yuan (2000). Holmberg and Hellstrand (1998) propose an exact solution method for the uncapacitated problem based on a

Lagrangian heuristic. A dual ascent procedure is treated by Balakrishnan et al. (1989), which finds lower bounds within $1 - 4\%$ of optimality. Heuristics and meta-heuristics (such as Tabu Search, Simulated Annealing and Genetic Algorithms) are also widely used. See for instance the paper by Crainic et al. (2000), who look at a path-based formulation of the same problem and solve it with tabu search. Other papers looking into these meta-heuristics are among others: Bai et al. (2012), Chouman and Crainic (2012) and Pedersen et al. (2009).

To allow for a more interactive use of this solution direction, short calculation times are crucial. In this paper we look at the problem of scheduling services and assigning transportation units to it. We start with modelling this problem as an Integral Multi-Commodity Network Design (MCND) problem. We will present novel reduction approaches to reduce the computation time when solving the problem. The MCND problem will be introduced in Section 2. In Section 3 the proposed reduction approaches are introduced, using the specific structure of the problem. Next, in Section 4 computational results will be presented and we will end with conclusions in Section 5.

2 Multi-Commodity Network Design Problem

The main goal of this paper is about efficiently and simultaneously routing transport means and scheduling transportation units. Without losing any generality, we will say vehicle if we mean a transportation mean and container if we mean the transportation unit. One of the models that could be used here is the Capacitated Fixed Charge Network Flow Problem from Ghamlouchee et al. (2004), Hewitt et al. (2010), Magnanti and Wong (1984) and Rodríguez-Martín and Salazar-González (2010). We have a directed graph $G = (V, E)$ (or multigraph) that contains all the nodes and arcs in the network. We have a set of commodities K that represent the bookings/orders. Every commodity $k \in K$ has, without loss of generality, one source node s_k and one sink node t_k. The parameters c_e, for $e \in E$, are the capacities of the arcs. The parameters $f_{e,k}$, for $e \in E, k \in K$, determine the per unit cost of commodity k on arc e. The parameters $d_{v,k} = d_k$ if $v = s_k$, $d_{v,k} = -d_k$ if $v = t_k$ and $d_{v,k} = 0$ otherwise, where d_k is the demand/size of commodity k. The variables $x_{e,k}$ depict the magnitude of the flow of commodity k on arc e. Finally, we define the design variables y_e, $\forall e \in E$, that are one if the service at link e is active and zero otherwise. In intermodal transport these design variables are normally one if and only if the corresponding vehicle travels the corresponding link. Many possible arcs to travel are added for a vehicle and after the optimization process, it is decided which design variables are one; ergo, which routes the vehicles should travel. The graphs for these models are often time-space networks, but other graphs can also be used (Sharypova, 2014). The optimization problem now looks like:

$$\min \sum_{k \in K} \sum_{e \in E} f_{e,k} x_{e,k} + \sum_{e \in E} g_e y_e \tag{1}$$

$$s.t. \sum_{e \in \delta^+(v)} x_{e,k} - \sum_{e \in \delta^-(v)} x_{e,k} = d_{v,k} \qquad \forall v \in V, \forall k \in K \tag{2}$$

$$\sum_{k \in K} x_{e,k} \le c_e y_e \qquad \forall e \in E \tag{3}$$

$$x_{e,k} \ge 0, y_e \in \{0,1\} \qquad \forall e \in E, k \in K \tag{4}$$

The first part of the objective function minimizes the cost using the $f_{e,k}$. The second part is a link cost, if a vehicle travels a certain link $e \in E$, then a certain fixed cost g_e is added. The flow conservation constraints (2) make sure that the total amount of a commodity that enters the node also leaves the node, except for the sources and sinks. The capacity constraints (3) say that if an arc in the network is not travelled by a vehicle, then no commodity flow may be on

that arc. If a vehicle does travel an arc, then the container flow on that arc can be at most the capacity of the edge.

This model is in some papers, see Chouman and Crainic (2012), Pedersen et al. (2009), Vu et al. (2012) and Vu et al. (2014), extended to include what are called design-balanced constraints:

$$\sum_{e \in \delta^+(v)} y_e - \sum_{e \in \delta^-(v)} y_e = 0 \ \forall \ v \in V \tag{5}$$

These constraints make sure that everywhere a vehicle arrives, it also leaves. This means that the routes for the vehicles are directed cycles. So the network we use, should contain directed cycles. When working over a time-space network, an additional arc should be added from the sink of vehicle type w of set W to the source of vehicle type w to make sure it is possible to have a directed cycle.

In Sharypova (2014) a similar continuous time ILP (Integer Linear Programming problem) is proposed. This model also has time variables and some more types of constraints. An extension of the design-balanced service network design problem is given in Li et al. (2017). The model takes into account the usage of vehicles and the opening of corridors. In Andersen et al. (2009) an other extension is derived and in Joborn et al. (2004) a model that shares some resemblances is applied to freight car distribution in scheduled railways. A completely different ILP that can handle the same sort of problem is given in Huizing (2017).

The problem we will propose is similar, though contains a few key differences. First, We will consider two vehicle types: not flexible, high capacity, low cost vehicles that need to be scheduled in advance (barges, train etc.) and flexible, low capacity, high cost vehicles (trucks, transporters, etc.). From here we will refer to the first type as barge and to the second type as truck. Second, only the first part of the objective function of the service network design problem is used. Third, the flow conservation constraints for the vehicles are slightly different than the design-balanced constraints: in our model the number of non-truck vehicles is pre-specified and only for the non-truck vehicles, vehicle flow conservation constraints are added.

We call our problem the Integral Multi-Commodity Network Design (MCND) Problem. The model uses a time-space network, wherein the routes of the vehicles are not known in advance. The arcs in the time-space network are possible links that a vehicle can travel. For the trucks we add an arc for every time stamp from every terminal to every terminal. Naturally, the travel time is taken into account. We repeat this process for the first barge, second barge etc. Arcs corresponding to different vehicle (types) that run between the same time-space nodes are not merged. This way it is assured that all the links of all the possible routes they can take are included in the time-space network. The Integral MCND problem then is:

$$\min \sum_{k \in K} \sum_{e \in E} f_{e,k} x_{e,k} \tag{6}$$

$$\text{s.t. } \sum_{e \in \delta^+(v)} x_{e,k} - \sum_{e \in \delta^-(v)} x_{e,k} = d_{v,k} \qquad \forall \ v \in V, \forall \ k \in K \tag{7}$$

$$\sum_{e \in \delta^+(v) \cap E_w} y_e - \sum_{e \in \delta^-(v) \cap E_w} y_e = b_{v,w} \qquad \forall \ v \in V, \forall \ w \in W \backslash \{truck\} \tag{8}$$

$$\sum_{k \in K} x_{e,k} \leq c_e y_e \qquad \forall \ e \in E \backslash E_{truck} \tag{9}$$

$$\sum_{k \in K} x_{e,k} \leq c_e \qquad \forall \ e \in E_{truck} \tag{10}$$

$$x_{e,k} \geq 0, y_e \in \{0,1\} \qquad \forall \ e \in E, k \in K \tag{11}$$

For all non-truck arcs e in the network, we have created a discrete design variable determining if the arc is used (11). The y_e are binary variables. The container flows are modelled with the variables $x_{e,k}$ and still have to be integral and non-negative (11). We assume that trucks do not necessarily need to be used the whole day, whereas barges do have to be used the whole day.
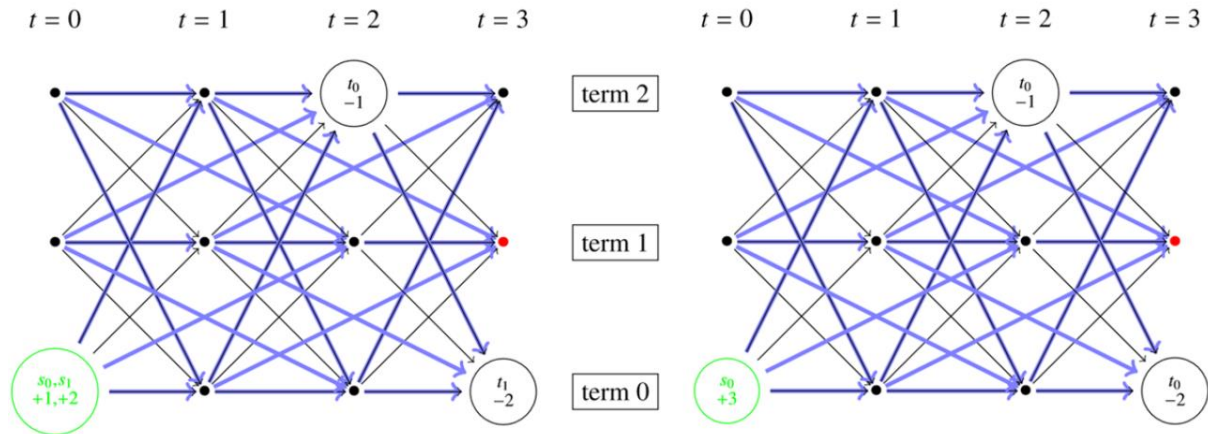
Figure 1: Combined bookings shared source.

For the paths of the barges to make sense we should add constraints that disallow the barge to teleport or travel multiple links at the same time. Flow conservation constraints for $w \in W \backslash \{\text{truck}\}$ (8) can do exactly this in the same the flow conservation constraints (7) work for the commodities. In these constraints we have $b_{v,w}$ which describe the time-space nodes that are the sink and source for a $w \in W \backslash \{\text{truck}\}$. In more detail for such w we have that $b_{v,w}$ equals b_w if v is the source node of w, equals $-b_w$ if v is the sink node of w and 0 otherwise, where b_w is the number of vehicles of type $w \in W \backslash \{\text{truck}\}$. This is normally 1 unless the vehicle reduction has been applied. The capacity of an arc is dependent on the number of vehicles that travel the arc (9). For the truck arcs we have different capacity constraints (10). Normally a vehicle has the same capacity the whole day. So we can then replace the c_e in the capacity constraints for the arcs, by capacity constants for the vehicle, c_w. For the trucks, however, c_e is the maximum number of trucks that can be deployed on link $e \in E_{\text{truck}}$. We assume a truck can carry exactly one container. Thus, the number of trucks that travel an arc $e \in E_{\text{truck}}$ is equal to the number of containers that are trucked on that arc $\sum_{k \in K} x_{e,k}$.

3   Variable Reductions

Reducing the number of variables of an ILP may reduce the computation time required to solve it. For that reason we will look at several ways to remove variables from the MCND ILP, as proposed in the previous section. A simple approach is to arbitrarily remove arc variables. However, then we might remove arcs that would be used in an optimal solution of the original problem. So in this section we try to introduce variable reductions in a smart way that do not change the optimal solution value too much. Note that the used variables are indexed over the locations, time stamps, vehicles and commodities in the MCND problem. Reducing the size of those sets will reduce the number of variables. . We will present the reduction in the next subsections, ordered using the set they reduce.

3.1   Commodity Reductions

Reduction A: Same Sink/Source In the model we assume all the containers in one booking combined in one commodity. This way there are less variables than if all containers would be a separate commodity. It is however possible to reduce the number of commodities even more if the following condition holds. If multiple bookings have the same sink, then these bookings

can be combined into one commodity, as shown in Babonneau et al (2006). This can be done also if they share the same source, see Figure 1. In that figure, the values of $d_{v,k}$ are visualized for the sink and source nodes of the commodities. In the left figure, a commodity is a booking, in the right figure a commodity is two bookings.

The problem with combining them if they have different sinks and sources, is that a container of booking 0 can be transported to the sink of booking 1, if they are put in the same commodity. If two bookings o_0 and o_1 have similar sinks for example if they have to be transported to the same destination location, then the same reduction is possible. If o_0 has to be there one time stamp earlier, then we can set the sink of o_1 to the same sink as that of o_0. Note that by doing this the optimal solution may become worse. After this we combine them in a single commodity.

Reduction B: Disjoint Time Frame Bookings In the ILP, arc variables are defined for a booking for every vehicle arc in the time-space network. Even those that start before the booking is released or end past its deadline. Suppose we have two commodities of which one has its deadline before the release time of the other one. Note that these bookings can be combined by putting them together in one commodity.

We can combine bookings in a greedy way: We start with the first one that is released and we add to the same commodity the first booking that is available after its deadline. We repeat this until it is no longer possible to add more bookings to the same commodity. After which we repeat this process for the next commodity. Clearly these bookings in the same commodity will not use the same arcs because there is no time stamp for which they are simultaneously available in the network. Every booking is available during a certain time frame.

Theorem 1. *This greedy algorithm finds an optimal way to combine the bookings, that is, minimizing the number of commodities, such that their time frames do not overlap.*

Proof. For readability we assume that none of the release times are equal, however, the proof can be extended for cases where there are bookings with equal release times. Suppose we have an allocation that minimizes the number of commodities by combining bookings in a certain way. In that allocation we start with examining the first booking b_{i_1} that is released. If the next (in time) booking in the same commodity, b_{i_2}, is not the first one released after the first booking, b_{i_1}, then we swap the first booking released after it; b_{i_3} and everything in the same commodity as b_{i_3} later in time, with b_{i_2} and everything released after b_{i_2} on the same commodity as b_{i_2}. Then we repeat this process for b_{i_3} etc. Until we are done for the commodity and then we move to the first booking released that is not on a commodity that we already handled and do the same for that commodity, but we do not move the bookings that are on a commodity that is already 'done'. The solution remains feasible and the number of commodities that are used does not increase. When we are done with all the commodities, we have found an allocation that is found by the greedy algorithm. □

3.2 Vehicle Reductions
Reduction C: Same Vehicle Type In the MCND problem we have a set of vehicles $W = \{truck, barge0, barge1,... \}$. The trucks are already combined in the model, it is also possible to combine the barges in the model assuming they all have the same travel times and capacities. So then we get $W = \{truck, barge\}$. If there are barges of types A and B we take $W = \{truck, typeAbarge, typeBbarge\}$. In the MCND model the y_e variables are not binary variables anymore, but more general discrete variables. They keep track of the number of barges that take arc e. In the capacity constraints these variables are multiplied with the capacities per barge to model the total barge capacity for a certain link.

If the barges are modelled individually, then for every barge a source and sink has to be given. With the reduction, it is possible to add multiple sources and sinks. So the barges still have the freedom to start from or end at different locations. Though, we can only specify the number of barges that has to arrive at a certain sink. It is not specify which individual barge has to arrive there, if there are multiple sinks. Furthermore, if too many sinks and sources are added, the number or possible paths for the barges might increase too much, also increasing the size of the feasible region.

An advantage of bundling different vehicles in the model together into a single vehicle type, is that this is a way to avoid problems with symmetry and reduce the number of variables in the model. If the individual vehicles are modelled separately, many different solutions that are equivalent in practice have different variable allocations in the model. For instance, if there are ten identical barges that start at location 0 and one container needs to be moved from location 0 to location 1, then barge 0 can transport the container or barge 1 can transport it, etcetera. As the barges are identical, these solutions are equivalent in practice. If these vehicles are put together in one index w in the model, then the container is not allocated to a specific barge in the model. That has to be done in a post-processing step.

3.3 Arc Reductions

Reduction D: Source/Sink Location In this reduction we use the property that if some part of the route the commodity needs to be trucked, then it suffices to do that as soon as it is possible to do so. We also use the fact that it is always shorter to truck directly to a location, than through another location.
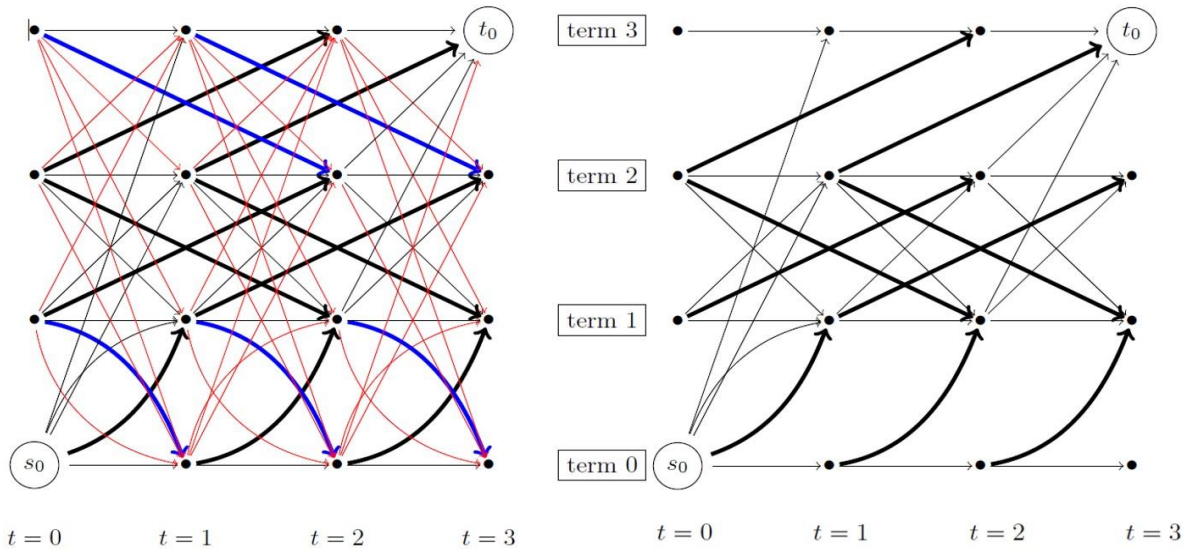
Figure 2: Reduction D for MCND.
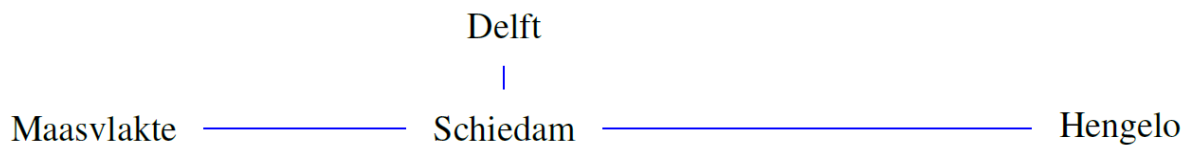
Figure 3: Waterway Connections

In the MCND problem on a time-space network some non-horizontal truck arc variables adjacent to a source location of a booking can be removed. It suffices to only add truck arc variables for a commodity from its origin location to every other location at its release time. The other non-horizontal truck arc variables adjacent to the source location can be removed. Similar things can be done for its sink location, though the arc from the source location to the

sink location at the release time is never removed. Additionally, non-truck vehicle arc variables that go to the source location or leave from the sink location can be removed. In Figure 2 we apply reduction D. The truck arcs are the thin arcs, the barge arcs the thick arcs. The truck arc variables that are removed for booking 0 are in red and the barge arc variables that are removed in blue.

Reduction E: Obsolete Barge Links Arcs in the time-space network that can never be travelled by some barge, because they start before the time the barge can be at the location, are removed. These links can never be taken by any container. Similarly barge arcs can be removed that depart too late at a location.

3.4 Location Reductions

Reduction F: Minimal Paths We call a ($loc1$,$loc2$) path in a network minimal if the path has no sub path that is a ($loc1$,$loc2$) path. For every commodity k we have that every path that is not a minimal (s_k,t_k) path in the space network can be removed. In our model we can use that every location that is not on a minimal (s_k,t_k) path in the space network can be removed for commodity k. In Figure 3 we see a space network with the waterway connections of several locations. Let $k \in K$ be a commodity with source location $\chi(s_k)$ =Maasvlakte and sink location $\chi(t_k)$ =Hengelo, then we can conclude that arc variables that correspond to links that go to/from Delft do not have to be added for commodity k, if this reduction is applied.

Reduction G: Direct Connection The network of the locations, waterways and roads can have a specific, recognisable, structure. This structure can be used. If shipping from location $loc0$ to location $loc2$ means shipping through location $loc1$. Then no arcs from $loc0$ to $loc2$ have to be added. It suffices to have arcs from $loc0$ to $loc1$ and from $loc1$ to $loc2$. See Figure 4 for an example, there the red barge arcs are removed because of the structure of the waterways. We recommend taking a dense time grid with this reduction, because larger time steps may adversely affect the accuracy of the travel times between certain locations.
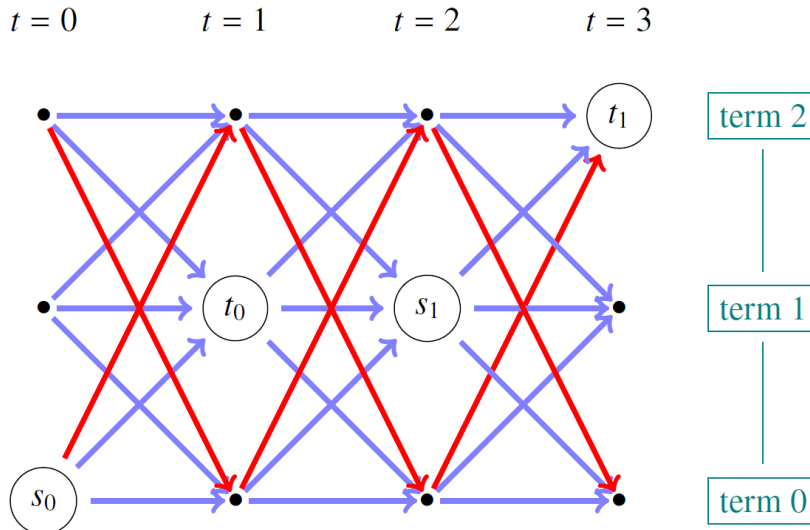
Figure 4: Direct Connection Reduction.

Reduction H: Locations In-between Every commodity k has an origin location $\chi(s_k)$ and a destination location $\chi(t_k)$. Let $d(\chi(s_k),\chi(t_k))$ be the Euclidean distance between $\chi(s_k)$ and $\chi(t_k)$, then we set all variables going to or from a location loc with $d(\chi(s_k),loc) > d(\chi(s_k),\chi(t_k)) + \delta$

and/or $d(\chi(t_k),loc) > d(\chi(s_k),\chi(t_k)) + \delta$ to zero. The δ should be chosen large enough to include locations that could be interesting for commodity k. Instead of the distance as the crow flies, it is also possible to use the trucking time for every pair of locations. This reduction can cut away optimal solutions. For example, in some problems, first trucking a container further away from your destination before shipping it to the destination, would have given the optimal solution.
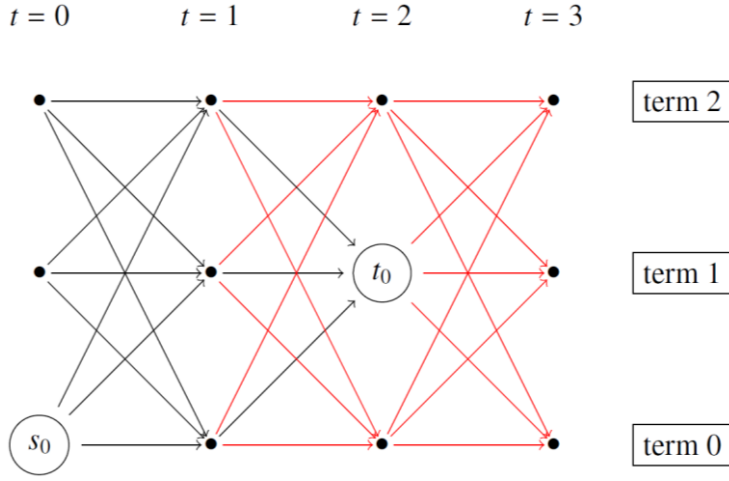
Figure 5: Obsolete Time Reduction

3.5 Time Reductions

Reduction I: Obsolete Time Reduction Let $v \in V$ be a time-space node, then we define $\tau(v)$ to be its *time* and $\chi(v)$ its *location*. Clearly a commodity can never take arcs that begin before its origin node time or end after its deadline. Instead of combining bookings in a commodity as in reduction B, one could remove those obsolete arcs entirely from the model. For every commodity $k \in K$ we remove all variables with $t + a(loc1,loc2,w)$ bigger than the time of its sink node $\tau(t_k)$, so $t + a(loc1,loc2,w) > \tau(t_k)$. We also remove all arcs with $t < \tau(s_k)$.

This reduction can even be enhanced by also removing variables with: $t + a(loc1,loc2,w) = \tau(t_k)$ and $loc2 \neq \chi(t_k)$, where $a(loc1,loc2,w)$ is the travel time for vehicle (type) w from location $loc1$ to location $loc2$. Similarly for the source we obtain $t = \tau(s_k)$ and $loc2 \neq \chi(s_k)$.

In Figure 5 we see an example of the truck arc variables the basic reduction removes for commodity 0 in red.

Reduction J: Time Slot Reduction It is not always possible to go to a terminal. If the available time slots are known, then that information can be used to severely reduce the number of variables in the model. If an arc goes to a time-space node for which the location is not available at that time, then we instead let the arc go to the time-space node at that location that corresponds to the soonest time at which the location is available. If no such time exists we remove the arc completely. If we get parallel arcs that correspond to the same vehicle type, then we merge them. We do a similar process for if the time-space node from which the arc leaves is not an available time-space pair.

4 Results

In this section we present results of the reduction in calculation time by using some of the proposed network reductions on a test instance. The instance has eight terminals locations and

two groups of six barges. All barges that belong to the same group have the same capacities, travel times, and begin and end location. Therefore, all barges in the same group are modelled with one variable $w \in W$ in the model (Reduction C) unless stated otherwise. We assume an infinite number of trucks at every terminal, but restrictions may be added if that is desired. The travel times of the vehicles are based on data from practice and the truck travel times on data from Google Maps (Page and Pichai, 2018). Every truck can carry exactly one (40 feet) container. We choose to look at a time span of 36 hours with time steps of one hour, where 50 bookings and 100 containers are scheduled. We let the cost on the non-horizontal truck arcs be equal to the travel time of the arc. This models a company that owns barges and has to pay additional cost when trucking containers. We make sure that it is possible to truck a booking to its destination, so its deadline should be (at least one time stamp) later than its release date. Besides the terminal locations, there are two customer locations in the model. The customer locations are not reachable by barge. So in the time-space network none of the barge arcs are incident to customer locations (that are not accessible by barge). Trains or other (types of) vehicles are initially not in the model, but could easily be added. We solved our ILPs with IBM's CPLEX solver (IBM, 2017).

In all the experiments reduction I is used, because it is not beneficial to add variables that cannot be non-zero in any feasible solution. The variables that are removed by reduction I and those that are removed by reduction E can never be used even if they are included in the model. The solver CPLEX removes many of those variables already automatically in the pre-processing phase. Therefore, these two reductions may influence the time for the pre-processing more than the time required for the actual solving. Though, an experiment in the past did show that reduction I also reduced the computation time of the solving phase. We will turn the reductions A-G on and off to see how they influence the computation time. In Table 1 the results are shown. Computation times are the total computation time for solving the problem on a DELL E7240 laptop with an Intel(R) Core(TM) i5-4310U CPU 2.00 GHz 2.60 GHz processor. The laptop is operational on a 64-bit operating system.

Table 1: Numerical results of reductions

Reduction	Active	Parameter	Comp. Time	Solution
A	No	$K=25$	$7.12s$	2600 (opt.)
A	Yes	$K=25 \rightarrow 20$	$5.86s$	2600 (opt.)
A	No	$K=50$	$67.45s$	3760 (opt.)
A	Yes	$K=50 \rightarrow 39$	$61.16s$	3760 (opt.)
B	No		$61.16s$	3760 (opt.)
B	Yes		$43.35s$	3760 (opt.)
C	No	$|W|=6$	$1667.61s$	3760 (opt.)
C	Yes	$|W|=5$	$628.58s$	3760 (opt.)
C	Yes	$|W|=4$	$183.51s$	3760 (opt.)
C	Yes	$|W|=3$	$61.16s$	3760 (opt.)
D	No		$117.61s$	3760 (opt.)
D	Yes	Sink Incoming	$61.16s$	3760 (opt.)
D	Yes	Sink In/Out	$64.58s$	3760 (opt.)
D	Yes	Complete	$58.50s$	3760 (opt.)
F	No		$129.98s$	3760 (opt.)
F	Yes		$61.16s$	3760 (opt.)
G	No		$> 300.00s$	-
G	Yes		$61.16s$	3760 (opt.)

Reduction A is used to reduce the initial number of commodities $|K| = 50$ to $|K| = 39$. For this reduction the computation time of the ILP with this reduction and without are compared and we also split some commodity into sub commodities to investigate the effect of taking a larger set $|K|$ on the computation time. Our set of vehicle types $W = \{$truck, typeAbarge, typeBbarge$\}$ is obtained by applying reduction C. If we only merge some of those barges of the same type or none of them, then we are using reduction C partially or not at all. In those cases the set of vehicle (types) W is larger as we see in the table in the comparisons for reduction C. Reduction D is also implemented completely and partially to get some better insight in the effect of the reduction.

5   Conclusion

Reduction A seems to help a little, but clearly is most effective if there are many bookings with the same/similar sinks. The reduction may be less effective than expected, because adding multiple sources for a commodity may make the problem more difficult to solve. From theory it is expected that reduction A is beneficial, if it is the number of commodities that blows up the computation time and many bookings have the same sink location. Reduction B surprisingly leads to better results, though it increases the number of variables because it was implemented together with reduction I. Reduction C is a very powerful tool. Reduction C does require a company to have many identical vehicles, though. Reduction D halves the computation time for our instance. Reduction F is effective, though we do need to do pre-calculations to use it. Reduction G is very effective. We do need however to know the structure of the waterways to use it. Reduction H is expected to do well just like other location reductions. It is however possible that good solutions will be removed by using this reduction. Reduction J may be the most powerful reduction of them all. If the time windows at which locations can be visited are small, then many variables will disappear from the problem. The effectiveness of this reduction depends on the number of time stamps at which terminals are accessible. If there are few of those moments, than it will probably drastically reduce the computation time.

Acknowledgements

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Synchromodality in the Physical Internet: Real-time Switching in a Multimodal Network with Stochastic Transit Times

Hannah Yee[1], Joren Gijsbrechts[1] and Robert Boute[1,2]
1. Research Center for Operations Management, KU Leuven, Belgium
2. Technology and Operations Management Area, Vlerick Business School, Ghent, Belgium
Corresponding author: joren.gijsbrechts@kuleuven.be

Abstract: *Environmental concerns raise the need for more efficiency and sustainability in the freight transportation sector. For this purpose, the Physical Internet is introduced, which aims to connect logistics networks into one hyperconnected supernetwork. To transport freight over such an integrated network, the innovative concept of synchromodality is presented. Synchromodality is defined by the usage of multiple modalities when planning shipments, where real-time switching between transportation modes is possible. In this work, we introduce a synchromodal planning model that constructs optimal transportation routes in a multimodal network with stochastic transit times, formulated as a mixed-integer linear programming problem. To cope with the transit time stochasticity, transportation routes are adapted in accordance to real-time information about the transit time outcome. In a numerical study, we demonstrate the potential advantages that synchromodality entails in terms of costs, service quality and environmental impact.*

Keywords: *Physical Internet, synchromodality, multimodal network, stochastic transit times, optimization, mixed-integer linear programming*

1 Introduction

The logistics industry and its ecological footprint cause an increased pressure for more efficient and sustainable operations. In 2015, the transportation sector represented 18% of all man-made CO_2 emissions, with freight transportation accounting for almost half of these emissions (ITF, 2017). Moreover, if current practices are pursued, the OECD projects a 60% increase in transportation emissions by the year 2050, primarily driven by growing freight transportation emissions. The European Commission strives to limit further environmental damage and is determined to transition to a low carbon economy by the year 2050. The roadmap towards achieving this target enforces the transportation sector to cut its emissions by at least 60% (European Commission, 2011). Consequently, a fundamental change is needed in freight transportation operations to achieve the desired CO_2 emissions reductions.

In order to transition towards more efficiency and sustainability in the freight transportation sector, Montreuil (2011) introduced the holistic concept of the Physical Internet. The Physical Internet, inspired by the digital internet, aims to make the global logistics system more connected, leveraging technologies and algorithms. As such, separate logistics networks and services are integrated into one hyperconnected network, which includes multiple transportation modes.

Transporting freight over such an integrated network raises the opportunity to realize a modal shift, which is a promising method to accomplish significant decarbonization in the freight transportation sector (McKinnon, 2016). This modal shift implies that transportation modes such as rail and barge transportation gain importance over road transportation, because they are less carbon-intensive. Currently road transportation prevails, representing approximately three-

quarters of all inland freight transportation in the EU (Eurostat, 2018), in spite of having the highest carbon intensity per ton-km. It is then rather evident that increasing the share of alternative transportation modes can result in substantial carbon emission reductions. In fact, one of the key goals of the Transport 2050 plan is a 50% shift from road to rail and barge transportation by 2050. In addition, these transportation modes are often available at a lower unit transportation cost, which is even more favorable for the companies involved. However, greener transportation modes are typically less flexible as they have longer shipping times and require larger quantities to make them economically advantageous, which makes road transportation favored again.

Up to now, the modal shift towards more sustainable transportation modes has been rather limited. Unimodal road transportation is still the most preferred freight transportation mode. Its flexibility and speed cause road transportation to be perceived as superior and create a barrier to use other transportation modes, regardless of the advantages offered by these alternatives (Tavasszy, Bedhani & Konings, 2015; Meers et al., 2017). This emphasizes the need for innovations that exploit the advantages of each transportation mode at all time, in order to encourage the modal shift and improve sustainability.

One such innovation is presented by the concept of synchromodality, which emerged during the past decade. Synchromodal freight transportation is defined by the usage of multiple modalities when planning shipments, depending on the characteristics of the freight, where switching between transportation modes is possible (Tavasszy, Janssens, van der Lugt & Hagdorn, 2010). The integrated view of different modalities allows for optimization of trade-offs between the different transportation modes (Tavasszy et al., 2015). The innovative aspect of synchromodality is that transportation decisions can be made based on real-time information about the transportation network. In other words, transportation routes are not fixed in advance but can be adapted to real-time information, under the reasoning that more informed decisions are better (Reis, 2015). Consequently, the best transportation mode is chosen at all times, given the characteristics of the freight and the prevailing network conditions (ALICE, 2014). For instance, less urgent shipments can use slower but more sustainable transportation modes, while shipments with a closer due date make use of faster transportation modes. This approach provides more planning flexibility, which facilitates in dealing with uncertainty in the network (e.g.: transit time, service availability, etc.).

Another crucial element of synchromodality is that logistics service providers (LSPs) act as the principal agents, i.e. they are in charge to decide which transportation mode is used (Dong et al., 2017). The underlying concept is that shippers make mode-free bookings at an LSP, which is key to enable real-time planning. The shipper only specifies the core requirements, such as the due date and destination, and gives the LSP the responsibility to construct the transportation route. This provides the LSP with the freedom to select the optimal transportation modes in response to real-time conditions.

Along these lines, synchromodality entails a more efficient utilization of all modalities. As a result, it supports the modal shift from road transportation towards other transportation modes and corresponding CO_2 reductions are realized (ALICE, 2014). Nevertheless, due dates can still be respected thanks to the increased planning flexibility. Thus, it can be concluded that synchromodality presents an opportunity to achieve a more sustainable transportation system without giving in on service quality.

Real-time planning is a key aspect of synchromodality. Hence, dynamic planning models are essential to ensure the successful implementation of synchromodality (Pfoser, Treiblmaier & Schauer, 2016). However, models concerning synchromodal freight transportation planning are

rather limited, as it is a relatively new concept. The purpose of this paper is to develop a model that supports an LSP in constructing the optimal transportation routes for a set of orders, with the objective of minimizing total transportation costs. Our model includes stochastic transit times to reflect the reliability of transportation modes. For instance, an unreliable rail system can result in occasional delays and consequently more variation in the rail transit times. Adapting routing decisions to real-time information can assist to cope with this stochasticity. The implementation of synchromodal planning while dealing with stochastic transit times has not yet been studied. As such, we contribute to the literature with this work, while providing insight in the potential cost and environmental benefits of synchromodality.

2 Literature review

Transportation models can be classified under different levels, depending on their planning horizon, as proposed by Crainic and Laporte (1997). At the operational (short-term) planning level, models operate in a dynamic environment and include the time dimension. Decisions are made in response to real-time data that becomes available at every time step. Given the features of synchromodality, the model developed in this work is classified under the operational planning level. Literature reviews on multimodal freight transportation planning acknowledge that there are not many models at the operational level yet (SteadieSeifi, Dellaert, Nuijten, van Woensel & Raoufi, 2014; Van Riessen, Dekker & Negenborn, 2015). This raises the opportunity to contribute to the literature by developing the proposed model of this work. Accordingly, existing models for synchromodality at the operational level are reviewed, as this is the planning level to which this work contributes.

Several papers deal with uncertainty regarding the freight demand in a synchromodal system. Xu, Cao, Jia & Zang (2015) determine the optimal container capacity allocation at an operational level, where overage and shortage in capacity are penalized. Perez Rivera & Mes (2016) decide on selecting services and transfers to transport freight to their destination, while minimizing cost over a multi-period horizon. Both models assume that there is probabilistic knowledge about the demand arrivals. Nevertheless, the model of Xu et al. (2015) does not apply in great extent to this work. The model only optimizes current capacity decisions to the given demand probability but does not allow to adapt plans afterwards. In this regard, the model of Perez Rivera & Mes (2016) is far more interesting, as it also allows to adjust the planning at each time step. Again, decisions are made in consideration of the probability on future demands, where the entire planning horizon is taken into account. However, only the part of the transportation plan related to the current decision moment is implemented. In the next period, decisions are optimized in response to the newly available demand information. On this subject, Perez Rivera and Mes show applicable features on modeling the decision variables in a multi-period planning horizon. Moreover, both models are noteworthy for the fact that they anticipate uncertainty through probabilistic knowledge. In the problem setting of this work, a similar approach can be implemented to anticipate the stochasticity of the transit times when optimizing the transportation plans.

Other research focuses on planning adaptation when dealing with disturbances. Van Riessen, Negenborn, Dekker & Lodewijks (2013) look into service disturbances, such as early service departure, late service departure and service cancellation. In their work, they construct the transportation planning for one week and adapt it whenever a service disturbance occurs. Planning decisions are optimized in response to new information that becomes available, which is similar to the approach of Perez Rivera & Mes (2016). However, the proposed model only considers adjusting the planning when there is a disturbance in the weekly network service design, otherwise the plan is executed as initially planned. Thus, van Riessen et al. (2013b)

await the occurrence of disturbances, whereas we take an anticipatory stance by incorporating the transit times stochasticity. Nevertheless, it is interesting to observe once again that the literature implements adaptation of the transportation plan based on new information.

Another study implementing adaptive planning is the work of Li, Negenborn & De Schutter (2015), which deals with disturbances concerning changes in demand flow and traffic conditions that influence the transit time. Their model decides on the optimal multimodal container flow at every time step of the planning horizon in order to minimize costs and is modeled as a linear programming problem. Yet, only the decisions for the current time step are implemented, which allows to adapt the planning in future periods. Uncertainty in demand flow and traffic conditions is tackled by using an estimate of their future values, and these estimates are then taken into account when optimizing the problem. In the problem of this work, it is not adequate to merely use one single estimate for the transit time between two terminals. The reasoning is that it is known that different transit times can occur. Therefore, the different transit time scenarios and the corresponding probability distribution need to be considered when making decisions. This work aims to address the stochasticity accordingly, while the approach of Li et al. (2015) does not allow to anticipate that parameters can take on different values.

To summarize, synchromodal freight transportation models that allow real-time adaptation in response to an uncertain element exist in the literature, yet they are still scarce. Current studies include models and planning methods that deal with uncertainty in demand, service disturbances or traffic conditions. In spite of the fact that the consequence of disturbances and uncertain traffic conditions can be identified as transit time stochasticity, the discussed studies do not include the anticipatory aspect such as this work does. Hence, no existing research in the field of synchromodality copes with anticipated transit time stochasticity in the transportation planning problem. This points out the opportunity to contribute to the literature with this work.

3 Methodology

In this paper, we aim to develop a planning model that supports an LSP in constructing transportation routes for a set of orders with the objective of minimizing total costs. The model includes stochastic transit times, which is dealt with by adapting routing decisions to real-time information. We use the model to investigate the impact of real-time planning adaptability in terms of costs, service quality and modal split, when operating in a multimodal network to create insight in the advantages that synchromodality entails.

3.1 Network description

The model is applied to a multimodal network, which includes multiple transportation modes such as road, rail and barge transportation, to enable the integration of multiple modalities. In this work, the multimodal network is represented as a directed graph $\mathcal{G}(\mathcal{A}, \mathcal{N})$, where $\mathcal{N}$ represents the set of terminals and $\mathcal{A}$ represents the set of legs that connect the terminals. The set of terminals $\mathcal{N}$ includes the set of origin terminals $\mathcal{N}_o$, the set of intermediate terminals $\mathcal{N}_t$ and the set of destination terminals $\mathcal{N}_d$. Set $\mathcal{N}_o$ covers the shipper terminals where shipments originate, set $\mathcal{N}_d$ contains terminals which are destinations for shipments and set $\mathcal{N}_t$ comprises all intermediate terminals where freight can be transshipped. Consequently, transportation orders are shipped from a terminal in set $\mathcal{N}_o$ to a terminal in set $\mathcal{N}_d$. The set $\mathcal{A}$ includes the existing legs between terminals for all transportation modes. A leg (i, j, m) in set $\mathcal{A}$ is therefore defined by the two terminals (i) and (j) it connects and the transportation mode it represents (m). Given this network description, a transportation route essentially consists of a sequence of legs that connects the origin terminal to the destination terminal of the order. An example of a

multimodal network in this representation is illustrated in Figure 1. The example models three transportation modes: truck (T), barge (B) and train (R). According to this example, the sets are:

$\mathcal{N}_o = \{1,2\}, \mathcal{N}_t = \{3,4,5,6\}, \mathcal{N}_d = \{7,8,9\}, \qquad \mathcal{N} = \mathcal{N}_o \cup \mathcal{N}_t \cup \mathcal{N}_d = \{1,2,3,4,5,6,7,8,9\}$

$\mathcal{A} = \{(1,3,\text{T}), (1,3,\text{R}), (1,4,\text{T}), (1,4,\text{B}), (1,5,\text{R}), (1,6,\text{B}), (2,3,\text{T}), (2,6,\text{T}), (2,6,\text{B}),$
$(3,4,\text{T}), (3,4,\text{R}), (3,6,\text{T}), (3,9,\text{R}), (4,5,\text{B}), (4,5,\text{T}), (4,6,\text{T}), (4,8,\text{R}), (5,7,\text{T}),$
$(5,7,\text{R}), (5,8,\text{T}), (5,9,\text{R}), (6,5,\text{T}), (6,8,\text{T}), (6,9,\text{B}), (6,9,\text{T})\}$
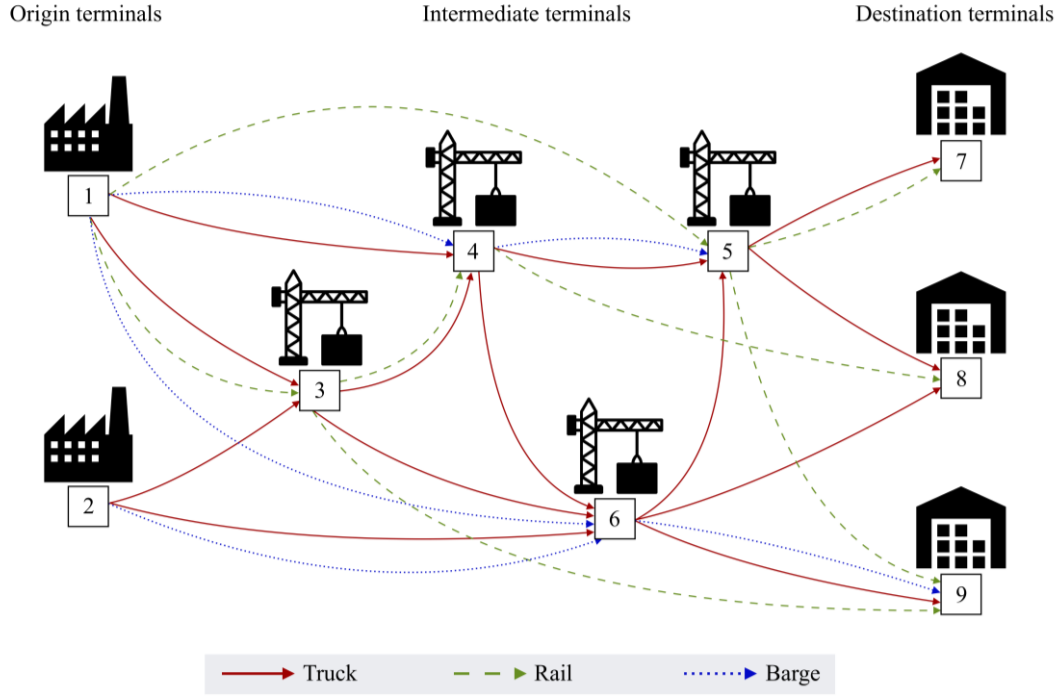
Figure 1: Example of the network representation.

The network has several characteristics that are relevant for the transportation planning problem. With respect to the transportation legs, every leg has a variable transportation cost ($c_{i,j,m}^V$). Furthermore, the legs are characterized by a transit time ($l_{i,j,m}$), represented as a discrete number of time periods. This work considers a network in which these transit times are stochastic. The stochasticity is modeled through a number of transit time scenarios (S) for each leg, where each scenario has a known probability ($p_{i,j,m}^S$). The model is built for stochastic transit times; however, it implicitly covers the case of deterministic transit times, in which the probability of a certain transit time realization equals one.

The terminals of the network also have features that need to be taken into account. Transshipment costs ($c_{g,m}^T$) are incurred whenever a freight unit is transshipped from transportation mode g to m at an intermediate terminal. All these network characteristics are taken as input parameters for the transportation planning problem.

3.2   Model description

When implementing synchromodality, it is critical that the LSP provides the transportation service at the lowest possible price that attains an acceptable service quality to convince shippers to make bookings (Pfoser et al., 2016; Verweij, 2011). To this end, the model constructs transportation routes with the objective of minimizing total costs. These costs include

the variable transportation costs, the terminal transshipment costs, and a penalty that is incurred when an order exceeds its due date. Including a penalty for late delivery ensures that the model strives to reach the due date. How much the LSP is penalized for late delivery depends on the relative importance of on-time delivery to a low booking price.

The LSP determines the optimal transportation route for every order that needs to be shipped. Each order is characterized by an origin terminal (o_n), a destination terminal (d_n), a number of freight units (f_n) and a number of periods until the due date (k_n). In the model, it is assumed that orders are not split up during the transportation, such that the customer receives the entire order at once. This way, the customer can be sure that the shipment contains the requested number of units, and the receiving procedures, such as unloading or inspection, only need to be performed once.

Transportation routes are optimized in a network which features stochastic leg transit times, with a predefined probability distribution over the possible transit time scenarios. These transit times are expressed in terms of time periods, so the LSP is actually planning over a time horizon. Consequently, it is required to add a time dimension to the planning decisions, in order to clarify which routing decision is made at which time step. In the optimization model, the planning horizon is expressed as a number of time periods (T) and is set at least equal to the longest path that exists in the network, such that all possible transportation plans fall within this horizon. It is assumed that the network remains the same in all time periods of the planning horizon.

When an order travels a leg with a stochastic transit time, the outcome of the transit time only becomes known upon arrival at the end terminal of the traveled leg. In other words, it is not possible to determine in advance which transit time will occur. Yet, the optimal mode selection for the remainder of the transportation route depends on the realized transit time duration. For instance, when a leg turns out to have a long duration, switching to a faster transportation mode for the next part of the route can compensate for this. On the other hand, it can occur that the actual transit time is short. This earliness can be exploited by switching to slower transportation modes for the rest of the route to benefit from cost advantages. In other words, the realized transit time influences the urgency of the order when it arrives at a terminal, which affects the optimal routing decision. Therefore, the planning must allow that transportation routes are adapted based on real-time information about the actual transit times.

To this end, the model specifies the optimal decision to be taken in a terminal given the time period in which the decision has to be made, which is depends on the transit time realizations. Accordingly, the model actually provides a decision guide conditional on the time period that the decision has to be made. This implies that the LSP only executes the decision that applies to the actual time period he is in, without fixing the subsequent part of the transportation route. This enables him to adapt the transportation plan later on in accordance to transit time information that becomes available in real-time. The optimal transportation decision at a particular time step is determined with the purpose of minimizing the expected costs, given the stochasticity in the transit times. To achieve these expected cost calculations, the model anticipates the optimal decisions that will be made in future periods whenever a particular scenario is realized, while taking the corresponding probabilities into account. The next subsection clarifies how these aspects are implemented in an optimization model.

3.3   Optimization model

The developed optimization model is formulated as a mixed-integer linear programming problem. An overview of the notation is given in Table 1.

Table 1: Notation used in the optimization model.

Sets	
$\mathcal{N}$	Set of terminals
$\mathcal{A}$	Set of legs that connect the terminals
$\mathcal{M}$	Set of transportation modes available in the network
$\mathcal{O}$	Set of orders
$\mathcal{T}$	Planning horizon, $\mathcal{T} = \{0,1,2,\ldots,T\}$
$\mathcal{S}$	Transit time scenarios, $\mathcal{S} = \{1,\ldots,S\}$

Parameters	
T	Time horizon
S	Number of transit time scenarios per leg
$c_{i,j,m}^{V}$	Variable transportation cost of sending one freight unit over leg (i,j,m)
$c_{g,m}^{T}$	Cost of transshipping one freight unit from transportation mode g to transportation mode m
ρ	Penalty per freight unit per period of late delivery
$l_{i,j,m}^{s}$	Transit time of leg (i,j,m) under scenario s as a number of time periods
$p_{i,j,m}^{s}$	Probability of transit time scenario s for leg (i,j,m)
o_n	Origin terminal of order n
d_n	Destination terminal of order n
f_n	Number of freight units in order n
k_n	Due date of order n
Z	Large value

Decision variables	
$x_{i,j,m,t}^{n}$	1 if order n is transported over leg (i,j,m) at period t, 0 otherwise

Output variables	
$w_{i,g,m,t}^{n}$	1 if order n is transshipped from transportation mode g to transportation mode m in terminal i at period t, 0 otherwise
$E[C^{V}]_{i,j,m,t}^{n}$	Expected variable transportation cost for order n until reaching its destination when transporting over leg (i,j,m) at period t
$E[C^{T}]_{i,g,m,t}^{n}$	Expected transshipment cost for order n until reaching its destination when transshipping from mode g to mode m in terminal i at period t
$E[\rho]_{i,j,m,t}^{n}$	Expected penalty cost for order n when reaching destination its destination when transporting over leg (i,j,m) at period t

The objective function and constraints of the optimization model are presented as follows.

Minimize

$$\sum_{n \in \mathcal{O}} \sum_{(i,j,m) \in \mathcal{A}} E[C^{V}]_{i,j,m,0}^{n} + \sum_{n \in \mathcal{O}} \sum_{g,m \in \mathcal{M}} E[C^{T}]_{i,g,m,0}^{n} + \sum_{n \in \mathcal{O}} \sum_{(i,j,m) \in \mathcal{A}} E[\rho]_{i,j,m,0}^{n} \qquad (1)$$

The objective function (1) minimizes the total expected cost of the routing decisions made at the start of the planning horizon, $t = 0$. These expected costs include the variable transportation costs and transshipment costs of the entire route until reaching the destination, and the expected penalty costs for late delivery. This optimization determines the set of optimal decisions over the entire planning horizon, because the expected costs anticipate the optimal decisions that will be made in future periods whenever a particular scenario is realized.

With regard to the constraints to which the model is subjected, there are three sets of constraints: the network flow constraints (2)-(7), the expected cost constraints (8)-(9) and the expected penalty constraints set (10). Each of these sets is presented consecutively.

3.3.1 Network flow constraints

$$\sum_{(o_n,j,m)\in\mathcal{A}} x^n_{o_n,j,m,0} = 1 \qquad\qquad \forall n \in \mathcal{O} \tag{2a}$$

$$\sum_{(i,j,m)\in\mathcal{A}} x^n_{i,j,m,0} = 1 \qquad\qquad \forall n \in \mathcal{O} \tag{2b}$$

$$x^n_{i,j,m,t} \leq \sum_{(j,k,h)\in\mathcal{A}} x^n_{j,k,h,t+l^s_{i,j,m}} \qquad\qquad \forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, \forall t \in \mathcal{T}, \forall s \in \mathcal{S} \tag{3}$$

$$\sum_{(i,j,m)\in\mathcal{A}} x^n_{i,j,m,t} \leq 1 \qquad\qquad \forall n \in \mathcal{O}, \forall i \in \mathcal{N}, \forall t \in \mathcal{T} \tag{4}$$

$$x^n_{d_n,d_n,storage,T} = 1 \qquad\qquad \forall n \in \mathcal{O} \tag{5a}$$

$$\sum_{(i,j,m)\in\mathcal{A}} x^n_{i,j,m,T} = 1 \qquad\qquad \forall n \in \mathcal{O} \tag{5b}$$

$$1 + w^n_{i,g,m,t+l^s_{k,i,g}} \geq x^n_{k,i,g,t} + x^n_{i,j,m,t+l^s_{k,i,g}} \qquad \forall(k,i,g) \in \mathcal{A}, \forall(i,j,m) \mathcal{A}, \forall t \in \mathcal{T}, \forall s \in \mathcal{S} \tag{6a}$$

$$w^n_{i,storage,m,0} \geq x^n_{i,j,m,0} \qquad\qquad \forall(i,j,m) \in \mathcal{A}, i \in \mathcal{N}_o \tag{6b}$$

$$x^n_{i,j,m,t} \in \{0,1\} \qquad\qquad \forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, \forall t \in \mathcal{T} \tag{7a}$$

$$w^n_{i,g,m,t} \in \{0,1\} \qquad\qquad \forall n \in \mathcal{O}, \forall i \in \mathcal{N}, \forall g,m \in \mathcal{M}, \forall t \in \mathcal{T} \tag{7b}$$

The first set of constraints (2) to (7) includes the network flow constraints, which ensures that a connected path is formed from the origin to the destination terminal for each order. Constraint (2a) initiates the transportation route by imposing that a leg is selected from the origin terminal of the order at the start of the planning horizon. In addition, constraint (2b) makes sure that this is the only terminal from which a transportation route can be started for the order. Constraint (3) ensures that a connected sequence of legs is selected, while taking the time dimension into account. More specifically, this constraint ensures that whenever a particular leg is selected for an order, another connected leg must be selected at the time the order arrives at the end terminal of the traveled leg. However, there are multiple scenarios for the transit time. For this reason, a connected leg must be selected for every possible arrival time, given the transit time scenarios. Thus, a connected path is constructed for every possible scenario that can occur. Constraint (4) enforces that at most one leg can be selected for an order that is present in a terminal at a time step. This is in line with the assumption that orders are not split up during the transportation

Subsequently, constraint (5a) and (5b) make sure that the order arrives at its destination for all potential scenario instances. With constraint (5a), the model imposes that the order must be in the storage of its destination terminal, i.e. the order has arrived at its destination, by the end of the planning horizon. Subsequently, constraint (5b) imposes that only this storage leg is allowed to be selected for the order at the last time period. Together, these constraints ensure that the order reaches the destination for every possible development of scenarios. Thereafter, constraint (6a) deals with the transshipment variable $w^n_{i,g,m,t}$ when transshipping an order from one

transportation mode to another in a terminal, while (6b) specifically deals with this variable for origin terminals at time 0. At last, constraint (7a) and (7b) define the relevant decision and output variables as binary.

3.3.2 Expected cost constraints

$$E[C^V]_{i,j,m,t}^n \geq c_{i,j,m}^V f_n + \sum_s p_{i,j,m}^s \sum_{(j,k,h)\in\mathcal{A}} E[C^V]_{i,j,m,t+l_{i,j,m}^s}^n - Z(1-x_{i,j,m,t}^n)$$

$$\forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, \forall t \in \mathcal{T} \qquad (8a)$$

$$E[C^V]_{i,j,m,t}^n \geq 0 \qquad\qquad \forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, \forall t \in \mathcal{T} \qquad (8b)$$

$$E[C^T]_{i,g,m,t}^n \geq c_{g,m}^T f_n + \sum_s p_{i,j,m}^s \sum_{(j,k,h)\in\mathcal{A}} E[C^T]_{i,m,h,t+l_{i,j,m}^s}^n - Z(1-w_{i,g,m,t}^n) - Z(1-x_{i,j,m,t}^n)$$

$$\forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, i \in \mathcal{N}_t, \forall g \in \mathcal{M}, \forall t \in \mathcal{T} \quad (9a)$$

$$E[C^T]_{i,g,m,t}^n \geq \sum_s p_{i,j,m}^s \sum_{(j,k,h)\in\mathcal{A}} E[C^T]_{i,m,h,t+l_{i,j,m}^s}^n - Z(1-w_{i,g,m,t}^n) - Z(1-x_{i,j,m,t}^n)$$

$$\forall n \in \mathcal{O}, \forall(i,j,m) \in \mathcal{A}, i \in \mathcal{N}_o, \forall g \in \mathcal{M}, \forall t \in \mathcal{T} \quad (9b)$$

$$E[C^T]_{i,g,m,t}^n \geq 0 \qquad\qquad \forall n \in \mathcal{O}, \forall i \in \mathcal{N}, \forall g,m \in \mathcal{M}, \forall t \in \mathcal{T} \qquad (9c)$$

Constraint (8a) to (9c) define the computation of the expected costs. To begin with, constraint (8a) and (8b) specify the expected variable cost of transporting an order over leg (i,j,m) at time t. The expected variable cost constraint (8a) includes three elements. The first element is the variable cost of selecting the leg, which depends on the cost of the leg and the number of freight units in the order. The second element is forward-looking, as it anticipates the expected cost of the next decision that will be taken when the order arrives at the end terminal of the selected leg. At this point, the corresponding probabilities for the transit time scenarios are taken into account. It is the uncertainty in the transit time outcome that causes the model to work with expectations of the future variable costs. This forward-looking aspect iterates forward until the end of the time horizon. Consequently, it covers the expected cost from the current time period until the end of the time horizon, or stated differently, until reaching the destination terminal, as defined by constraint (5a) and (5b). Finally, the third element of constraint (8a) and (8b) ensure that the expected variable cost only holds a positive value when the leg (i,j,m) is selected for order n at time t, and holds a value equal to zero otherwise.

Given this formulation, the value of $E[C^V]_{i,j,m,t}^n$ represents the expected variable cost for order n until reaching its destination when selecting leg (i,j,m) at time t. Accordingly, the value of $E[C^V]_{i,j,m,0}^n$ in the objective function represents the expected variable cost to reach the destination for each routing decision made at the current time step, $t = 0$.

Constraint (9a) to (9c) are constructed in a similar manner to determine the expected transshipment cost for order n until reaching its destination when transshipping from transportation mode g to m in terminal i at time t. Constraint (9a) applies to intermediate terminals, while constraint (9b) concerns the origin terminals. This formulation ensures that only the transshipment cost from transshipping at intermediate terminals is taken into account. Moreover, both constraints are constructed so that the expected transshipment cost only holds a positive value when there is effectively a transshipment from transportation mode g to m, otherwise constraint (9c) ensures that the cost is set equal to zero. With regard to the forward-looking element, the last part of the formulation makes sure that the forward-looking element only matters for the leg (i,j,m) that is selected.

3.3.3 Expected penalty constraints

$$E[\rho]_{i,j,m,t}^n \geq \sum_s p_{i,j,m}^s \sum_{(j,k,h)\in\mathcal{A}} E[\rho]_{j,k,h,t+l_{i,j,m}^s}^n - Z(1-x_{i,j,m,t}^n)$$

$$\forall n \in \mathcal{O}, \forall (i,j,m) \in \mathcal{A}, i \in \mathcal{N}_0 \cup \mathcal{N}_t, \forall t \in \mathcal{T} \qquad (10a)$$

$$E[\rho]_{i,j,m,t}^n \geq (t - k_n)f_n\rho - Z(1-x_{i,j,m,t}^n)$$

$$\forall n \in \mathcal{O}, \forall (i,j,m) \in \mathcal{A}, i \in \mathcal{N}_d, \forall t \in \mathcal{T} \qquad (10b)$$

$$E[\rho]_{i,j,m,t}^n \geq 0 \qquad \forall n \in \mathcal{O}, \forall (i,j,m) \in \mathcal{A}, \forall t \in \mathcal{T} \qquad (10c)$$

Finally, the expected penalty cost constraints are presented. Constraint (10a) and (10b) determine the expected penalty cost that will be incurred when reaching the destination when selecting leg (i,j,m) at time t. The origin and intermediate terminals are subjected to constraint (10a), which merely includes the forward-looking element until the destination is reached. When the destination is reached, constraint (10b) applies, where the expected penalty cost is calculated as the number of time periods the order arrives late multiplied with the number of freight units and the penalty. When the order does arrive on time, no penalty is incurred, as constraint (10c) sets the penalty cost equal to zero in this case. Constraint (10a) incorporates the incurred penalty costs, as defined in (10b), with the appropriate probabilities. The last element of constraint (10a) or (10b) and constraint (10c) ensure that the expected penalty cost equals zero for legs that are not selected.

4   Numerical study

4.1   Experimental design

A numerical study is performed to illustrate the optimization model and study the performance of synchromodality.

The multimodal network configuration presented in Figure 2 is used for the experiment. The network consists of three successive corridors connecting one shipper terminal, two intermediate terminals and one destination terminal, with an equal distance between every two consecutive terminals. Three transportation modes, namely, road, rail and barge transportation, are available between the consecutive terminals.
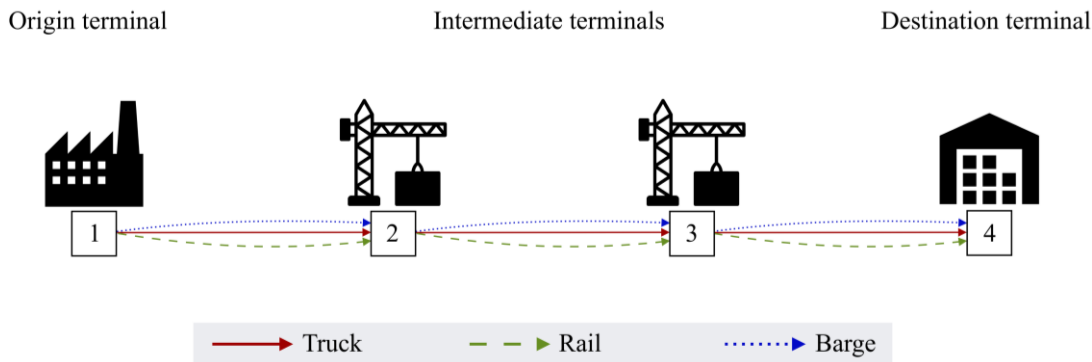
Figure 2: Representation of the network used in the numerical study.

Table 2 provides an overview of the used input parameters, which are composed based on representative industry standards and proportions, extracted from related research papers (Zhang et al. (2017), Li et al. (2015)) and numbers reported by a leading European logistics service provider (Contargo, 2018). Since the distance between the consecutive terminals is identical for the network in this experiment, the input parameters regarding transit time and cost are as well. The experiment works with three transit time scenarios, for which the probability

distribution is assumed to be positively skewed (50% 30% 20%). Transshipment costs equal 20€/TEU when transshipping between two different transportation modes, but no transshipping cost is incurred when there is no modality switch. The penalty per period of late delivery is set equal to 75€/TEU. Furthermore, the planning horizon consists of 27 time periods, which equals the longest possible path that can occur in this network. Finally, the analysis keeps track of the expected CO_2 emissions. The emissions per TEU for every transportation mode in the network are exhibited in Table 2 as well. The experiment considers the transportation planning for ten orders with a due date ranging from 14 to 23. More specifically, the first order is due within 14 periods, the second order is due within 15 periods, and so on. All orders contain one freight unit (i.e. one TEU) and originate from shippers with a transportation demand between origin terminal 1 and destination terminal 4.

Table 2: Variable cost, transit time and CO_2 emission parameters used in the experiment.

Transportation mode	Variable cost (€/TEU)	Transit time scenarios	CO_2 emissions (kg CO_2/TEU)
Road	200	3 / 4 / 5	200
Rail	120	5 / 6 / 7	70
Barge	80	7 / 8 / 9	50

To illustrate the implications of the model, the optimal synchromodal solutions for the orders with due date 18 and due date 20 are displayed in Figure 3. The solutions are presented in a time-expanded representation, where the horizontal axes represent the terminals and the vertical axes represent the time period. As such, this representation shows the optimal decisions to be taken in a particular terminal, given the time period in which this decision has to be made, which depends on the transit time realizations. For instance, this implies the following for the order with due date 18, as shown in the top graph of Figure 3. If the order arrives early at terminal 3 in time period 10, the optimal decision is to opt for barge transportation. However, if it arrives in time period 11 to 13, rail transportation is optimal. If the transit times turn out to have a long duration, causing the order to arrive in time period 14, it is optimal to choose the faster road transportation. These examples clearly demonstrate how a synchromodal transportation policy provides planning adaptability to cope with transit time stochasticity. When an order arrives early at a terminal, it is optimal to opt for a less expensive but slower transportation mode. However, when a longer transit time emerges and the order arrives later at the terminal, the optimal decision is to use a faster transportation mode to compensate for the tardiness. Hence, the solution allows to choose the best transportation mode for the next part of the route dependent on the realized transit times.

The graphs in Figure 4 summarize the total cost and modal split for every order in the experiment to establish an understanding of the effect of the due date. It is clear that the less urgent the order, the more the transportation route relies on slower, greener and less expensive transportation modes. As a result, the total cost declines as the due date is further in time. From this point of view, shippers can benefit from lower prices when they arrange their shipments to have more extended due dates.

4.2 Analysis

To analyze the performance of a synchromodal transportation system, five different transportation policies are executed for the proposed network. Subsequently, the different policies are compared with regard to expected costs, service quality, modal split and emissions. This way, insight can be gained in the advantages that synchromodality entails. The following policies are evaluated:

(1) Unimodal road transportation
(2) Unimodal rail transportation
(3) Unimodal barge transportation
(4) Multimodal transportation, without the possibility of real-time switching
(5) Synchromodal transportation

Policies (1) to (3) are trivial, the same transportation mode is used for the entire route from origin to destination. For policy (4), a multimodal setting is considered without the real-time aspect of synchromodality. This implies that transshipping to another transportation mode is allowed at the intermediate terminals, yet, the switch cannot be dependent on the time the order arrives at the intermediate terminal. In other words, the shipping route is planned in advance and cannot depend on the transit time outcome. Comparing policy (4) and (5) gives insight in
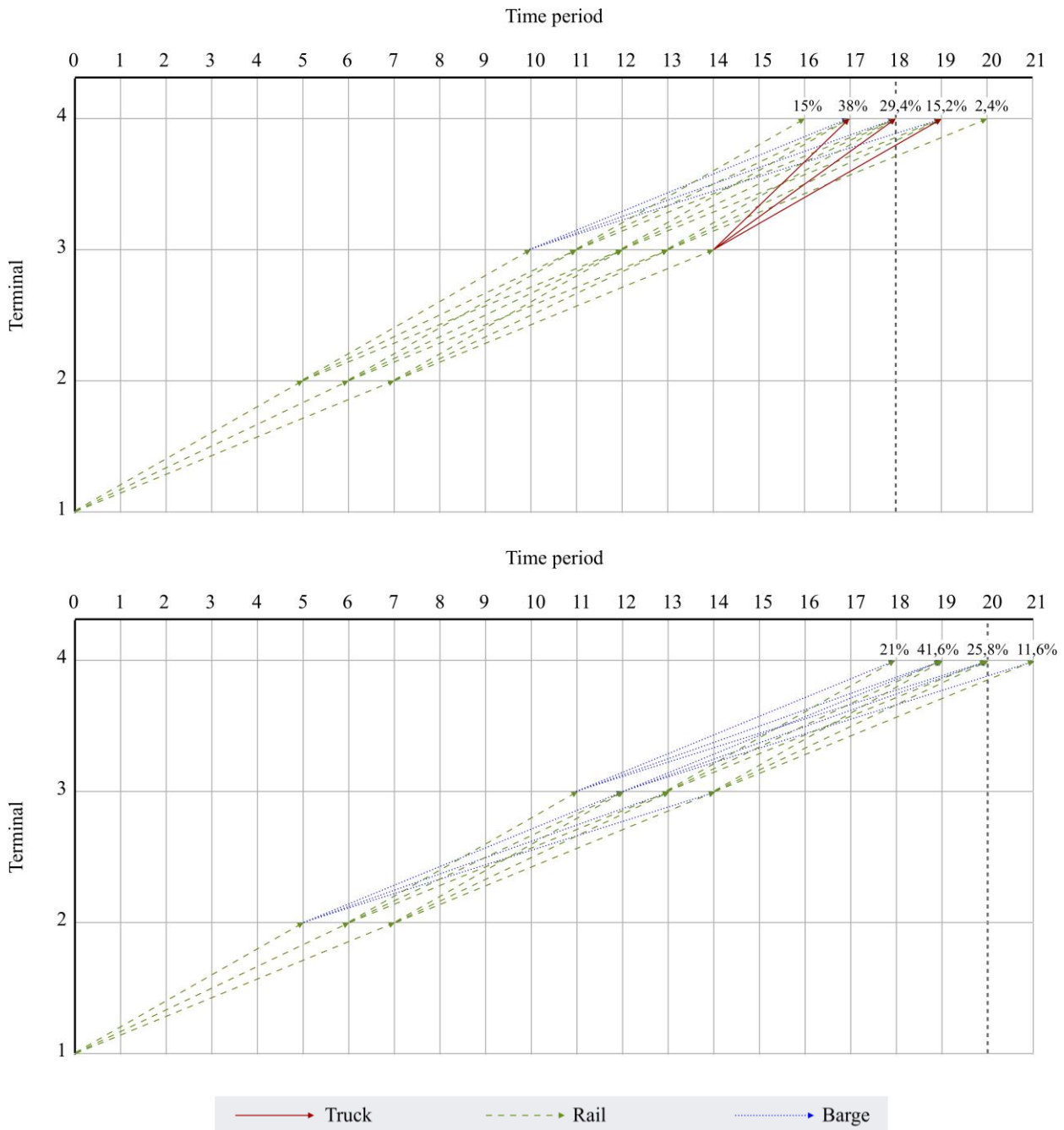
the value of the additional planning flexibility that real-time switching brings along, which characterizes synchromodality.

Figure 3: Time-expanded representation of the synchromodal solutions for the orders with due date 18 and due date 20 in the experiment. The horizontal axes represent the terminals while the vertical axes represent the time period. The solution shows the optimal decision to be taken in a terminal, given the time period in which the decision has to be made, which depends on the transit time realizations.
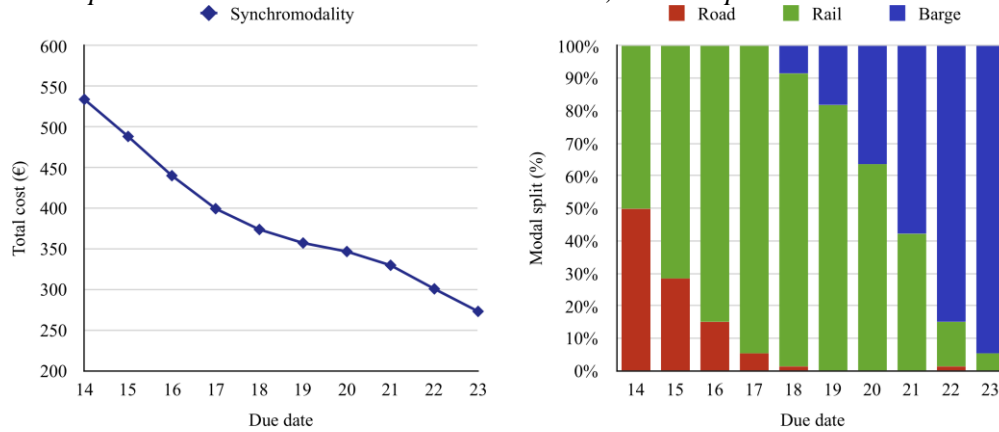
Figure 4: The results for the orders in the experiment, with due dates ranging from 14 to 23. The left panel shows the expected total cost for every order with the corresponding due date in the experiment. The right panel exhibits the expected modal split for every order.

Table 3 reports the results of the experiment for the different transportation policies. Total cost and emissions are expressed as the sum over all orders, while the other factors are expressed as the average over the set of orders. Periods overdue measures the average number of periods an order is expected to arrive late at its destination, and is used as a measure of service quality, where a lower value signifies a higher service quality. The measure is calculated as the probability that the order exceeds the due date multiplied with the lateness whenever this is the case. In this way, the periods overdue measure combines the likelihood and the severity of the due date overrun.

Table 3: Results of the experiment for the different transportation policies in terms of expected values. Total cost and emissions are expressed as the sum over all orders, the other factors are expressed as the average over the set of orders.

Transportation policy	Total cost (€)	Periods overdue	Emissions (kg CO_2)	% Road	% Rail	% Barge
(1) Unimodal road	6000,60	0,0008	6000,0	100%	0%	0%
(2) Unimodal rail	4145,25	0,7270	2100,0	0%	100%	0%
(3) Unimodal barge	5895,00	4,6600	1500,0	0%	0%	100%
(4) Multimodal	3947,40	0,5432	2200,0	6,67%	66,67%	26,67%
(5) Synchromodal	3844,98	0,3173	2313,5	10,10%	59,83%	30,07%

Firstly, these results demonstrate the advantage of using a synchromodal transportation system compared to a unimodal road, rail or barge transportation policy. With synchromodality, a significantly lower emission level is obtained than with unimodal road transportation, which is often the policy used in practice. Moreover, shipments are carried out at roughly two thirds of the costs. With regard to the slower and greener modalities, synchromodality results in a substantially better service quality, indicated by a smaller number of expected periods overdue.

Subsequently, benchmarking synchromodality against multimodal transportation provides insight in the additional value of real-time adaptation when combining multiple modalities in

the transportation route. Multimodal transportation already manages a cost reduction compared to unimodal road and a service quality improvement compared to unimodal rail or barge, yet, the improvements are limited. Allowing transshipments to depend on the arrival time at the terminal results in an additional service quality improvement, measured by a 40% decrease in periods overdue, while delivering the orders at an even lower cost. The underlying reason is that routing decisions can be responsive and adapt to the real-time conditions. Consequently, synchromodality allows the LSP to provide transportation services at a favorable price, while offering a reasonable service quality. This way, shippers are more attracted to book the services of the LSP, as an inadequate service quality often refrains them from doing so. However, it has to be noted that synchromodal transportation does rely more on road transportation in order to better respect the due dates, leading to an increase of 5% in carbon emissions compared to the multimodal case. Nevertheless, emissions remain far below the unimodal road emissions, and thus synchromodality definitely gives rise to a considerable environmental benefit. These results confirm that synchromodality entails a combination of advantages that allows to deviate from unimodal road transportation, realizing an environmentally favorable modal shift.

To better understand the value of real-time routing decisions under different parameter values, sensitivity analyses are performed for several input parameters. Firstly, the impact of the penalty per period of late delivery is investigated. The graphs in Figure 5 represent the results for different values of the overdue penalty, showing the following. When the penalty is raised, the number of periods an order is expected to be overdue decreases, as depicted in the middle panel of Figure 5. This is a logical consequence, as a higher penalty implies that it is more costly for an order to arrive late. To achieve this more punctual compliance to the due date, the transportation routes substitute rail and barge for the respectively faster road and rail transportation. This can be seen in the modal splits shown in the right panel of Figure 5. As a result, total costs increase, as displayed on the left panel of Figure 5. Thus, depending on the relative importance of service quality to low costs, the penalty can be set accordingly. For multimodal transportation, costs increase more steadily than for synchromodal transportation, while synchromodality is superior on service quality as well from a penalty of 50 and onward. Consequently, the higher the penalty, the more advantageous synchromodality becomes compared to multimodality.
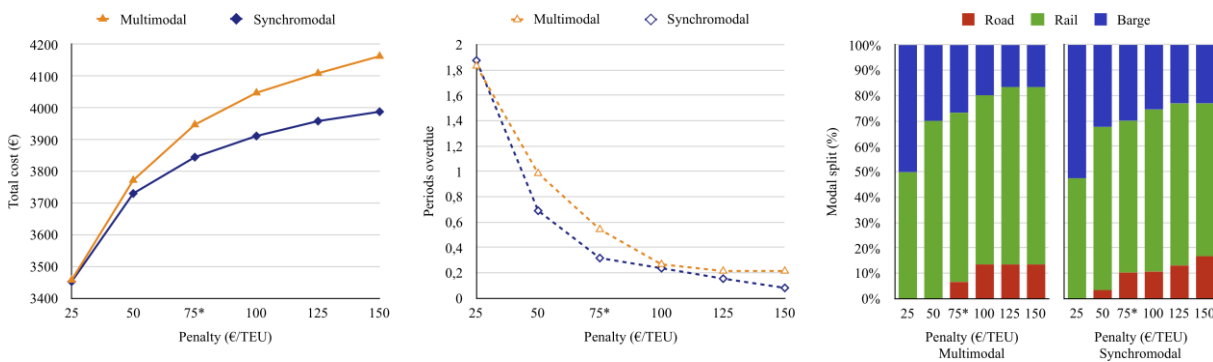
Figure 5: Sensitivity analysis for the penalty per period of late delivery. All graphs show the result for different penalty values for both the multimodal and synchromodal transportation policy. The asterisk indicates the base case setting. The left panel shows the total cost over all orders in the experiment. The middle panel exhibits the average number of periods overdue. The right panel presents the modal split.

Furthermore, a sensitivity analysis is performed for the transshipment cost. Figure 6 exhibits the results in terms of total costs, number of periods overdue and number of transshipments. These results demonstrate the impact of a reduction in transshipment cost. For synchromodality, this implies that transportation routes can be responsive to the real-time conditions at a lower

cost. As a result, more transshipments are made to adapt the routes better to the transit time outcome. This can be observed on the right panel of Figure 6, depicting the expected number
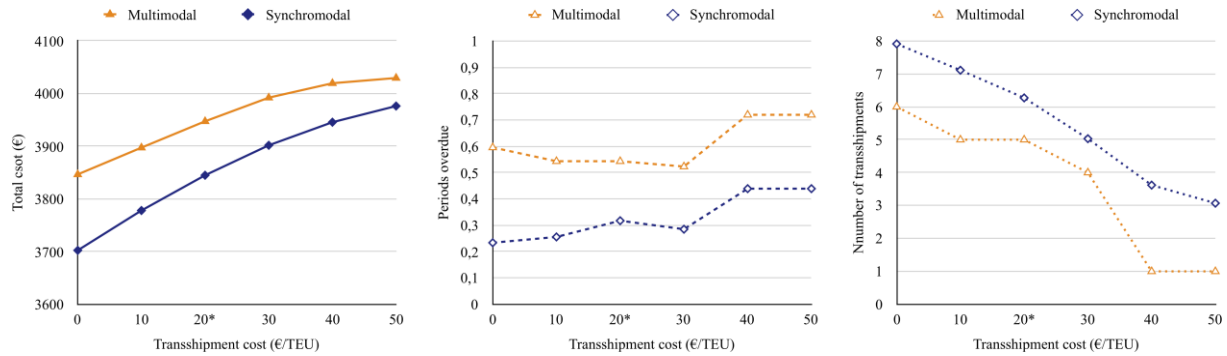
of transshipments over all orders. Moreover, when transshipment costs go down, total costs decrease more steadily for synchromodality. Therefore, the lower the transshipment costs, the more beneficial a synchromodal policy becomes in comparison to a multimodal policy. In addition, the middle panel of Figure 6 shows that synchromodality maintains a better performance in terms of due date overrun, regardless of the transshipment cost.

Figure 6: Sensitivity analysis for the transshipment cost. All graphs show the result for different transshipment cost values for both the multimodal and synchromodal transportation policy. The asterisk indicates the base case setting. The left panel displays the total cost over all orders in the experiment, showing how synchromodal transportation is more beneficial when the transshipment cost is lower. The middle panel exhibits the average number of periods overdue. The right panel presents the total number of transshipments over all orders.

At last, the effect of a CO_2 emission tax is investigated. The carbon tax is expressed in euro per metric ton CO_2 and the emission values from Table 2 are used. Figure 7 displays the results of this analysis, whereby the carbon tax ranges from 0 €/ton CO_2 to 400€/ton CO_2. A first consequence of an increasing carbon tax is a rise in total costs, as the costs of all transportation modes go up. This is shown on the top left graph of Figure 7. Moreover, the tax induces an increase in the relative cost of road transportation, as road transportation has a higher carbon intensity and therefore incurs a higher tax in absolute terms. As a result, the cost difference between the transportation modes increases as the carbon tax goes up, making rail and barge transportation relatively more attractive in terms of costs. This diverging effect on the costs can be seen on the bottom left graph of Figure 7.

Accordingly, a carbon tax supports the objective of improving the modal split. However, to make road transportation disadvantageous enough to shift transportation away from road towards rail and barge, the carbon tax needs to be at least 100€/ton CO_2 in the experiment. In this case, the synchromodal policy reacts to the tax by reducing the share of road transportation. For the multimodal policy, a slightly higher carbon tax of 125 €/ton CO_2 is required. The change in modal split can be seen on the right bottom graph of Figure 7, while the top right graph depicts the corresponding emissions. The results support the findings of van den Driest, van Ham and Tavasszy (2011), stating that the CO_2 emission tax has to be quite high in order to establish a change in modal split. In reality, on the other hand, the implemented carbon taxes are often set far below these impacting values (World Bank & Ecofys, 2018). Furthermore, in order to ultimately transition to a transportation system that eliminates road transportation, the carbon tax needs to take on a value of 325€/ton CO_2 and 400€/ton CO_2 for respectively a multimodal and synchromodal policy.

Nevertheless, it has to be noted that the shift towards more sustainable transportation modes also implies a shift to slower modes. This leads to an increase in the expected periods overdue,

as presented in the top middle graph of Figure 7. Again, a consistently lower number of periods overdue is observed for synchromodality, verifying that the synchromodal policy achieves a better service quality regardless of the carbon tax.
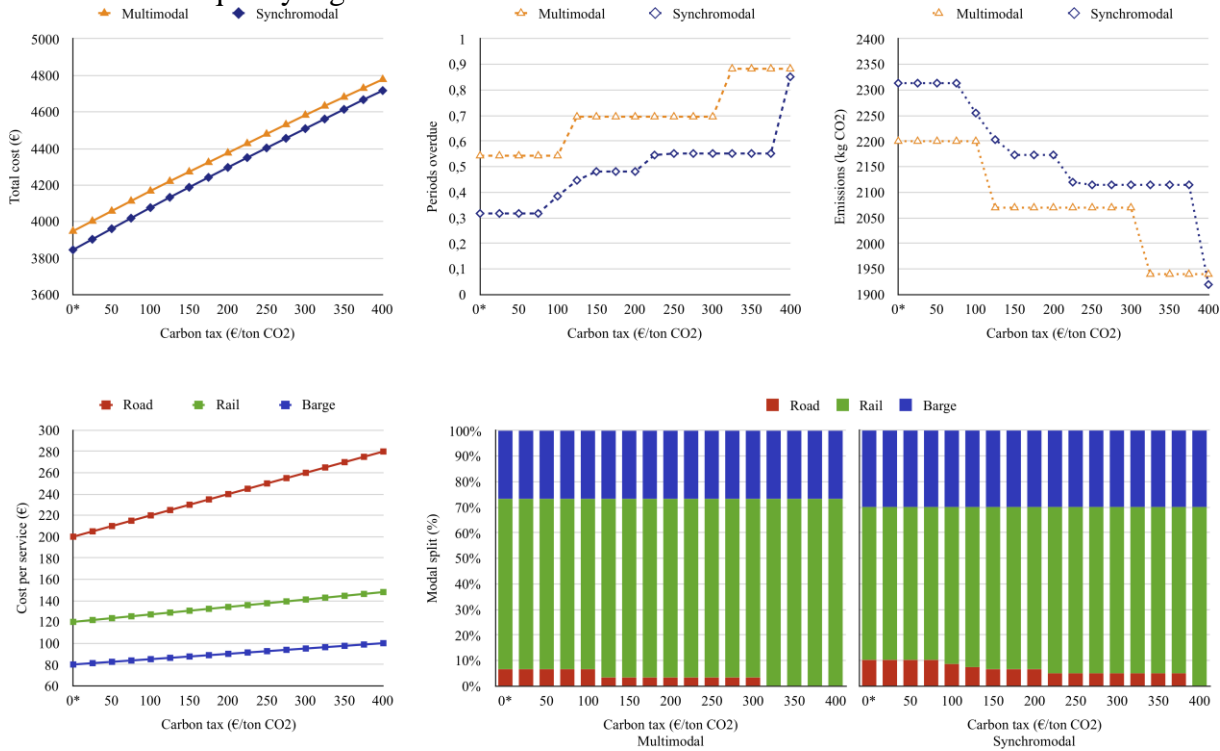
Figure 7: Sensitivity analysis for the carbon tax. All graphs show the result for different tax values for both the multimodal and synchromodal transportation policy. The asterisk indicates the base case setting. The top graphs respectively show the total cost over all orders, the average number of periods overdue and the emissions over all orders. The bottom graphs exhibit the cost per service for every transportation mode (left) and the modal split (right).

This numerical study shows how synchromodality consistently performs better in terms of costs, where the relative cost reduction is larger when the penalty cost is higher and when the transshipment cost is lower. Moreover, the increased planning adaptability facilitates in respecting due dates, which generally results in a lower number of periods overdue for the synchromodal transportation policy.

5   Conclusion

Synchromodal planning can consistently reduce the total transportation cost in comparison to unimodal and multimodal transportation policies. Moreover, it is observed that synchromodality realizes significant emission reductions compared to unimodal road transportation and service quality improvements compared to unimodal rail or barge transportation. The value of real-time planning adaptation is investigated by benchmarking synchromodality to a multimodal transportation policy. The results show that synchromodality outperforms multimodality with regard to transportation costs and service quality, which are the two most important features in order to attract shippers. This verifies that synchromodality allows to induce a shift towards more sustainable transportation modes at an advantageous cost without compromising on service quality. Furthermore, sensitivity analyses suggest that the relative improvements that synchromodality entails, thanks to its planning adaptability, increase when the overdue penalty goes up or when the transshipment cost goes down. The carbon tax

analysis indicates that at least a tax of 100€/ton CO_2 is required to encourage a further modal shift and reduce emissions.

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The Digital Twin concept and its role in reducing uncertainty in synchromodal transport

Tomas Ambra[1,2,3], An Caris[2], Cathy Macharis[1]
1. Vrije Universiteit Brussel, MOBI research center, Brussels, Belgium
2. Hasselt University, Logistics research group, Diepenbeek, Belgium
3. Research Foundation Flanders (FWO), Brussels, Belgium
Corresponding author: tomas.ambra@vub.be

Abstract: Transparency and information exchange are important parts of synchromodality that contribute to better overview of options when tackling delays, dynamic switching, and handling of unexpected events that affect delivery lead-times and costs. The most challenging aspect when making decisions in a complex adaptive dynamic system, is the ever-changing environment as we introduce more flexibility which may lead to more unpredictable outcomes. This paper presents 2 simple illustrative cases to asses different transparency levels and the adaptive behavior of assets; 1) a static case where assets do not have the ability to respond proactively to disruptive events, and 2) a dynamic case where assets have the ability to query their environmental context and exchange information. The severity of the events is captured by probability distribution functions by deploying Monte Carlo simulations to showcase the potential benefits of the Digital Twin concept in a synchromodal context. The links between current Digital Twin applications and synchromodal transport are discussed in order to spark a new wave of reducing uncertainties in dynamic environments. Lastly, the paper sheds more light on how to connect closed virtual simulations with the real physical system.

Keywords: Digital Twin, Synchromodality, Uncertainty, Monte Carlo, Simulation, GIS, agent-based modeling

1 Introduction

Synchromodal transport presents an extension of intermodal transport, which is a combination of two or more modes in one integrated journey with standardized loading units, by introducing more flexibility and transparency to facilitate dynamic re-routing and modal switching in near to real-time (Ambra et al., 2019b). Synchromodality can be thus perceived as real-time, dynamic and optimized intermodal transport. Given its real-time dynamics and flexible nature, different actors and transport modalities need to work together and adapt according to unexpected events as well as contextual information that affect transport processes. These events and contextual information can be positive or negative perturbations that shape freight movement and transport mode selection, such as newly incoming orders, transport delays, cancellations, collaborative bundling opportunities, accidents, water levels, strikes and many more. However, real-time mode selection requires involvement of extra parties in the process to solve transparency issues as to who has the cargo and where it is located. Crucial elements in this regard are situational awareness of the current system state and projections of how the system will evolve once different actors take different actions. While there already exist real-time control towers (ESRI geo-event server, MPO, ActiveViam etc.), and data

fetching/scrapping tools (Webhouse.io, VisualScrapper, Spinn3r etc) that have the ability to integrate data via JSON at a single reference point, these applications provide past and present positions of assets and trends. In this paper we depart from the past and present assets' states and focus on how future problems could be mitigated and emerging opportunities utilized if there is a possibility to speed-forward into the future. In order to estimate where assets (barges, trains and trucks) will be in 2, 3 or 5 hours based on congestions levels and infrastructural developments, and which terminals, distribution centers and other moving assets will be in their vicinity, is a challenging task. To acquire such future states of assets, one would need a time-machine to travel into the future, observe how the future looks and then return back to present time to make a decision. A time-machine will mostly likely not be developed yet, but the rather new digital twin concept might come close to this metaphor.

The digital twin concept is the latest wave in simulation technology as it uses simulation models to project possible behavior(s) of the real system. Simulation technology's inception is dated around the 60s when simulation was limited to a small range of individual topics such as mechanics, when in the 80s it was used in fluid dynamics and other engineering designs. Starting from the year of 2000, simulation allowed for multilevel and multidisciplinary system approaches to test and assess overall system designs, and from 2015 onward, simulation has formed the core of the digital twin concept by providing seamless assistance along different tasks and processes with direct connection to operation data (Boschert & Rosen, 2016). Gartner claims that digital twins will be adapted by half of large companies who will consequently gain a 10% improvement in effectiveness (Pettey, 2017). Hence, the concept is receiving more attention, but it has never or rarely been considered in the synchromodal context. In the following section, the digital twin concept and its current applications are reviewed in order to understand what it is, but also what it can become. As this paper addresses the adaptive nature of synchromodality, we pose 2 research questions: (1) Is synchromodal dynamic switching and re-routing always a better solution? (2) How can the digital twin concept/technology reduce uncertainties? The objective of our work is to deepen the understanding of digital twins and their potential use in synchromodal transport. The paper is structured as follow: section 2 reviews the digital twin concept and its use, section 3 presents the methodological approach where we describe our experimental design as well as the benefits of simulation, and section 4 describes the experimental results together with the potential role of digital twins in connecting virtual simulations with real physical environments. Concluding remarks are presented in section 5.

2 Literature review

The Digital Twin (DT) term itself was introduced to the broad public by NASA in its technology roadmap for modelling, simulation, information technology and processing where the DT is defined as "an integrated multi-physics, multi-scale probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin" (Shafto et al., 2012). Since then, the term has been altered and also challenged by different authors. Boschert and Rosen (2016) perceive it as a description of a component, product or a system that evolves with the real system. Grieves and Vickers (2017) define it as a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. According to Alam and El Saddik (2017), the DT is "an exact cyber copy of a physical system that truly represents all of its functionalities". Zheng et al. (2019) term the DT as "an integrated system that can simulate, monitor calculate, regulate, and control the system status and process".

However, Batty (2018) perceives the DT as a cliché and states that a computer model can never represent a DT as many physical elements of the real system are ignored. While Batty's argument is valid, one should also consider the necessary abstraction levels needed to build a credible enough model to capture the simulated phenomena sufficiently. This is to say that "boiling the ocean" will not yield added value in many simulation models. Digital simulation models for freight transport will not require to model detailed physical processes at the micro level for routing strategies and estimated time of arrival (ETA) calculations. In fact, Batty (2018) himself concludes that bringing the digital model closer to reality is rational when building computer models. A DT is not a mere detached virtual representation of a physical twin, but rather a living organisms that interacts with its physical twin via sensors and receivers connected through the Internet of things (IoT). Even though there are other terms which depict the notion of physical and digital objects interacting on a continuous basis such as the digital mirror model, digital reflection, avatar or a digital shadow (Erikstad, 2017), the DT term appears to be adapted by most of the authors in their applications.

With regard to the existing applications, Brenner and Hummel (2017) have developed a digital shop floor management system based on the DT notion. A three-dimensional DT is devised by Knapp et al. (2017) in manufacturing to predict variables affecting metallurgical structures. However, the digital representation is not connected to its physical counterpart via sensors and the DT notion does not clearly correlate with the earlier definitions. Schleich et al. (2017) propose a simple reference model for DT in product design and manufacturing. In the work of Söderberg et al. (2017), the DT is referred to as a simulation for real-time control and optimization of products and production systems, where the authors specify data models to move from mass to a more individualized production. Alam and El Saddik (2017) develop a driver assistance application where the DT is to identify various driving events and provide recommendations for drivers, insurance companies and emergency units. Uhlemann et al. (2017) introduce a learning factory based on the DT to demonstrate its benefits and familiarize the workers with new technologies and their implementation. Tao et al. (2018) focus on how to generate and converge cyber-physical data and apply their framework in three cases that relate to product design, product manufacturing and product service. Lastly, Zheng et al. (2019) apply the DT to model a welding production line.

The digital twin concept has been so far applied to manufacturing, shop floor management and product engineering designs of artefacts/objects. As the scope of current research is confined to 4-wall environments and products, our work will take the DT concept to the next level by exploring its potential use outside of the 4-wall environments and object designs, by adapting the concept to synchromodal freight transport processes and movements of assets in geographic space by using Geographic Information Systems (GIS) and agent-based modelling (ABM). As all the reviewed applications are at their infancy, our paper does not provide a ready-to use DT model for synchromodality, but it rather explores its potential use for synchromodal transport. Synchromodality/Synchromodal transport is to support optimal integration of different transport modes and infrastructure in order to induce a modal shift from road to inland waterways and rail by making the modal options, and synchronization of orders and available capacities, more dynamic, flexible and acceptable. A review of the synchromodal concept and its applications has been done explicitly by Ambra et al. (2019b) which is why we refer the reader to their work for a more detail overview. We depart from the notion of synchromodality depicted earlier in the introduction.

3 Methodology

A high-level methodological approach is proposed in this section to reap the potential benefits of the DT concept. The theoretical basis of this paper rests on the notion that the DT relates to a living dynamic simulation environment that mimics the real physical system by continuously updating its virtual environment in order to provide support to certain tasks and evaluate most probable implications. In fact, the digital virtual environment exists in parallel with the real system and updates itself through sensors based on specified intervals and/or events. Nevertheless, it is rather vague whether the DT should be perceived as an object or technology. The latter refers to a simulation method/approach to modelling and connecting virtual and physical environments. To clearly distinguish entities and concepts in this paper, the DT is perceived as a technology (DTT; Digital Twin Technology) that connects the Physical Twin (PT) with its Digital Twin (DT). The DT is a digital instance of the physical object. The DT exists in a Digital Twin Environment (DTE) also introduced by Grieves and Vickers (2017). In the following subsection, the DTE will be discussed as well as its agent-based components that can act as DTs once connected to real PT's. The PTs represent assets such as barges, truck, trains, vans and parcels that may send and intercept message via sensors and receivers.

3.1 The role of simulation in data-centric and process-centric realms

To understand how DTT can improve current decision making processes, the role of simulations and its relevance is addressed first. Mathematical and data-centric models (machine learning models) are able to learn from past outcomes, predictions and errors. However, relying purely on mathematical and data-centric models for decision making in complex systems is risky as they are limited to forecasting and assessing effects of events in the aftermath; meaning that a similar event must have occurred historically and this effect is known at present. The challenge comes when the system is exposed to previously unexperienced or unseen events (Figure 8 red). An example of such an unexpected development outside of historical bounds is/was the Randstat case within the Rhine-Alpine corridor where a sinkhole in a tunnel caused unprecedented train disruptions; no mitigation schemes had been available for shifting to inland-waterways or other service providers. The disruption effect nearly froze operations of HUPAC for weeks. In this regard, computational/simulation models can reinforce data-centric models by offering process-centric approaches.
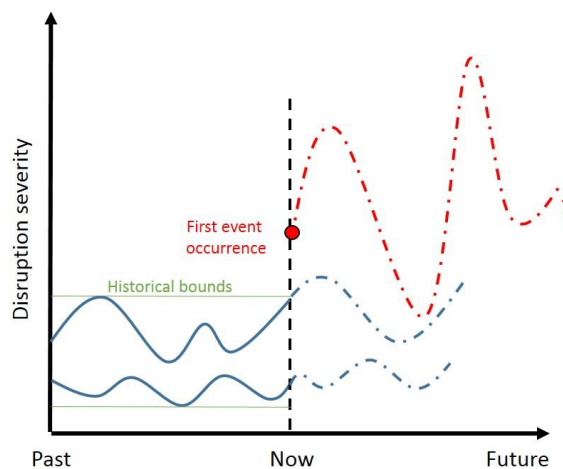
Figure 8: Theoretical illustration of an event that never occurred within the experienced historical bounds, and its potential consequences. The lines depict lead-times of orders when exposed to disruption.

The less data is available for an analysis, the more added value a simulation can provide. In an event for which there is no data, or the phenomena under study do not exist, simulation can generate a vast amount of data and execute model runs outside of historical bounds. Simulation works best when business processes are well understood, the preferences clearly stated and the fidelity of physics well mimicked. The latter refers to barge arrival calculations based on water levels, depth, currents, weather conditions, engine type, load factors and upstream/downstream direction. Similar rules apply to truck movements that are affected by congestions levels, road type and its layout as well as trains that share the railway infrastructure with passenger trains. On the other hand, mathematical and data-centric models can help simulations by using data driven approximations to reflect on processes more accurately and better inform simulation models where behavioral processes are hard to identify.

Mathematical and data-centric approaches are powerful as long as the studied system does not contain complex interdependencies and consecutive events that require spatial and temporal awareness. By means of simulation, business rules and objectives will determine the evolving system when projecting into the future, as these rules will mimic how businesses act over time. Pure analytical solutions are goal seeking and lack decentralized biases that exist in reality which is why they may not capture counterintuitive elements as good as simulation does; things one would never think about once entities start affecting each other. The DTT can mimic the physical system through virtual reality by making use of GIS for better spatial intelligence, agent-based models for decentralized local behaviors of entities such as transport means, and discrete event models for process-centric logic in terminals and other 4-wall environments.

3.2   Experimental design

The essence of the DTT for synchromodal freight transport is in representing space via Geographic Information Systems (GIS) that have the ability to mimic real-world environments and entities. GIS should thus form the Digital Twin Environment (DTE); the cornerstone of the DTT where entities (DTs) may learn how to react and adapt to seen and unforeseen events. A fine-grained DTE will also contribute to more detailed external cost calculations as the real cost of transport goes beyond the immediate internal costs related to transport and logistics operations. There is a wide variety of externalities such as congestion, accidents, noise, air pollution, loss of space, infrastructure damage and the impact of up and downstream processes which create additional burdens for society and ameliorate climate change.

The main modelling canvas that will serve as the DTE is a digital map that comprises of road, rail and iww vector files. The vector files, also called shapefiles, are acquired from ETISplus which is the European Transport policy Information System, and Eurogeographics. The vector data files contain the TEN-T networks for roads, railways, airports, ports and the watercourse system identified by Directorate-General for Mobility and Transport (DG MOVE). As indicated in Figure 9 the cyan colored polylines represent navigable iww and yellow lines represent railway freight priority links. The other dark image on the right depicts all geocoded locations of European ports and inland terminals. Each location contains attributes with regard to mode switching possibilities and terminal size. The GIS environment presented herein provides agents (digital objects) with real-world locations based on the WGS84 geographic coordinate system, having Greenwich (0, 0) as its prime meridian. As the WGS84 coordinate system is used as a reference system by GPS, Google Maps as well as by Microsoft in its Bing Maps, it represents a good base for mirroring the real physical world and physical assets since these assets are governed by a such geo-referenced system already.
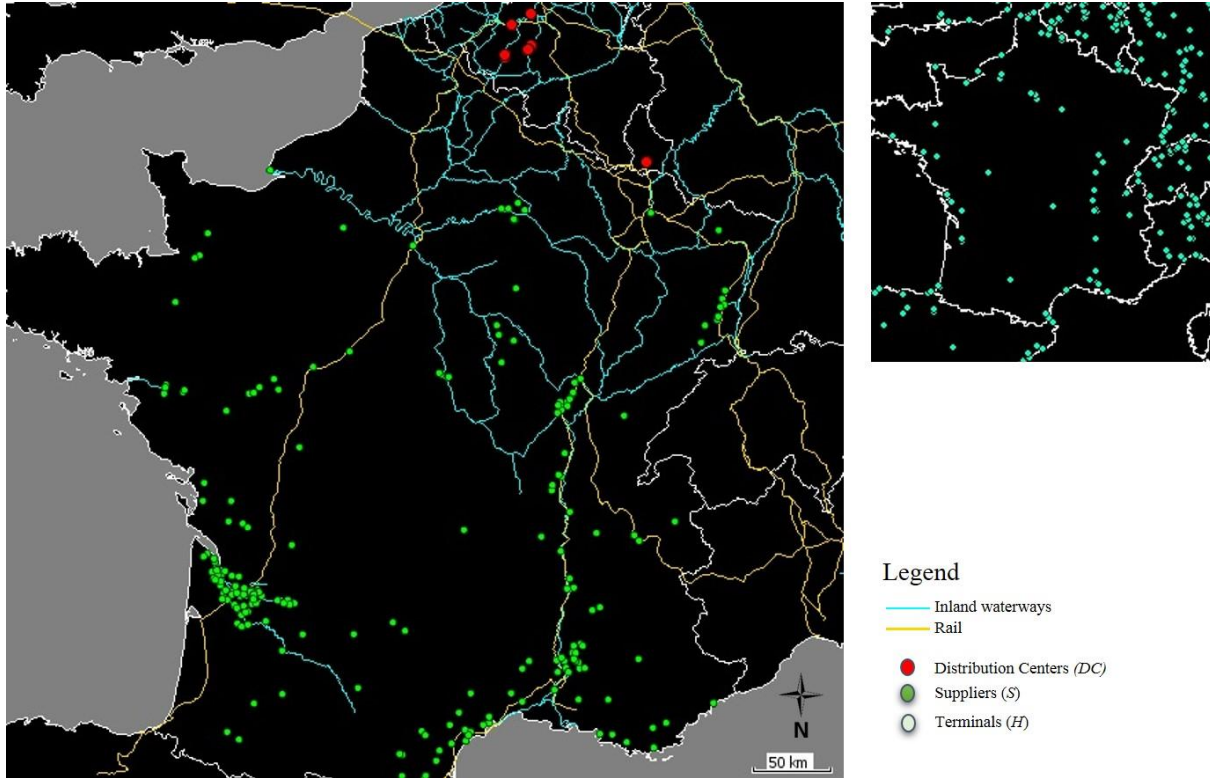
Figure 9: The left image illustrates our study area depicting 220 origins (S), six destinations (DC) and 325 terminals (H). Road shapefiles were excluded for visual clarity. The right image represents all European terminals

The experimental design is a shortened version of Ambra et al. (2019a). We start with an initial solution that refers to orders being transported from green supplier locations (*S*) to red distributions centers (*DCs*). Figure 9 depicts these origins and destinations. The flows represent intermodal journeys where trucks collect orders at *S* locations and depart to the nearest terminal (*H*). The main leg is carried out via inland waterways or rail, until the next unloading terminal where the order/container is transshipped on a truck which delivers the order to its corresponding (*DC*). Figure 10 illustrates such and intermodal journey to which we will refer to as the freight system. The system contains multiple similar intermodal stretches in parallel due to the fragmented spatial context of the orders' origins as well as destinations. This system will be exposed to perturbations to assess its reconfiguration/resilience.
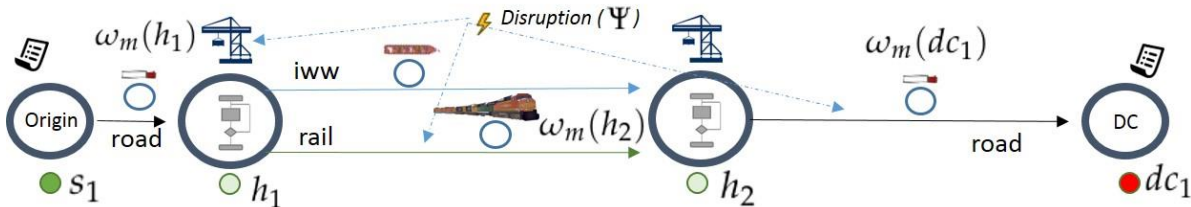
Figure 10: A visual example of an intermodal delivery indicating how Ψ disruptions affecting agents in ωm(.) transition state.

The trucks, trains, barges, orders and terminals are represented as agents. The agents have the ability to self-organize locally which may lead to significant reconfiguration of relationships and processes based on internal perturbations or external shocks (Bak, 1996). Agents can process and exchange information with other agents as well as perceive other entities, obstacles or sense their surroundings. Given the decentralized nature of agents, their ongoing delivery

processes may reconfigure depending on the geographical location of the disruption, without unnecessarily bothering other agents and their ongoing processes. In this paper the agent reconfiguration is tested by imposing disruptions upon them. We consider disruptions Ψ in a form of three disruption profiles (Table 3). Profile 1 ($\Psi1$) is applicable to road only, to simulate the overall delivery performance of intermodal orders if a truck agent arrives late, or not-depending on how far the individual trucks are from terminals. We assume that these disruptions, slightly more severe than daily congestion, last 1–3 h. Profiles 2 ($\Psi2$) and 3 ($\Psi3$) last 3-6 hours and 1-3 days respectively. Iww accident data were not available, which is why this study was limited to mainly rail disruptions. The disruption duration is linked to uniform distribution functions which determine the length with each new disruption occurrence. Many model realizations with Monte Carlo simulations are carried out to approximate the stochastic probability distributions; during each realization the model draws a different value from the probability range depicted by the uniform distributionfunctions.

Table 3: Disruption profiles and their severity

Ψ	Description (*Example*)	Probability of occurrence per year	Duration
1	**Frequent and short** (Delays caused by detours, blockages, light accidents, road works, etc.)	30% - 40%	Uniform (1, 3) h
2	**Less frequent and short** (Breakdowns, maintenance, moderate weather conditions, trees on rails etc.)	6% - 9%	Uniform (3, 6) h
3	**Less frequent and mid-long** (Strikes, severe weather conditions, floods, train collision, derailment etc.)	6% - 9%	Uniform (1, 3) d

The simulations cover 1 year and are based on order requests acquired from a retailer in Belgium. Order placement starts when the real-time simulator enters a new week. When the simulator enters week 3 for instance, all order requests that correspond to week three will be sent out to their S locations. Starting from the initial solution displayed in Figure 11, disruption profiles are deployed to stress-test the system resilience to perturbations. Two simulations are compared; S1 represents the intermodal static solutions and S2 the synchromodal dynamic solutions.
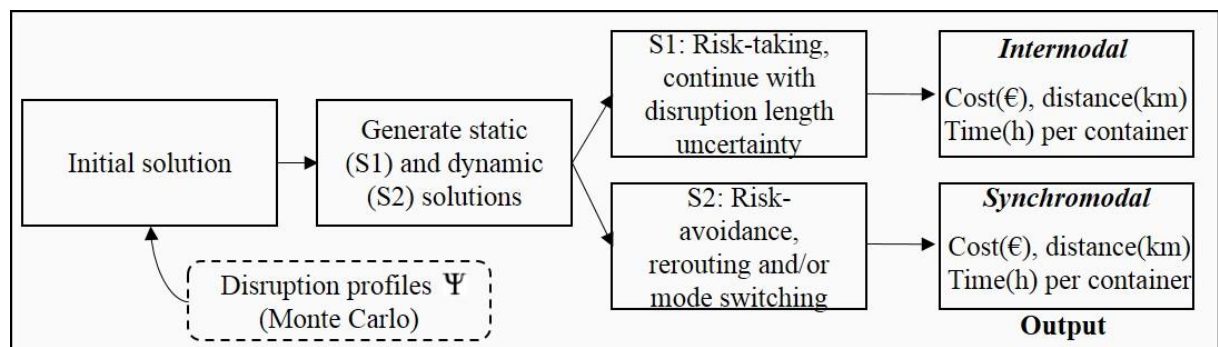
Figure 11: Schematic overview of the short experimental design

The former, S1, is labelled as risk-taking which means that once the disruption profiles Ψ from Table 3 are applied, all the agents in transition state ωm (.) will be exposed to delays caused by Ψ given their current geolocations in space and time at the moment of occurrence (Figure 10). The entity inside the (.) expression in the ωm state indicates the destination towards which the agent is headed. In the static case (S1) the agents are delayed without knowing the disruption length. The latter, dynamic (S2), means that agents receive information about each disruption and proactively seek alternatives, labelled as risk-avoidance. Planning is done as late as possible

so that the planners have enough time to detect disturbances and respond to them proactively. For profile 2, the trains will be able traverse a path in case of terminal breakdown. This may result in re-routing where the truck agent will move to the next nearest terminal. A search radius of 300 km is added to query iww terminals first. This was to find potentially cheaper options and also avoid trucks seeking rail terminals further inland in the opposite direction. The radius applied to orders situated within the Rhine–Alpine corridor which are closer to Basel in Switzerland. For longer-term disruptions in profile 3 such as rail strike, the LSP will seek other than rail alternatives, such as inland waterway transport.

Information regarding calibration and validation as well as more detailed simulation descriptions and pseudocodes can be found in Ambra et al. (2019a). Let us recall that we re-use a simplified version of the authors' original case, and herein provide an additional DTT dimension to introduce a first step towards synchromodal DTT.

4 Results and discussion

The results of the experimental design are described and discussed as first, to show how notifications in a transparent network can contribute to freight transport processes in disrupted settings. The second part of the section is devoted to the DTT for synchromodality.

4.1 Intermodal and synchromodal result comparison

This subsection is to answer our first research question (*Is synchromodal dynamic switching and re-routing always a better solution?*). The results concern individual orders after reaching their final distribution center. Each dot in Figure 12 represents a single order for simulation 1 (red) and simulation 2 (green) plotted on axes representing its cost and lead-time. It can be inferred that some green orders incurred slightly higher costs due to longer distances. This development can be attributed to the pro-activeness of agents that seek other available terminals in the synchromodal case (green) once the disruption event is imposed. The most visual outliers are between 60 and 66 h which can be explained by the risk-avoiding approach of synchromodality choosing terminals further away and incurring delays by unnecessary detours. A cost decrease is observed between 45 and 50 h for green synchromodal dots where choosing barge services located closer to the order's final destination yielded lower costs as compared to the red intermodal dots above them.

Figure 12: Comparison of order delivery performances after exposing simulation 1 and 2 (S1 and S2) to disruption profile Ψ2 for static intermodal (red) and dynamic synchromodal (green) solutions.

Both simulations are stochastic as they work with random numbers generated by the disruption profiles. The S1 and S2 are executed with the random seed being fixed in order to reproduce

comparable simulations. This is to ensure the same sequence of random numbers is drawn from the uniform distribution functions that represent our disruption profiles. However, disruption profile Ψ2 may assign a delay of 3.5 h to orders from week 1 and 5.5 h to orders in week 2, which in fact means that orders from week 1 are not exposed to 5.5 hour delays. Such a sensitivity analysis of the disruption profiles is shown in Figure 13 and Figure 15 (for profile Ψ3) by executing 100 replications of S1 and S2 simulations under profile Ψ2.

The colored areas in Figure 13 represent envelopes for each time "slice". These can be perceived as extended box-plots where the envelope coloration shows quartile intervals. The darker the color, the more percent of orders accumulated in the given area when replicated for different delay inputs. Such an overview of order delivery fluctuations provides a better visual understanding of the stochastic uncertainty embodied in our model.
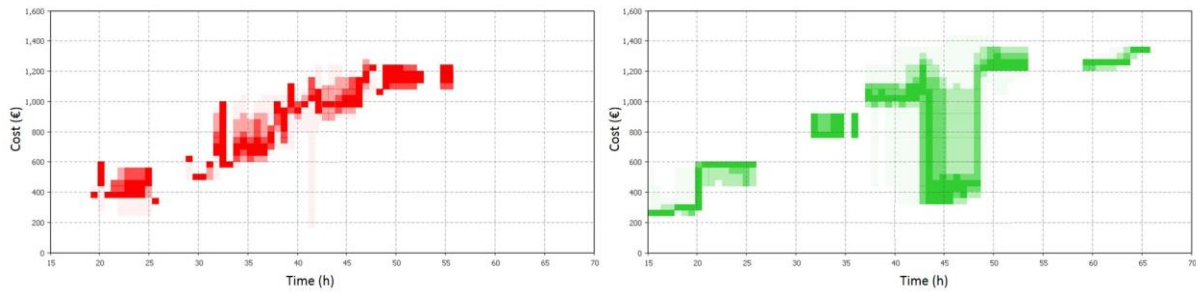
Figure 13: Monte Carlo experiments related to Figure 12 with disruption profile Ψ2 for static intermodal (S1 red) and dynamic synchromodal (S2 green).

After exposing S1 and S2 to disruption profile Ψ3 (Figure 14), the proactiveness of synchromodality (green) yields significantly better performance in terms of costs and lead-times. This development was caused by the fact that all truck agents search iww solutions as the usage of rail is omitted. In this case the geo-spatial search went beyond the 300 km radius, ignoring several rail terminal options that lay in between, until the nearest iww terminal was found. In comparison with the less severe disruptions under profile Ψ2 (Figure 12 vs Figure 14), it can be observed that synchromodal dynamic solutions cope better with more severe disruptions, whereas shorter disruptions (profile Ψ2) do not require immediate deviations and proactiveness.

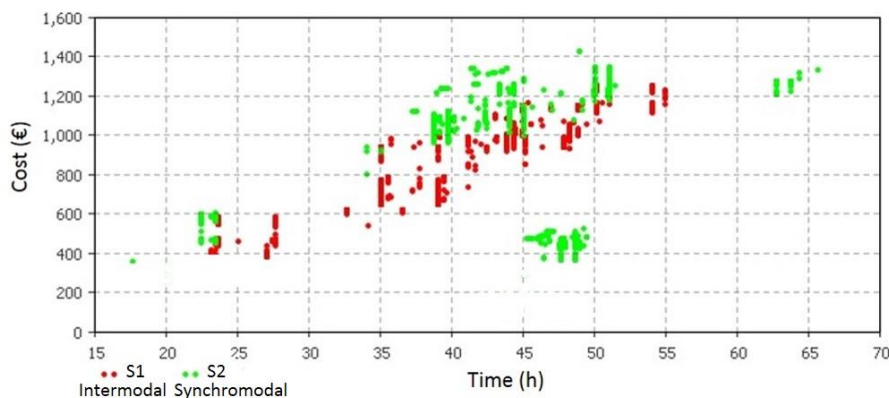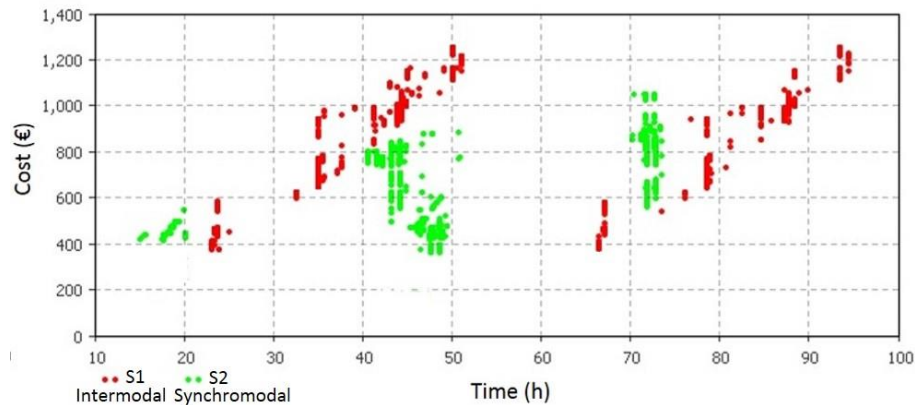*Figure 14: Comparison of order delivery performances after exposing simulation 1 and 2 (S1 and S2) to disruption profile Ψ3 for static intermodal (red) and dynamic synchromodal (green) solutions*

A more representative overview of the results is shown in Figure 15 which demonstrates the strength of synchromodality once tested for all disruption lengths; the fluctuations in S2 (green)

under profile Ψ3 are more stable than S1 (red) indicating rather unpredictable outcomes that can fluctuate widely. The proactive synchromodal nature of the S2 simulation reduces the delivery uncertainty by design; trucks avoid disrupted rail options whereas S1 is fully exposed to the rail disruptions. The small fluctuations in S2 (Figure 15, green) are cause by disruption profile 1 which delays trucks by 1 to 3 h. The design shows the benefits of a transparent user network that rests on information exchange and reactive behavior of assets which should form the efficient and connected Physical Internet flows.
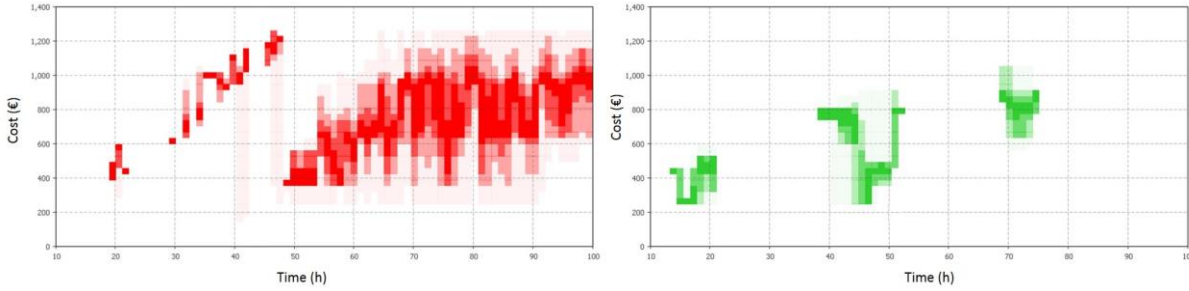
Figure 15: Monte Carlo experiments linked to Figure 14 with disruption profile Ψ3 for static intermodal (S1 red) and dynamic synchromodal (S2 green).

To this end, however, the simulations rely on network openness and benevolence of other carriers to flexibly change modes at any time in a virtual environment. New sensor technologies and techniques that can collect and integrate real-time information will be imperative to determine the disruption severity, its length and spatial occurrence in order to reduce uncertainties depicted by the probability distribution functions. The earlier mentioned network openness can be achieved through IoT technologies and geo-spatial coverage, by 5G network for instance, in order to reach out to assets by facilitating information exchange, remote-control and automation. But how can we connect the risk-free virtual environment and its functionalities to the physical system so that users can assess different what-if scenarios when needed? The next section sheds more light on this question but also on our second research question (*How can the digital twin concept/technology reduce uncertainties?*).

4.2   A Digital twin technology for synchromodality

The DTT should be able to interrogate assets and their context(s) that surround(s) them. The predictive elements will start from the historical and current asset states where the physical twins (PTs) will be queried with regard to their ongoing working conditions, current geolocations via latitude and longitude (x, y coordinates), their history states and performances. These parameters will form the basis of the DT, being the digital instance of the physical twin. The future projections will rely on the fidelity of physics that govern asset movements while taking into account information from external sources (AIS, weather forecasts, traffic jams, accidents, strikes, newly incoming orders, etc.). Figure 16 depicts how to transform PTs into DTs via a mirroring platform where real-physical assets can be converted into object instances. The Internet of Things (IoT) sphere contains many applications and technologies that can be incorporated in one coherent network. As the Physical Internet involves multiple companies with various geographical scales that require different reach, network coverage and different technologies need to be used for sensing objects. In this regard, connecting application silos as well as sensor/beacon technology and its attributes together will play an important role.

The "things" in the IoT notion need to have an environment that will be similar to the DTE and its coordinate system for accurate location intelligence and geo-fencing (as described in section 3.2). The DTE can then receive contextual information from the physical environment through real-time geo-servers that may integrate external sources of information

at one reference point. Such servers allow for process integration via real-time data analytics once real-time data inputs are gathered.
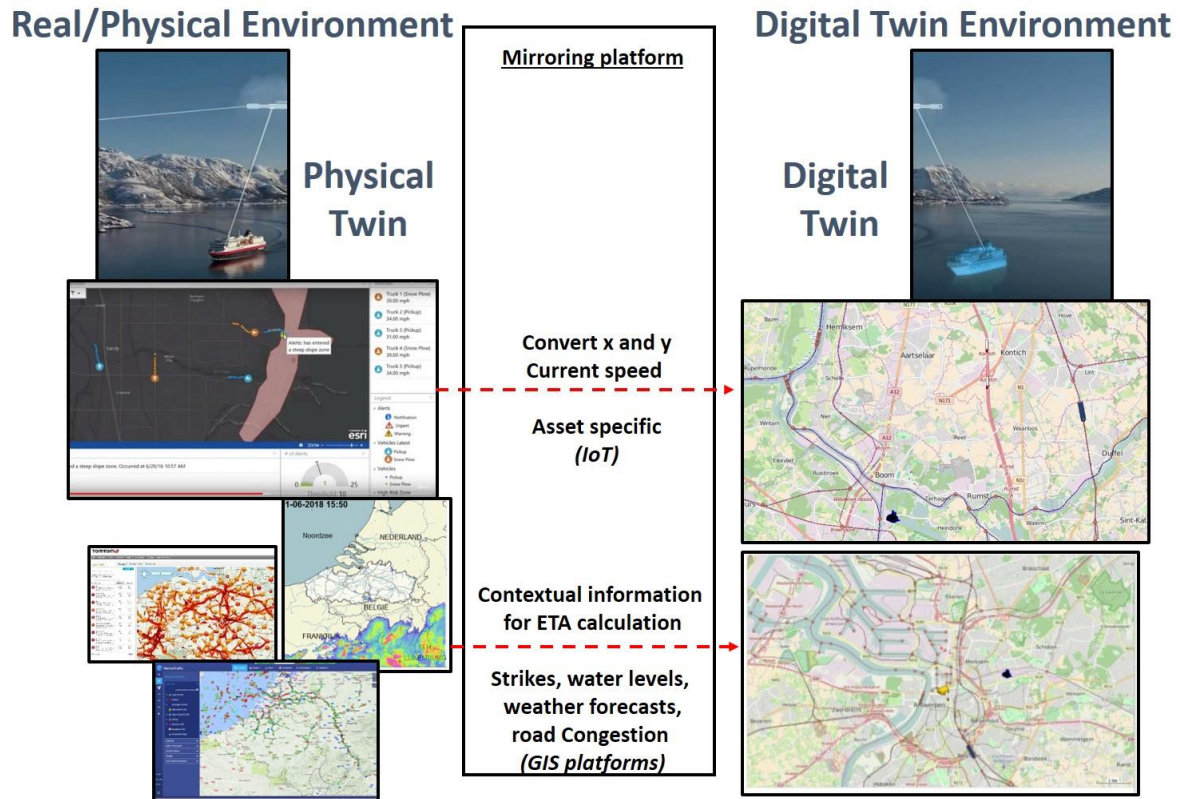
Figure 16: Demonstration of a mirroring platform. Left-hand side figures are borrowed from ESRI, waterinfor.be, marinetraffic.com and Mfame. Right-hand side is the virtual environment of our SYMBIT model.

As mentioned in the introduction, applications that monitor the physical environment (Figure 16, left-hand side) provide past and present positions of assets and trends. The real added value of the DTT is its ability speed-forward into the future to simulate and account for possible outcomes and uncertainties. Given the combination of data- and process-centric modelling, simulations will help by generating data and training models in situations that have never happened before; when reality kicks in alongside the simulation scenario trajectories, we will already have solutions as we will have tested those in the virtual world. By means of agent-based and discrete event modelling, it is possible to understand emergence of patterns and devise mitigation strategies in virtual geo-referenced space while taking into account external effects. Furthermore, decentralized algorithms can expose and tackle the "I didn't see that coming" developments that may be realized only by having decentralized action taking based on individual spatial and temporal attributes of assets/agents with their objectives and biases.

In this regard, the DTT and its mirroring platform would query available assets, contextual information, and evaluate multiple scenarios in parallel as illustrated in Figure 17. Multiple digital instances/agents such as barges, trains, trucks, terminals and dc's will feed data into the DTE where Monte Carlo simulations will take over and execute future possible states and patterns that may emerge once individual agents with their own biases and objectives start taking actions and affect each other. The Monte Carlo simulations will draw input values from probability distribution functions from historical and hypothetical disruption profiles, and impose delays, blockages and other events upon agents during model executions (as demonstrated in the previous section). These events trigger a transition from agents' current

ongoing process states to new "disrupted" composite states where agents will seek for alternatives from a decentralized perspective and their individual context (geo-location, distances, infrastructure etc.).
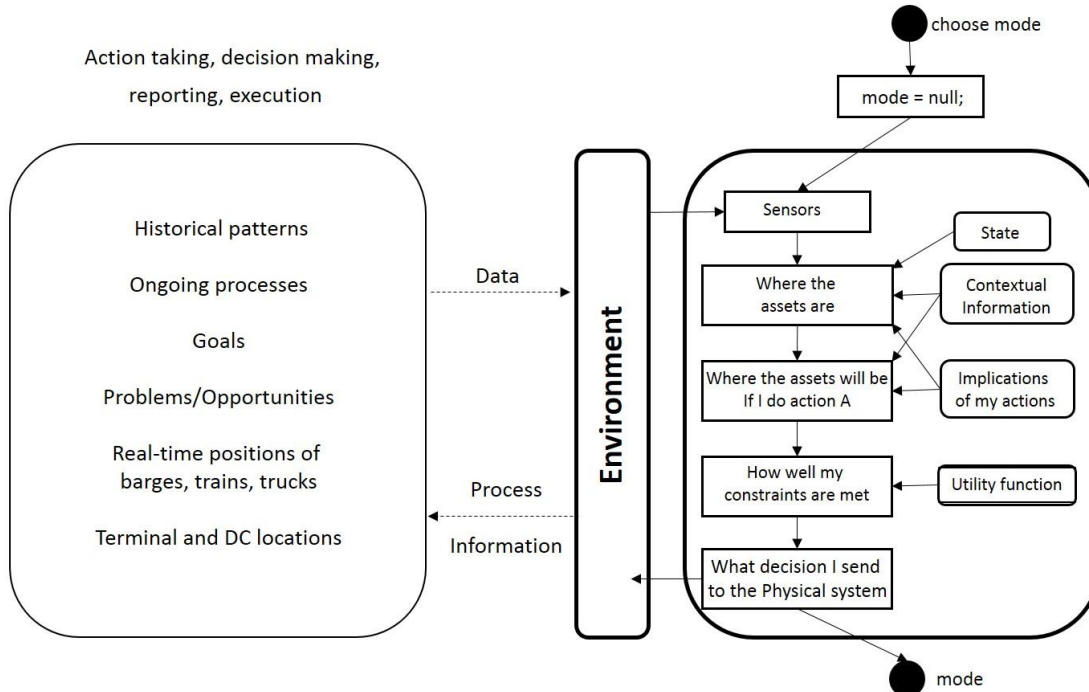
Figure 17: Conceptual illustration of the digital and physical Twin interaction. Right-hand side of the figure is adapted from Russell et al. (2003).

As indicated in Figure 17, the real physical system will provide data to the virtual space, and in return the virtual space will provide information flow and process specifications to the real system after evaluation several virtual sub-spaces (multiple virtual realities). Such a risk-free environment will allow for analysis and evaluation of triggering events (new orders, disruptions, delays…) which induce physical movements, and vice-versa, physical movements may trigger information flows once certain assets arrive at a specific location or enter a geo-fence. The moving (barges, trains, trucks, vans etc.) and stationary (terminals, DCs etc.) assets can be perceived as physical objects that can communicate their location to the DTE. As the Internet of Things deals with the *Intern*et as the network or virtual space, and *things* as physical objects (Atzori et al., 2010), the DTT can go beyond getting mere data out of sensors, and rather focus on the data processing mechanics, machine learning and business automation within the DTE. This is to say that the Digital Twin concept is not just a digital representation of a disconnected entity, but it shifts and updates alongside its physical counterpart and proceeds current physical reality to facilitate decision making by providing most probable outcomes. This can lead to optimization of routing and mode switching strategies with regard to which mode to use, where to switch, what terminals are located enroute, how far the handling points are and if the assets will make it before closing hours given the assets' current geo-locations.

5   Conclusion

The paper explored the digital twin conceptand its potential role in synchromodal transport. From a methodological point of view, agent-based modeling has an ability to simulate information availability/exchange that is linked to consequent reactive agent behavior induced

by it. This ability is tested in our SYMBIT model by exposing static and dynamic solutions to disruptions where individual agents reconfigure based on their positions in space and time. Knowing the state of the transport system and its evolution allows for more accurate and efficient policy rules to mitigate undesired effects of the system and its sub-parts. Synchromodal dynamic solutions are more relevant when dealing with longer-term disruptions as short-term disruption might not always yield better results if assets are managed too proactively; leading to unnecessary deviations that could increase delivery costs and lead-times. As far as the digital twin dimension of the paper is concerned, simulation-based solutions are useful for failure prediction, developing systems, new designs and optimization of various system processes. The digital twin concept presents an imperative step to fuse virtual models with physical environments and their processes. To further explore and deepen the understanding of digital twins for synchromodality, a new DISpATch (Digital twIn for SynchromodAl Transport) project has been set up by 4 knowledge centers and 13 companies in Flanders. DISpATch will focus on connecting the modelling logic embedded in virtual environments with the physical system processes, and vice versa. The project consortium will devote 4 years to this task by combining inventory managements algorithms, integrated network planning and freight transport uncertainty and predictability simulations.

Abbreviations

DT   Digital Twin
PT   Physical Twin
DTT   Digital Twin Technology
DTE   Digital Twin Environment
IoT   Internet of Things
GIS   Geographic Information System
Iww   Inland waterways
ABM   Agent-based modeling

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User Equilibrium in a Transportation Space-Time Network

L.A.M. Bruijns[1,2], F. Phillipson[2] and A. Sangers[2]

1. Delft University of Technology, Delft, The Netherlands
2. TNO, The Hague, The Netherlands

Corresponding author: frank.phillipson@tno.nl

Abstract: We provide a method to obtain a User Equilibrium in a transportation network, in which we transport containers for multiple agents. The User Equilibrium solution is defined as the solution wherein each agent can travel via their cheapest paths possible, and no agent is harmed by the route choice of other agents. The underlying model used is the Space Time Network (STN), in which the travel time of modalities is fixed and independent of the occupancy of the network. The System Optimal solution is the solution in which the total costs of the network are minimised. An approach is presented to find a toll scheme to create a User Equilibrium solution in this tolled STN, while maintaining the System Optimal solution of the initial STN.

Keywords: User Equilibrium, System Optimal Solution, Space Time Network, Intermodal and Synchromodal Transport

1   Introduction

In this paper we look at a transportation system where individual agents control logistic units. This occurs in Physical Internet and in Synchromodal networks. For an overview of those concepts and differences between them, we refer the reader to Ambra et al. (2019). The agents in such a network can be logistic service providers or clients controlling the stream of their containers, or intelligent containers or other smart logistic units themselves. Looking at the planning of such systems. We have to look at two aspects: information and the degree of control and optimisation. Both can take either a local view, where only own information is known and optimisation done is for an individual objective. Or a global view, where information is available for the entire network and the optimisation is aimed at a shared goal. We can distinguish (De Juncker et al., 2017) four different systems in a synchromodal framework, see Figure 1. If the information is available globally but every agent only optimises their own objective, we call the approach selfish. If the information is available globally and the decision is aimed to optimise the entire network, it is called social. If the information is only available locally and optimisation is also local, it is a limited approach. Lastly, if the decision is aimed at global optimisation with local information, we call it a cooperative approach.

In logistic (service) network planning problems Space-Time Networks (STN) are often used for the representation, see for example Andersen and Crainic (2009), Crainic (2000) and Del Vecchyo et al. (2018) . On this STN a non-negative integral Minimum Cost Multi-Commodity Flow problem (MCMCF) is solved to get the overall optimal (social) solution. However, if links have capacity constraints and there are multiple agents travelling or sending their commodities over the network, some agents may not receive the shortest or most economical path. They may be unhappy (in a selfish model) with the total solution, even when this solution is the optimal solution for all agents together, a system optimal solution. Note that all kind of modalities (or combinations) can be modelled using this approach.

To reach a solution in which all agents are satisfied, and do not want to change their paths, we would actually need a 'User Equilibrium' (UE) solution. However, in most cases this UE is overall a worse solution than the overall optimal 'System Optimal' (SO) solution. There is an expected gain (Roughgarden and Tardos, 2002) for the total system in case of cooperation, reaching a system optimal solution. Swamy (2007) shows that selfish, here meaning locally optimising, systems have their price: they prove that, in traffic assignment problems, travel times induced by selfish agents might be the same as the total travel time incurred by optimally routing twice as much traffic and indicate that adding central control or incentives gives an overall improvement of the system. However, in networks with high load the performance might not suffer too much, as can be found in Peeta and Mahmassani (1995). So optimising the total network and then sharing the benefits from an overall optimal solution between all agents is beneficial for all. On the other hand, it is not easy, as it requires a mental shift to get to give up control.
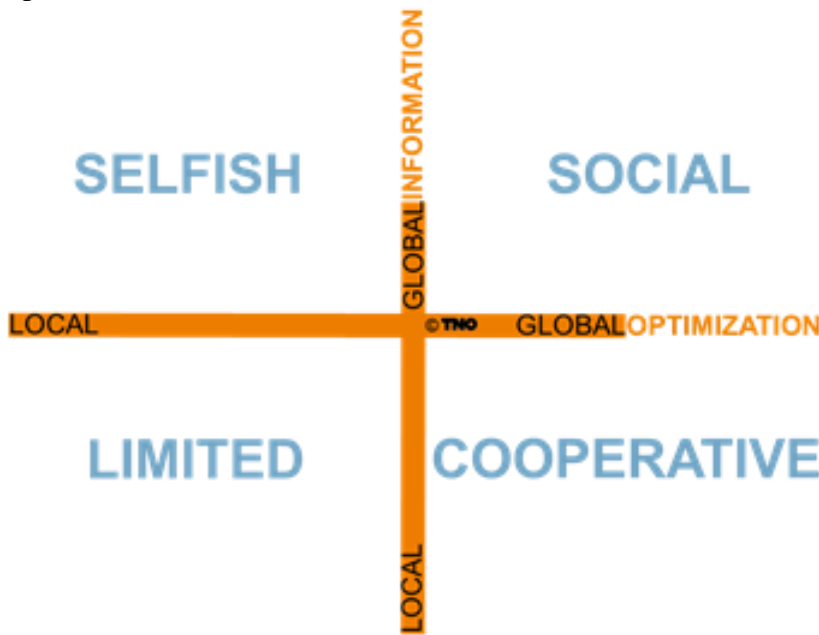
Fig. 1: Different models of a synchromodal network.

In this work we propose for the first time a definition of a *UE solution in a logistic STN*. We then *provide a method how to change the arc weights of the STN to create and find a UE solution in the modified STN*, by adding tolls, *that equals the system optimal solution*. Note that the practical implementation is far away, but this can be used to propose a reallocation of costs in which the benefit of the social optimal, with respect to the UE in the original STN, is shared in a fair way. In terms of Figure 1, we want to get the 'social' solution in a 'selfish' network.

For the second part, changing the arc weights to create a UE solution that equals the SO solution, we propose the following algorithm. The first step in this 'all toll algorithm' is to calculate the SO based on the path costs of agents travelling from their origin to their destination. The next step is to calculate tolls that are added to the paths in the network. These tolls are used to adjust the path costs, such that we can offer the agents a choice of tolled paths.

Now, when the agent gets assigned its cheapest tolled paths, those paths are in the SO solution and the solution is UE as well. The solution is a UE because the offered path costs are the cheapest option according to the information available for the agent, the new tolled STN.

In the next section we discuss the literature on User Equilibria and toll systems in traffic assignment problems. To the best of the authors' knowledge no literature exists for UE in freight logistic networks. In Section 3 the definition of UE in STN is given and a method is presented to find a UE that equals the solution of the system optimal. The method is illustrated by two examples in Section 4. We conclude with some remarks and directions for future research.

2   Literature review

Most of the literature about User Equilibria is based on network congestion, where travel times on roads depend on occupancy of travelling arcs, as in traffic assignment problems. Van Essen et al. (2016) give a proper review of ways to force a UE into a System Optimum (SO) by diffusing travel information to stimulating some agents to travel non-selfishly to achieve cheaper total costs. Peeta and Mahmassani (1995) investigate both the SO and the UE Time-Dependent Traffic Assignment. They show that the more goods have to be transported, the more the solutions of the two models differ from each other. Bar-Gera (1999) provides a solution method for the UE traffic assignment problem which is computationally efficient, memory conserving and an origin-based solution method. Xu et al. (2012) propose a stochastic UE for a passenger transport network.

Miyagi et al. (2012) consider a traffic assignment problem from the view of game theory. They assume drivers have knowledge of the network and a Nash Equilibrium (which corresponds to a UE) is achievable. Wagner (2014) shows that the existence of a Nash Equilibrium is guaranteed under some natural assumptions on the travel time models. Also Wang and Yang (2017) show the equality of Nash Equilibrium and UE. Levy et al. (2016) consider selfish agents in a traffic assignment problem, and apply properties of game theory on traffic problems. They start from finding a UE solution, in which all agents take the best route for themselves, based on their route choice experiences in the past. The question then is if it is possible to obtain a System Optimal solution, in which agents are still selfish.

The relationship between the UE and the System Optimal can be examined by the Price of Anarchy (Roughgarden, 2006), a system often used in both economics and game theory, that measures how the efficiency of a system degrades due to selfish behaviour of its customers. Bar-Gera et al. (2012) consider the UE problem with the focus on spreading flow over the network (not time-dependent). They also introduce several criteria which can be taken into consideration for choosing UE solution methods. Their most important addition to the subject is the condition of proportionality: the same proportions apply to all travellers facing a choice between a pair of alternative paths, regardless of their origins and destinations.

Corman et al. (2015) consider the application of multimodal transport to provide a UE solution, with the choice of modality based on the wishes of the agents. They assume that agents have access to a system for publishing demand and offering transportation possibilities. Moreover, they assume everybody has access to truck transportation, so transport is always possible, regardless of the fact that other modalities are not available. They define every agent as one unit of transport, which has to choose one specific mode for the whole travel distance. The goal is to assign agents to modes in such a way that no agent will change its departure time and its route (and thus will not change its mode), to provide all agents a sufficiently good route.

One commonly used approach for creating a UE is by using tolls. Hearn and Ramana (1998) make use of a toll pricing system by adding a toll term to the cost function for each arc. They also describe the Robinhood formulation, in which the sum of all tolls must be zero, so that there is no profit for the system. In this case they calculate the toll after a System Optimal

solution is found. According to Florian and Hearn (2003), the application of those types of toll is hard to implement on traffic networks regarding variable travel times, although the selective use of negative tolls to influence route choice of users might have some appeal. Yang and Han (2008) investigate the use of tolls with the help of the price of anarchy. Yang and Zhang (2008) constructed an anonymous link toll system to add traveller-dependent tolls. They concluded that there exist nonnegative links tolls identical to all users to decentralise the Wardropian System Optimum as a UE-CN (Cournot-Nash) mixed equilibrium, and the valid toll set is made up of a convex set of linear equalities and inequalities. They use nonnegative tolls only. Yang and Huang (2005a) state that Value Of Time (VOT) is a very important concept in transportation system modelling. The VOT of an order is a constant which denotes the importance of that agent. Didi-Biha et al. (2006) also use nonnegative tolls. Their goal is to maximise the toll revenue for the highway authority while the users of the network want to minimise their travelling costs. They introduce their bi-level programming Toll Optimisation Problem, both arc, arc-path and path based.

Yang and Huang (2005b) proved the existence of a Pareto refunding scheme that returns the congestion pricing revenues to all users to make everyone better off. This Pareto refunding scheme refunds class-specific and OD-specific toll revenue equally to all users in the same Origin-Destination pair in the same user class.

User Equilibria in (multi-) agent environments are also described as consensus seeking agents. Work on this is done by Ren and Beard (2005) and Liu and Liu (2012).

3 User equilibrium in STN

In this paper we propose the use of tolls on paths within as STN. For convenience we will use the terms agent for the controller of (at least) one unit of transport. This agent can send an order (multiple units) for transportation within the network and as unit we will say container. A Physical Internet system or an other self-organising system with smart units will fit within this method.

For each order there may be multiple paths to travel by, within the STN. We propose the following definition for a UE within an STN:

Definition 1 (User Equilibrium) A UE in an STN is reached when each agent can use their cheapest paths.

This is obviously not always possible when concerning only the initial networks, so we need to adjust the initial network using the path tolls to reach this UE. We will assume that agents are not familiar with the path costs in the initial STN, they only have knowledge of the tolled path costs. In this section, our goal is to find a Path Tolled UE. Our approach is to first find an SO solution, and then add tolls to paths, which create a new cost scheme for paths. When we offer the STN with the adjusted path costs to the agents, they can selfishly choose routes, and the outcome of their path choice will correspond with the path to order assignment within the SO. The difference between the two networks provides insight in the offered fairness by the solution and can be used to redistribute the gain between the agents.

The way of finding tolls which give us a UE solution in an initial SO problem is described in Algorithm 1, which is partly based on the solution algorithms used by Hearn and Ramana (1998) and Jiang and Mahmassani (2013). The difference with the framework of Hearn and Ramana is that we do not define the toll set, because in our approach there is no need to

obtainthis total set. The difference with Jiang and Mahmassani (2013) is that we apply tolls on paths instead of updating path assignment.

The Space-Time Network is a directed graph $G = (V,A)$, consisting of a set of nodes $v \in V$ and a set of directed arcs $a \in A$. Each arc a is a link between two nodes, an origin node v_1 and an end node v_2: $a = (v_1,v_2)$, along which a container can travel. We use x_a to denote the number of units of flow along arc a. An Origin-Destination-pair (OD-pair) w is a pair of two nodes, origin location w_O and destination location w_D, so $w = (w_O,w_D)$, which is not necessarily an arc. The number of containers an order wants to transport from w_O to w_D is denoted by d_w, the demand of order w. A path p consists of a sequence of (non-horizontal) adjacent arcs between two nodes. In our problem we only consider paths between origin and destination nodes. f_p denotes the path flow of path p (always integer), with $p \in P_w$, $w \in W$, where $\mathcal{P}_w$ is the set of all paths for OD-pair w and W is the set of all OD-pairs. The total path set is $\mathcal{P} := \bigcup_{w \in W} \mathcal{P}_w$. The costs of an arc a are denoted by c_a and the path costs of path p are denoted by C_w^p or C^p. The capacity of an arc is denoted by m_a and the capacity of a path is denoted by m_p. The available arcs in a path are denoted by

$$\delta_{ap} = \begin{cases} 1 \text{ if } a \text{ is contained in } p, \forall a \in A, p \in \mathcal{P} \\ \quad\quad 0 \text{ otherwise} \end{cases} \tag{1}$$

After finding the SO solution, we want to find path tolls (β_w^p) such that each agent is satisfied with its route, and thus a UE is achieved. We only use tolls to obtain both an SO and UE solution, so we do not need to make profit on the tolls. We will search for tolls that are as low as possible and we require that all tolls payed or received by agents sum up to zero. We will now go through the proposed algorithm. Finding the path tolls starts with an SO solution (Step 1), solving of which results in the optimal flows f_p (Step 2). Now, define the set of paths used in the SO solution (Step 3) by $h_{in,w} := \left\{ p \,\middle|\, f_p > 0, p \in \mathcal{P}_w \right\}$, and the sets of all other paths (which are not in the SO solution) by $\mathrm{h_{out,w}} := \left\{ p \,\middle|\, f_p = 0, p \in \mathcal{P}_w \right\}$.

We then solve a Nonlinear Programming Problem NP-β that consists of an objective function that minimises the path tolls of a certain path set, and a set of constraints. To realise low tolls on paths in $h_{out,w}$ we will minimise the tolls added to paths which are *not* in the SO solution, so we use as the objective function:

$$\sum_{\mathrm{w} \in \mathcal{W}} \sum_{p \in h_{out,w}} \left| \beta_w^p \right|. \tag{2}$$

To let the tolls sum up to zero we use the constraint:

$$\sum_{p \in h_{in,w}} \beta_w^p f_p = 0. \tag{3}$$

So, if there are tolls needed to obtain a UE, there will be one or multiple agents who need to pay toll, as well as there are one or multiple agents who receive toll. This last group thus has a discount on the routes which we want those agents to take. We do not want the toll received by an agent to be higher than the initial path cost (which would mean that an agent does not have to pay, but only receives money for choosing a certain path), so we use the constraints:

$$C_w^p + \beta_w^p \geq 0 \ \forall \, p \in \mathcal{P} \quad \Leftrightarrow \quad \beta_w^p \geq -C_w^p \ \forall \, p \in \mathcal{P}. \tag{4}$$

Now, the NP-β (step 4) consists of the following constraints:

$$\sum_{w\in\mathcal{W}} \sum_{p\in h_{in,w}} \beta_w^p \underline{f_p} = 0 \tag{5}$$

$$\beta_w^i - \beta_w^j \le C_w^j - C_w^i \ \forall \ (i,j), \ i \in h_{in,w}, \ j \in h_{out,w} \quad \forall \ w \in \mathcal{W} \tag{6}$$

$$\beta_w^p \ge -C_w^p \qquad\qquad\qquad\qquad\qquad\qquad \forall \ p \in \mathcal{P} \tag{7}$$

where Constraint (5) ensures that all tolls on paths used in the SO solution sum up to zero, Constraint (6) ensures the paths used in the SO solution for one order, have equal or lower costs than the paths for that order which are not in the SO solution, and Constraint (7) ensures no tolled cost can become negative.

The NP-β (Step 4) is non-linear, which makes this problem hard to solve. We therefore use the equivalent linear formulation of the problem:

$$\min \sum_{w\in\mathcal{W}} \sum_{p\in h_{out,w}} \gamma_w^p \tag{8}$$

$$\text{s.t.} \ \sum_{w\in\mathcal{W}} \sum_{p\in h_{in,w}} \beta_w^p \underline{f_p} = 0 \tag{9}$$

$$\beta_w^i - \beta_w^j \le C_w^j - C_w^i \ \forall \ (i,j), \ i \in h_{in,w}, \ j \in h_{out,w} \quad \forall \ w \in \mathcal{W}, \tag{10}$$

$$\beta_w^p \ge -C_w^p \qquad \forall \ p \in \mathcal{P}, \tag{11}$$

$$\beta_w^p \le \gamma_w^p \qquad\qquad\qquad\qquad\qquad \forall \ p \in \mathcal{P}, \tag{12}$$

$$-\beta_w^p \le \gamma_w^p \qquad\qquad\qquad\qquad\qquad \forall \ p \in \mathcal{P}, \tag{13}$$

$$\gamma_w^p \ge 0 \qquad\qquad\qquad\qquad\qquad\qquad \forall \ p \in \mathcal{P}, \tag{14}$$

where γ_w^p replaces the absolute value variable $|\beta_w^p|$.

Solving the NP-β (step 5) leads to toll that can be used to change the path costs (Step 6). The desired outcome of Algorithm 1 is that the solution to the SO-β problem is equal to the initial SO problem (Step 7). The resulting path costs are the only costs that are showed to the agents, so the agents do not have any knowledge about the initial STN and those path costs.

Algorithm 1 Calculating path tolls

1: Create SO problem:

$$\min \sum_{p\in\mathcal{P}} C_w^p f_p \tag{15}$$

$$s.t. \ x_a = \sum_{p\in\mathcal{P}} \delta_{ap} f_p \qquad \forall \ a \in \mathcal{A}, \tag{16}$$

$$\sum_{p\in\mathcal{P}_w} f_p = d_w \qquad\quad \forall \ w \in \mathcal{W}, \tag{17}$$

$$x_a \le m_a \qquad\qquad\quad \forall \ a \in \mathcal{A}, \tag{18}$$

$$f_p \in \mathbb{N}_0 \qquad\qquad\quad \forall \ p \in \mathcal{P}, \tag{19}$$

$$x_a \in \mathbb{N}_0 \qquad\qquad\quad \forall \ a \in \mathcal{A}. \tag{20}$$

2: Solve SO problem, output: path flow vector $\underline{f}$.

3: Create two lists for each order w:

$$h_{in,w} = \left\{ p \mid \underline{f_p} > 0, \ p \in \mathcal{P}_w \right\}, \ h_{out,w} = \left\{ p \mid \underline{f_p} = 0, \ p \in \mathcal{P}_w \right\}.$$

4: Create NP-β:

$$\min \sum_{w \in W} \sum_{p \in h_{out,w}} \gamma_w^p \tag{21}$$

$$\text{s.t. } \sum_{w \in W} \sum_{p \in h_{in,w}} \beta_w^p \underline{f_p} = 0 \tag{22}$$

$$\beta_w^i - \beta_w^j \le C_w^j - C_w^i \ \forall \, (i,j), \ i \in h_{in,w}, \ j \in h_{out,w} \quad \forall \, w \in \mathcal{W}, \tag{23}$$

$$\beta_w^p \ge -C_w^p \qquad\qquad\qquad\qquad\qquad\qquad\qquad \forall \, p \in \mathcal{P}, \tag{24}$$

$$\beta_w^p \le \gamma_w^p \qquad\qquad\qquad\qquad\qquad\qquad\qquad\; \forall \, p \in \mathcal{P}, \tag{25}$$

$$-\beta_w^p \le \gamma_w^p \qquad\qquad\qquad\qquad\qquad\qquad\quad\; \forall \, p \in \mathcal{P}. \tag{26}$$

5: Solve NP-β, output: β_w^p.

6: Add tolls β_w^p to the SO problem, SO-β:

$$\min \sum_{p \in \mathcal{P}} \left(C_w^p + \beta_w^p \right) f_p \tag{27}$$

$$\text{s.t. } x_a = \sum_{p \in \mathcal{P}} \delta_{ap} f_p \quad \forall \, a \in \mathcal{A}, \tag{28}$$

$$\sum_{p \in \mathcal{P}_w} f_p = d_w \qquad\quad \forall \, w \in \mathcal{W}, \tag{29}$$

$$x_a \le m_a \qquad\qquad\quad\;\; \forall \, a \in \mathcal{A}, \tag{30}$$

$$f_p \in N_0 \qquad\qquad\qquad \forall \, p \in \mathcal{P}, \tag{31}$$

$$x_a \in N_0 \qquad\qquad\qquad \forall \, a \in \mathcal{A}. \tag{32}$$

7: Solve SO-β problem, output path flow vector f.

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4   Numerical examples

We illustrate the algorithm, by solving two examples. In the first example there are three locations, V = {1,2,3}, and five time steps. We have two connections between location $l = 1$ and $l = 2$ and two between $l = 2$ and $l = 3$. Those arcs all have capacity $m_a = 1$, and $m_a = \infty$ for (horizontal) waiting arcs. We have two orders, order 1 and 2 both start at location 1, order 1 has to go to $l = 2$ and order 2 to $l = 3$. Every node column shows a time step and each arc has cost $c_a = 1$. The two possible solutions are given in Figure 2, with s_w denoting the starting point and e_w denoting the end point for order w.

(a) The SO solution.　　　　(b) The alternative solution.
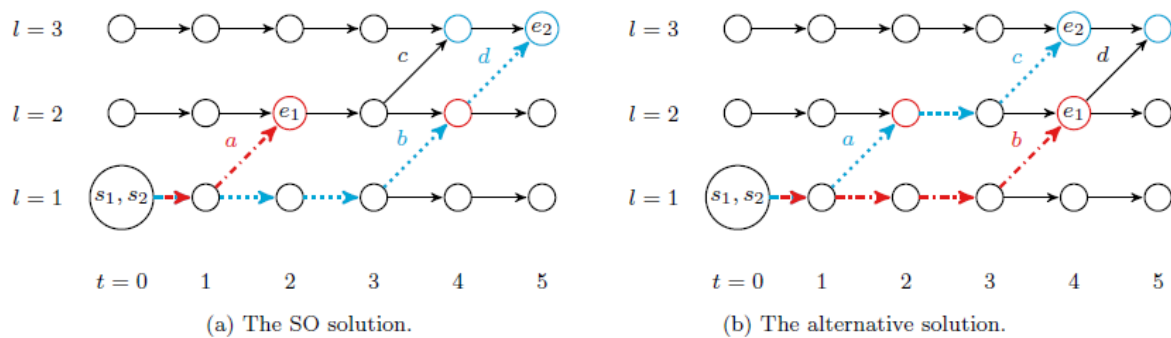
Fig. 2: STN with two orders, first example..

In Figure 2a we see the SO solution, resulting from Step 1 and Step 2, that is the solution where the total costs are minimized. Here order 1 is delivered first with cost $C_1^a = 2$ and therefore

order 2 can only take path bd with cost $C_2^{bd} = 5$. In Figure 2b a solution is given where both orders pay cost 4, that is path b for order 1, and path ac for order 2.

We can see that each order has its own preferable solution, that is the one in which they can travel via arc a, which is in the cheapest path for both orders. We have path costs $C_1^a = 2$, $C_1^b = 4$, $C_2^{ac} = 4$, $C_2^{ad} = 5$ and $C_2^{bd} = 5$, and the path sets following from the SO solution as obtained in Algorithm 1 in Step 3: $h_{in,1} = \{a\}$, $h_{in,2} = \{bd\}$, $h_{out,1} = \{b\}$, $h_{out,2} = \{ac, ad\}$.

The tolls given by Step 4 and Step 5 are $\beta_1^a = 1$, $\beta_2^{bd} = -1$, so all tolls on paths $p \in \bigcup_{w \in W} h_{out,w}$ are zero and so is the objective value of the NP-β. The best solution of the NP-β is indeed the solution as obtained from Algorithm 1 Step 5: $\beta_1^a = 1$, $\beta_1^b = 0$, $\beta_2^{ac} = 0$, $\beta_2^{ad} = 0$, $\beta_2^{bd} = -1$ and with those tolls we obtain the path costs: $C_{\beta1}^a = 3$, $C_{\beta1}^b = 4$, $C_{\beta2}^{ac} = 4$, $C_{\beta2}^{ad} = 5$ and $C_{\beta2}^{bd} = 4$, Both orders can travel via their cheapest paths, so both an SO and a UE are obtained.

In the second example (Figure 3) we have three orders, all with different demand: $d_1 = 3$ from location 1 to 2, $d_2 = 3$ from location 1 to 3 and $d_3 = 1$ from location 2 to 3. An SO solution is given in Figure 2, with s_w and e_w denoting the start end point of order w, respectively. All traveling arcs have capacity 1, except for arcs a, c and f, which have capacity $m_a = m_c = m_f = 2$, what we graphically show by multiple arcs between a pair of nodes.

We have path costs

$$C_1^a = 1, \quad C_1^b = 2, \quad C_1^c = 3, \quad C_1^d = 5,$$

$$C_2^{ae} = 2, \quad C_2^{af} = 3, \quad C_2^{ag} = 4, \quad C_2^{ah} = 5, \quad C_2^{bf} = 3, \quad C_2^{bg} = 4, \quad C_2^{bh} = 5, \quad C_2^{cg} = 4, \quad C_2^{ch} = 5,$$

$$C_3^e = 2, \quad C_3^f = 3, \quad C_3^g = 4, \quad C_3^h = 5,$$

The path sets following from the SO solution are:

$$h_{in,1} = \begin{Bmatrix} a, c, d \\ 1, 1, 1 \end{Bmatrix}, \qquad h_{out,1} = \begin{Bmatrix} a, b, c \\ 1, 1, 1 \end{Bmatrix},$$

$$h_{in,2} = \begin{Bmatrix} ae, bf, cg \\ 1, 1, 1 \end{Bmatrix}, \qquad h_{out,2} = \begin{Bmatrix} af, ag, ah, bf, bg, ch \\ 2, 1, 1, 1, 1, 1 \end{Bmatrix}$$

$$h_{in,3} = \begin{Bmatrix} f \\ 1 \end{Bmatrix}, \qquad h_{out,3} = \begin{Bmatrix} e, f, g, h \\ 1, 1, 1, 1 \end{Bmatrix}.$$

We see that none of the orders can travel via their cheapest paths, so we need tolls to create a UE. Solving the NP-β gives us $\beta_1^a = 2\frac{1}{3}$, $\beta_1^c = \frac{1}{3}$, $\beta_1^d = -1\frac{2}{3}$, $\beta_2^{cg} = -1$, $\beta_2^{ae} = 1$, $\beta_3^f = -1$, $\beta_1^b = 1\frac{1}{3}$. Note that path $b \in h_{out,1}$, so the toll on that path is not actually payed.
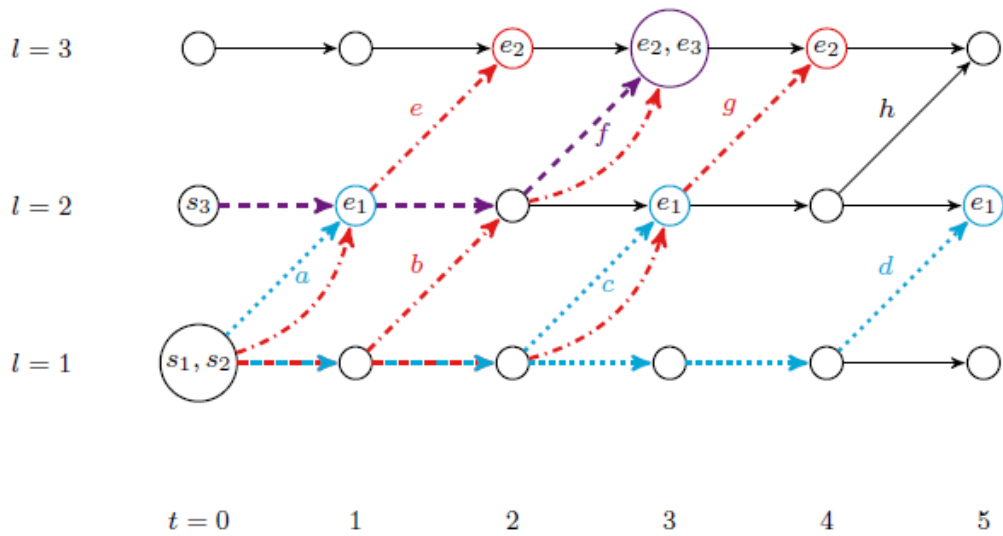
Fig. 3: STN with two orders, second example.

Table 1: Values $h_{out,w}$.

Order	1			2						3			
$p \in h_{out,w}$	a	b	c	af	ag	ah	bf	bg	ch	e	f	g	h
Initial path costs	1	2	3	3	4	5	3	4	5	2	3	4	5
Tolls	2⅓	1⅓	⅓	0	0	0	0	0	0	0	−1	0	0
Resulting path costs	3⅓	3⅓	3⅓	3	4	5	3	4	5	2	2	4	5

Table 2: Values $h_{in,w}$.

Order	1			2			3	
$p \in h_{in,w}$	a	c	d	ae	bf	cg	f	
Initial path costs	1	3	5	2	3	4	3	
Tolls	2⅓	⅓	-1⅔	1	0	−1	−1	
Resulting path costs	3⅓	3⅓	3⅓	3	3	3	2	

5 Conclusions

The goal of this work was to provide a method to obtain a User Equilibrium in a logistic, intermodal or synchromodal Space Time Network (STN), in which we transport containers for multiple agents. We defined a UE as the solution where each agent can send its containers via its cheapest paths. We expanded this goal to also finding a solution of assigning containers to modes where the solution is System Optimal and by adding tolls a UE simultaneously. The first step in all toll algorithms is to calculate the SO based on the path costs of containers travelling from their origin to their destination. The next step is to calculate tolls that are added to the path or order costs, depending on what kind of tolls we considered.

When applying path based tolls, we assume agents do not know the path costs of the initial network (and thus also do not know their initial cheapest paths). Here the tolls are used to adjust the path costs, such that we can offer the agents a choice of tolled paths. Then when the agent gets assigned its cheapest tolled paths, those paths are in the SO solution and the solution is UE as well. The solution is UE because the offered path costs are the cheapest option according to the information available for the agent. We succeeded in finding an approach to obtain both an SO and a UE solution on an STN. An practical note here is that using this approach in a real

system with selfish agents is not easy. However, we think that this method can be used for sharing the benefits coming from a centrally controlled network.

For further research, we propose to take due dates into account. When we do this, it can be the case that orders will arrive too late compared to this due date. We then need to add a penalty function to the cost objective function in order to minimise the number of orders arriving too late. With the tolls, it is possible to share the penalty costs by all orders who are causing the lateness of the delayed orders. Another aspect that should be looked at is fairness of the UE solution. In the presented approach a UE is found and the benefit of the SO is shared between the agents. We do not know, however, whether this sharing is done in the fairest way.

Acknowledgements

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A New 'Gain-Sharing' Business Model to facilitate the Physical Internet via a Competitive, Collaborative Logistics Platform

Alix Vargas[1], Andrew Traill[1], Carmen Fuster[1] and David Corne[2]
1. Connected Places Catapult (CPC), Milton Keynes, UK
2. Heriot-Watt University, Edinburgh, UK
Corresponding author: alix.vargas@cp.catapult.org.uk

Abstract: Collaboration in the freight industry has the potential to deliver significant socio-economic and environmental benefits and is key to the development of a Physical Internet. However, until now convincing logistics companies of the business case for collaboration has represented a significant barrier to generating those benefits. The Freight Share Lab (FSL) project, which is funded by Innovate UK, offers a solution. It demonstrates that there is a potential 'win-win' for logistics service providers and their customers, where "coopetition" can be delivered through a collaboration platform that yields significant commercial benefits for all participants. The platform developed by FSL project partners, Heriot-Watt University and Trakm8 PLC, uses a multi-fleet logistics optimisation and decision support algorithm, in the management of freight logistics assets which, when combined, deliver a lower priced service and reduced carbon footprint than would have been achievable by the original contract holder. The business model developed by Connected Places Catapult Ltd (CPC) ensures that both the original contract holder and those deployed by the FSL platform to fulfill the contract, retain their profit margins and share the differential between the operating costs of the former and the price charged by the latter, using game theory approach. The initial results obtained from model simulations using realistic data indicate there are significant financial benefits for FSL platform members using this 'gain-sharing' model.

Keywords: business model, logistics platform, gain sharing, physical internet, barriers to collaboration, efficiencies, business case, coopetition, increased utilisation, reduced emissions

1 Introduction

Horizontal and multilateral collaboration in the freight industry have the potential to generate significant benefits for society, the environment and the economy. Additionally, freight service providers would benefit from the reduced operating costs resulting from fewer trucks, lower mileage, and increased trailer utilisation, from which – assuming perfect competition – customers would also benefit. According to the World Business Council for Sustainable Development, collaboration between logistics operators using freight exchanges, can yield cost savings of c.20% and a reduction in CO_2 emissions of c.32% (wbscd, 2017).

The barriers to sharing logistics assets with others (potentially one's competitors) are significant. In large part, these barriers hinge around lack of trust between potential collaborators, a refusal to share data and a reluctance to change one's business model. However,

by demonstrating a clear business case and showing a 'win-win' for all stakeholders, industry is more likely to consider collaboration.

Yet collaboration should not compromise or exclude competition. Creating a competitive-collaborative business model that can capture the significant benefits from horizontal collaboration seems improbable. Without it however, further strides towards the commercial realisation of a Physical Internet would seem remote. The Freight Share Lab (FSL) project confronts such scepticism by showing that so-called "coopetition" can be established in a horizontal collaboration platform which demonstrates that elusive 'win-win' business case.

The FSL platform uses a multi-fleet logistics optimisation and decision support algorithm. This seeks out the logistics solution that can fulfil contracts at a lower price and with lower emissions by exploiting the combination of assets available to the FSL Platform (FSLP). The business model developed by CPC ensures that both the original contract holder and those companies that provide the assets deployed by the FSLP to fulfil the contract retain their profit margins. Not only that, but they also share the differential between the operating costs of the contract holder and the price of the fulfilment provider. The platform, therefore, is able to reward those operators that submit their contracts to the FSLP and those that the FSLP algorithm determines are the best to fulfil the contract. This feature drives competition between the members of FSL. The FSLP links freight providers with a wider pool of asset owners and operators: the larger the pool the more chance of finding a better solution. In theory, participating companies can only gain, financially, from this model.

The initial results obtained from model simulations using realistic data, indicate significant financial benefits for FSLP members using this 'gain-sharing' model. The analysis further demonstrates marked reductions in total mileage, implying increases in the average utilisation of trucks, thus leading to reduced road congestion and emissions. This could be a significant step forward in the development pathway proposed by the Alliance for Logistics Innovation through Collaboration in Europe (ALICE), for a Physical Internet by 2030-2040 and zero emissions-logistics by 2050.

This paper sets out the journey the FSL project team has made in arriving at this point and these conclusions. Section 2 provides a critical review of the literature regarding: collaboration in supply chains, collaboration in freight logistics, forms of collaboration, strategies for collaboration, barriers to collaboration and enablers for collaboration. Section 3 presents the freight collaboration platform architecture. Section 4 presents the adapted business model canvas for FreightShare Lab and details including: value proposition, key activities, customer segments and relationships, cost structures and revenue streams. Section 5 presents the results of the economic and wider social and environmental impacts. Finally, Section 6 includes the main conclusions and suggestions for further work.

2 Literature review and background

2.1 Collaboration in supply chain

The concept of collaboration in the supply chain has been discussed and applied extensively in both industry and academic circles (Cao and Zhang, 2011; Liao and Kuo, 2014). Several types of organisations are using collaboration in the supply chain to gain advantages in efficiency, costs and customer satisfaction (Alarcón, 2005). Collaboration-based business models enable cost reduction and improved customer service through shared information and assets and better coordinated collaborative network activities (Alarcón, 2005), and generate synergistic benefits that companies cannot achieve individually. It is important to recognise that there must be a

driving motive for all parties to work together, becoming a "committee of equals" that find greater value in collaboration to ensure long-term success (Sutherland, 2006) and allowing coordination to help meet common business objectives (Osório et al., 2013). Collaboration is possible when at least two actors share their efforts, data and/or assets to reach a common objective (Gonzalez-Feliu & Salanova, 2012). An increasing number of diverse forms of collaborative networks have emerged because of advances in information and communication technologies, market and societal needs, and the progress made in many international projects (Camarinha-Matos, et al., 2008). A collaborative network (CN) is defined as "A network composed of a variety of entities (e.g. organisations, people, machines) that are autonomous, geographically distributed and heterogeneous in terms of their work environment, culture, social capital and objectives, but they collaborate to better achieve common or compatible objectives, generating value together, and whose interactions are supported by computer networks" (Camarinha-Matos & Afsarmanesh, 2005).

2.2 Collaboration in freight logistics

This trend towards collaboration that seems to be engaging different suppliers and manufacturers in the supply chain field does not seem to have the same effect in the freight industry itself. This is mainly due to competition between operators and their low profit margins (Vargas et al., 2018). Peeta & Hernandez (2011) noted that a growing number of small or medium-sized carriers have launched collaborative networks in a bid to improve profit margins and competitiveness; yet, there remain significant inefficiencies in the sector.

Freight logistics both drives and enables economic growth as well as representing a major source of employment in Europe (Gonzalez-Feliu et al., 2013). Logistics and supply chains impose significant external costs on society (BESTUFSll, 2007). These cross-sectoral costs range from health and environmental costs of pollution and traffic congestion, costs of delays borne by road users, and nuisance costs, such as increased levels of noise, among others.

The Department for Transport (DfT) has reported that 'empty running' increased from 27% to 30% between 2006 and 2016 in the UK (DfT, 2017); capacity utilisation is only 68%. This translates to a meagre overall freight efficiency of just 47.6%. Considering that trucks are 'on the road' for barely a third of their time the remaining two-thirds being fallow periods including driver resting times and weekends, etc. (Frost & Sullivan, 2016), this translates to an asset efficiency of only 15%-16%. Collaboration in the freight industry would reduce the number of HGVs on the road, decrease GHG emissions, reduce empty running, and identify routes and journeys where operators can consolidate their loads into a single vehicle trip (TRL, 2017).There is clear potential evident for collaborative initiatives to deliver significant benefits in the freight industry, particularly if the right business models can be identified.

2.2.1 Forms of collaboration

There are two different, but inter-linked collaborative approaches. The first identifies who takes part in the collaboration, and defines its *physical structure*. In this approach three main categories have been used specifically for the transport industry (Caballini et al., 2014; Okdinawati et al., 2015): a) *vertical collaboration* which concerns two or more organisations at different levels of the logistics chain; b) *horizontal collaboration* which concerns two or more competing organisations at the same level of the logistics network; and c) *multilateral collaboration* which combines and shares capabilities both vertically and horizontally.

The second approach is the one on which FSL is particularly focused. In this approach, there can be different *types of coordination* established between the members. These forms of

coordination are (Dudek, 2009; Ribas and Companys, 2007): a) *centralised,* involving decision-making at a common higher level by generating synchronized instructions at lower levels; and b) *decentralised,* which implies consensus, agreement of objectives, indicators and equality rules between partners. This collaboration is usually achieved through communication and negotiation processes between the partners. This becomes an important factor in shaping the processes and procedures, terms and conditions, of the FSLP.

2.2.2 Strategies of collaboration

In freight logistics, collaborative strategies can take place in the transport of goods, warehousing, equipment pooling (e.g. container pools, pallet networks etc.) and other operations. They usually take the form of agreements and partnerships among a small number of companies and may even be ad-hoc rather than comprise any formal arrangement (Gonzalez-Feliu and Morana, 2011). Various authors have identified a number of strategies (Peeta and Hernandez, 2011; TRL, 2017; wbcsd, 2016), e.g.: cooperative alliances, route scheduling/planning, backhauling, freight exchanges, consolidation centres, delivery and servicing plans, and joint optimisation of assets and sharing capacity.

2.2.3 Barriers to collaboration

Strategies of collaboration and development of collaborative networks are, however, sparsely employed in the freight industry. By isolating barriers and limitations to collaboration, strategies to overcome them can be identified. Vargas et al. (2018) compiled the main barriers and limitations found in the literature and strategies to overcome them (Table 4).

Table 4 Barriers for collaboration in the freight industry and strategies to overcome them.

Barriers/Limitations for Collaboration	Author	Strategies to Overcome Them
Shipper concerns of having a different carrier from its usual contracted carrier.	(Peeta and Hernandez, 2011)	Concerns over branding could be resolved through use of independent third parties and non-liveried vehicles. Involving the shipper into the alliance, through agreements, showing them the advantages of collaboration.
Load compatibility can restrict the ability for loads to be shared.	(TRL, 2017)	Matching companies moving similar products with similar handling equipment on similar types of vehicles.
Responsibility for transportation operations.	(Fabbe-Costes, 2007)	If the collaborations for logistics sharing follow a contract or a chart where the responsibilities are well defined, these questions will not constitute an obstacle to sharing.
Legal barriers, there are laws that interfere with the ability to share data: competition law.	(Audy et al., 2012; Fabbe-Costes, 2007; Greening et al., 2015; Jenks et al., 2013; TRL, 2017)	The European Union (EU) recommends the use of a neutral trustee, to whom different stakeholders give data to be held and analysed preventing the transfer of commercial data such as, volumes, delivery addresses, costs, product characteristics, etc.
Lack of human resources, especially for small operators.	(Jenks et al., 2013)	By giving to a central entity the authority of decision making in terms of optimisation and route scheduling for a group of partners that are collaborating, there is no need to increase utilisation of human resources for fleet operators.
Significant coordination is needed to achieve data and asset sharing.	(Jenks et al., 2013)	In a centralised structure collaboration scheme, the central coordinator is responsible for coordination of the partners in the collaboration and the partners are committed to follow central instructions to allow the collaboration scheme to work.
Lack of available accurate data.	(Eckartz et al., 2014; Greening et al., 2015; TRL, 2017)	Definition of data structure requirements for collection of unified and accurate data for collaboration. The confidentiality of data collection will be defined through contracts between the partners in the collaboration and the central trustee authority.
Lack of trust and common goals.	(Peeta and Hernandez, 2011; TRL, 2017)	Use of clear contract agreements, where partners define confidentiality policies, service levels agreements, penalties in case of failing, payment conditions, coordination structure, management of unexpected events and contract duration.
Lack of a fair allocation mechanism for collaboration revenues.	(Audy et al., 2012; Nadarajah and Bookbinder, 2013; Peeta and Hernandez, 2011; TRL, 2017)	Giving different options for revenue sharing to the partners and showing them the cost benefits of each option will allow them to choose, during the negotiation phase, which mechanism will be used for revenue sharing.
A neutral third party is required to facilitate collaboration.	(Nadarajah and Bookbinder, 2013)	A trustee figure is necessary to implement collaboration. The trustee needs to be a connector between the collaboration partners. Partners might be reluctant to accept a third party, but, this can be overcome through contracts between each partner and the trustee.
There are clear regional imbalances in freight movement.	(TRL, 2017)	Use the practice of triangulation, where a truck is diverted from its main back route to a third point in order to pick up a return load, potentially increasing the mileage but reducing the amount of empty running.

Unawareness of the benefits of participating in collaborative projects.	(Kale et al., 2007)	Engagement of stakeholders to participate in collaborative networks is crucial. During the initial engagement, it is necessary to show to the possible partners the real benefits of similar collaborative projects.
High risk of strategic behaviour in auction collaborative process.	(Gansterer and Hartl, 2018)	Effective profit-sharing mechanisms are needed, since these have the potential to impede strategic behaviour.

2.2.4 Enablers for collaboration

A successful business model must consider known, tried and tested enablers for collaboration. Table 5 shows a compilation of enablers and opportunities found in the literature.

Table 5 Enablers and opportunities for collaboration

Enabler	Authors	Opportunity
Common Cultural Mind Set.	(NexTrust, 2017; Peeters et al., 2017)	The fundamental breakthrough for the success of collaborative projects in the freight industry comes from the willingness of the different industry actors to cooperate. It is critical that partners who decide to collaborate have a common cultural mind-set allowing the implementations of collaborative process to run smoothly. It is necessary that a fundamental change in the management of transportation sourcing and operations requires that shippers and carriers, make an actual "mental shift", de-coupling from their own networks first and then agreeing to re-connect with other shipper network flows.
Establishment of Non-disclosure Agreements.	(Bogens and Stumm, 2017; Jenks et al., 2013)	An important way to protect data and assets that are intended to be shared and to assure that owners of the data and assets are willing to provide them to the consortium, is to execute non-disclosure or privacy agreements. These may be part of legal contracts or separately negotiated documents. The use of this document will help to increase trust among the partners
Stakeholder Engagement.	(Jenks et al., 2013)	It is incumbent upon project leaders and participants in a collaboration project to get to know each other well, establishing .a bond and trust between partners prior to collaboration. In this way the partners get to know each other deeply and increase the sense of confidence and trust among them. This will ultimately assure the success of the project.
Technology Innovation.	(Jenks et al., 2013)	In many cases the implementation of a particular technology makes it easier to share data and assets and helps a project to succeed. An automated technology which could accomplish the identification, for instance, of a transportation vehicle without requiring the divulgence of certain data about that vehicle could be a motivator for participants.
Articulating Benefits of Sharing.	(Jenks et al., 2013)	It is important for project proponents to be able to explain to the public, to private sector participants, and to other stakeholders how they will benefit from the conduct of the project. Articulating benefits is an important part of project coordination. For instance, publishing analyses of the expected costs savings and benefits of the project reveals openness and transparency such that it could help to assure its success and the involvement of different stakeholders.
Legislative Changes.	(Fabbe-Costes, 2007; Jenks et al., 2013)	Normative and jurisprudence aspects of sharing are related to public administrations. Nowadays, the most important facilitators in this category are the different local laws and legislation that help the development of sharing approaches in urban and regional freight transportation. There are two types of approaches: restrictions to non-sharing and incentives to sharing. In the first approach, local authorities could use zero emissions zones to force carriers to collaborate with EV operators to avoid expensive penalties. In the second approach, local authorities could, for instance, incentivise the reduction of empty running, through reduced taxation for companies that join collaborative schemes.
Previous Relationships Among Partners.	(Fabbe-Costes, 2007)	When participants have already collaborated, because of common interests or because they belong to the same network o, transportation sharing is more naturally occurring; it can seem like a step forward in the relationship building among participants. Thus, the trust factor is already in place and the collaboration relationship flows smoothly.
Definition of Penalties for Non-Compliance.	(Kale et al., 2007)	Penalties for non-compliance with contract terms could be made through default payments for each shipment in which a default occurs. Moreover, in some collaborative arrangements, default payments may not be assessed on a shipment basis. The approach used to define the type of penalties for non-compliance with specific terms in a contract will be defined for the collaborative network. The partners that are committed will work with extra care to achieve their liabilities.

3   Freight Collaboration Platform Architecture

3.1   Operating Cycle, Data, and Algorithms

Most operators in the freight industry work in a daily cycle, whereby operations are planned on day 1, typically in the evening, and executed on day 2; delivery plans for Thursday (for example) will typically be calculated on Wednesday, based on up-to-date customer orders and availabilities, and then sent to drivers in advance. The FSL Collaboration Platform (FSLP) aligns with this general practice; that is, every day, data relevant to *tomorrow's* plan is collected, up to an agreed cutoff time (e.g. 7pm). Then, collaborative delivery plans are derived, and are sent to the members, for distribution to drivers and warehouses in advance of their execution the next day. In the remainder, the discussion of the FSLP will be on the context of this daily cycle. However, it is worth noting that this does not limit the concept. For example, separate

FSL platforms could independently handle nightwork, or multiday planning horizons, each focusing on a distinct subset of participants.

FSL members who use the FSLP can upload either, or both, of two main types of data: (i) **vehicles** that the member wishes to make available to the platform, and (ii) **jobs** that the member wishes to have processed by the platform. The member also indicates the type of sharing arrangements that are appropriate for them. Hence, at the cutoff time on any given day, the FSLP will have a dataset $D = (V, J, S)$, respectively denoting the full set of vehicles and jobs available, and the corresponding sharing arrangements. It may be tempting to view D as a single large-scale vehicle routing problem with specialised constraints (Laporte, 1992; Solomon, 1987). However, the typical scale of D (e.g. 20,000 jobs, 5,000 vehicles) compromises the ability of current algorithms to address this in a reasonable time-frame. Therefore, the FSLP instead operates a 'divide-and-conquer' strategy to partition D into a series of smaller problems, $D_1, D_2 \ldots, D_n$, and then solves each of these problems in turn.

The partitioning strategy makes use of a specialised metric, called *sharefactor*, which predicts the extent to which two FSL members would benefit by working together. Essentially (and highly simplified), asset sharing is effective to the extent that fleet A's orders are geographically more convenient for fleet B's vehicles to handle than they are for fleet A's vehicles. This notion is estimated for each job by a *sharescore*. In short, suppose two FSL members, A and B, submit their data (V_A, J_A, S_A) and (V_B, J_B, S_B) to the FSLP, and that their respective sharing arrangements are compatible (e.g. A's vehicles are able to carry B's jobs and vice versa). The *sharescore ss*(j) for each job from J_A is defined as follows: $ss(j)$ is Tc/Ts, where Tc is the time it would take for a vehicle from V_B to process the job if it were located for pickup at B's depot, and Ts is the time it would take a vehicle from V_A to process it from A's depot. A *sharescore* below 1 suggests a time and mileage advantage. Moreover, the *sharefactor*(A,B) for two fleets is the proportion of the combined jobs (from both J_A and J_B) that have a sharescore below 1. The larger the sharefactor, the larger the potential benefits for collaboration, since it suggests, for example, that an initial shuttling of orders between the depots could result in more efficient delivery, more than compensating for the shuttling costs.

Using primarily the *sharefactor*, calculated for all pairs and triplets of fleets, a fast filtering algorithm first ranks potential groupings of fleets for potential resource savings from collaboration. The FSLP then proceeds to consider each of these groups in turn, and solves the associated specialised fleet planning problem that arises from combining their assets according to their declared sharing arrangements among the group. Hence, following an initial phase that partitions the potentially nationwide logistics task into individual multi-fleet planning problems, each of the latter problems is then solved by a centralized collaborative planning strategy (Gansterer and Hartl, 2018) using a solver described next.

The fleet planning solver used by FSL is a variant of commercial software that is currently operating in the (single) fleet planning industry. Consistent with state of the art algorithms of its type, its design combines various aspects of metaheuristics search (Blum and Roli, 2003), many-objective search (Corne and Knowles, 2007) and traditional AI planning (Ghallab et al., 2004). The range of factors considered by the algorithm are those with material impact on time, costs, and mileage, including: a) *Costs*: Cost-per-mile, potentially different for different vehicles; driver cost-per-hour (and, if relevant, overtime costs per hour); a fixed cost per vehicle; an 'Opportunity Cost' of not delivering a job; this is commonly supplied by users of

fleet optimisation software, and can be considered as a penalty fee to be paid to the customer if the job is not delivered; b) *Times and associated constraints*: driver shift times and working time constraints; time windows for pickup and delivery of each job; service times for pickup and delivery of each job; driver briefing time; realistic times for every journey, given vehicle type; and c) *Capacity issues*: weight and volume capacity of each vehicle, weight and volume of each job, ensuring vehicles are never overloaded.

The solver produces a detailed schedule of activities, specifying an itinerary for all or some of the vehicles involved, similar to the itineraries typically delivered by fleet optimisation software. The schedule for a group of fleets (typically two or three) will usually process all jobs involved in the group, although this is not always possible. However, in such circumstances, a collaborative schedule will always be able to process at least as many of the jobs as would be achievable without asset sharing, and usually more.

3.2 Arrangements for Collaboration

Horizontal collaboration between FSL members is the essence of the proposed solution and business model. The key aspects of the 'sharing arrangements' data that FSL members supply (as indicated above) are now outlined. Essentially, each FSL member indicates its preferences in terms of the following four scenarios: a) Full Sharing without special arrangements; b) Full Sharing with morning transfer arrangements; c) Full Sharing with a consolidation site; and d) Partial Sharing with no arrangements, as well as any associated parameters. When the FSLP is considering a particular group of fleets, this group has already been determined to have compatible sharing arrangements. The Full Sharing scenarios are where FSL members are willing to both undertake other members' jobs as well as handing over some of their own jobs for others to handle, i.e. there is full sharing of assets and contracted jobs. Notice that this does not necessarily mean that each FSL member submits all of their vehicles and jobs to FSL, this only means that the member provides both one or more vehicles and one or more jobs. A standard use-case, for example, could be for a member to submit only the vehicles left unused and the jobs left unprocessed following their in-house planning. Whilst this would potentially limit the opportunity to increase revenue for members and limit the number of assets available to the algorithm, this might be considered a likely scenario in the early days of FSL whilst members build their 'trust' of the system.

The Partial Sharing scenario, currently under development, assumes some of the FSL members will only leave vehicles at the platform's disposal. However, FSL's business model requires members to input contracts for logistics jobs, for the platform to reallocate them to a more cost- and emission-efficient solution. For FSL to be sustainable and most effective, there must be sufficient members willing to share their jobs.

3.2.1 Full Sharing without special arrangements

In this scenario, the collaborating members have not set up any special arrangements (e.g. consolidating freight at a specific consolidation centre). For one member to handle a job provided by another member, the former will simply pick up that job from the latter's depot. A grafical representation of this arrangement is presented in Figure 18. This arrengement has the potential to be more efficient than single fleet operations if the collaborating members are quite near to one another, and/or if there is a significant geographical overlap in jobs, such as delivery

windows in the same areas during the same period of time. However, when the overlap in customer locations is low, the result of this collaboration may only slightly improve upon the 'no-sharing' default scenario.
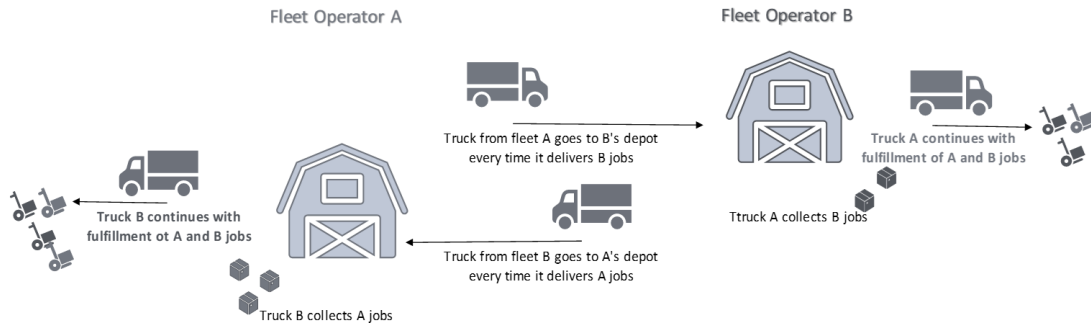
Figure 18: No Special Arrangements Collaboration Scenario

3.2.2 Full Sharing with morning transfer arrangements

In this scenario, each fleet in the group is prepared to accommodate a 'morning transfer' arrangement, whereby a vehicle with suitable capacity (from any of the fleets) will transfer jobs between depots at the beginning of the day. For example, a vehicle from member A will first load up with several jobs from JA that have a good sharescore, and take these to B's depot, and then return to A's depot carrying several jobs from member B that also have a good sharescore. Figure 19 illustrates the arrangement. The corresponding combined delivery plan will only be assigned by the platform if the efficiencies gained through collaboration significantly outweigh the costs of the 'morning transfer' shuttle arrangements.
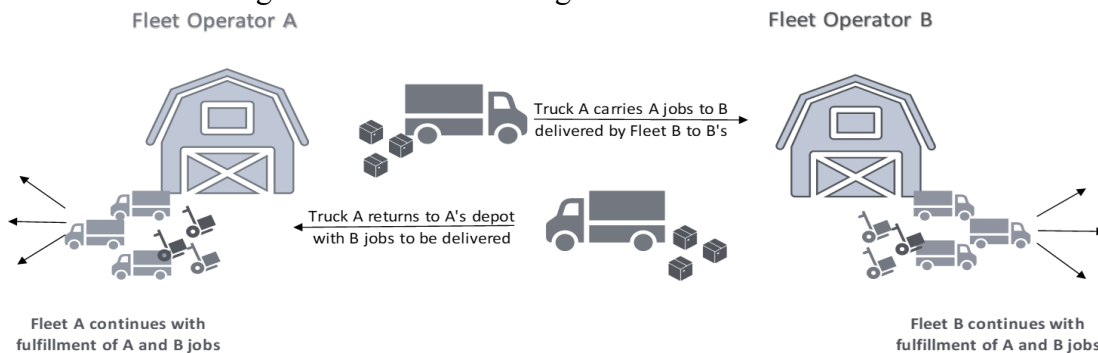
Figure 19: Morning Transfer Collaboration Arrangement Scenario

3.2.3 Full Sharing with a consolidation site

In this scenario, the collaborating companies have chosen a mutually agreed site, and one or more vehicles from each fleet in the group will transfer selected jobs to that site at the start of the day. This site may be a commercial consolidation centre or a site owned by one of the collaborating partners. This scenario resembles the 'morning transfer', but effectively reduces the additional costs when there are multiple nearby companies in the group.
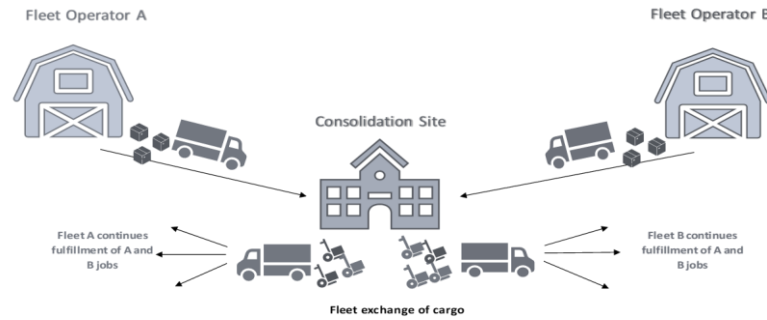
Figure 20: Consolidation Site Collaboration Arrangement Scenario

3.2.4 Partial sharing without arrangements

In this scenario, a collaborating company only supplies vehicle resources to the system, hoping to generate income from underutilized assets. The platform may identify those resources as being strategically located for efficiently fulfilling a subset of other fleets' contracts, and hence this might be seen as a form of subcontracting.

3.3 Estimated Benefits

While the algorithms discussed above were being developed, extensive experimentation was conducted to investigate the potential benefits in comparison to non-sharing scenarios. The experimental setup and results were reported in (wbcsd, 2016) and focused on 'full sharing with no special arrangements', using synthetic data. Here a briefly summary of the results: (i) with two fleets fully collaborating, the reduction in mileage and costs ranged from 16% to 53%, with a mean of 19% (ii) improvements were more marked in denser road networks (e.g. European vs US), where neighbouring cities tended to be closer, and (iii) with up to five fleets working together, savings as much as 70% could be achieved, with diminishing returns beyond five fleets. Following these early indications of potential benefits, the FSLP has been prototyped and a business model has been developed, as introduced in this paper. A number of simulations have been done using realistic data to ascertain how these estimated savings translate into business gains in a commercial setting; the outcome of this is summarised in section 5.

4 Freight Collaboration Business Model

Collaboration in the freight industry has the potential to deliver significant socio-economic and environmental benefits and is key to the development of a Physical Internet. Amongst the many barriers for collaboration, discussed in Section 2.2.3, convincing logistics companies of the business case for collaboration has until now represented a significant barrier. The business model developed by CPC aims to address these barriers by demonstrating there is a win-win for logistics service providers as well as their customers, where "coopetition" can be delivered through a collaboration platform yielding significant commercial benefits for all participants, based on game theory. In Netherlands, a similar platform was developed and was operating commercially, but failed to develop a healthy and scalable business model with the resources they had and therefore they had to shut down in 2018 (Ploos van Amstel, 2018). After discussion with Dr. Ploos Van Amstel, it was appointed that the FSL business model is not the same used by the Netherlands. At this stage, it is worth noticing that FSL has a very different business model than typical freight exchange platforms like Uber Freight, Quicargo, Returnloads or TG Matrix, and this session will describe those differences. Figure 21 provides a high level visual representation of the proposed adapted business model canvas (Osterwalder and Pigneur, 2010; Vargas et al., 2018). The following subsections will develop further the most critical elements of the proposed adapted business model canvas.

Key Partners:	Key Activities:	Value Proposition:	Customer & Key Partner Relationships:	Customers Segments
• Neutral trustee: managing the system and enabling the collaboration process • Shippers: Indirect beneficiary from competitive prices and reduced emissions	• Initiation • Plan exchange • Negotiation/revenue sharing • Execution • Performance measurement & revenue sharing execution • Feedback/improvement **Key Resources:** • Data regarding members' assets (fleets, warehouses, equipment, contracted jobs) • Personnel to manage & maintain the platform • Digital platform with optimization algorithms	• Collaboration between potentially competing service providers to increase efficiency, asset utilisation and reduced emissions • Managed & maintained by a neutral trustee • Automatic reallocation of jobs which deliver an optimised price solution • Fair distribution of additional profits achieved from collaboration • Provides optimised scheduling and routing for the collaborative solution • No subscription fee	• Customers are members of the FSL platform • Neutral trustee manages the membership and platform on their agreed terms • Relationships and negotiations between shippers and members remain independent from FSL • FSL allows freight exchanges to be members on behalf of their customers	• Fleet operators (small, medium and large size) are direct FSL customers. • Freight exchange platforms: these can be integrated with FSL to offer added value to their customers **Channels:** • Digital platform for operation • FSL webpage • Mobile app

Cost Structure:	Revenue Streams:
• Setup platform costs • Personnel costs • Operating and maintenance costs	• Additional revenue resulting from savings achieved through collaboration

Forms of Collaboration:	Strategies of Collaboration:
• Centralised for the platform to determine optimised solution • Decentralised for members to negotiate terms & conditions of the platform • Horizontal collaboration between potential competitors	• Route scheduling /planning • Joint optimisation of assets • Backhauling • Consolidation

Figure 21: Adapted business model canvas for FSL

4.1 Value proposition and business model validation

The objective of the FSL platform is to increase competitiveness, efficiency and utilisation, by creating a collaborative ecosystem. The platform will search for the most efficient delivery, in terms of operating costs, fleet utilisation and emissions for the fulfilment of contracts submitted by members of FSL using assets of FSL members.

With a wide geographic coverage of members' assets, this also increases the likelihood of capacity being available and in turn increases the chances of fulfilling more contracts in any given period of time. However, the FSL algorithm will only reallocate jobs where price and emissions are lower than those possible if performed by the contract holder. In the event that lower price and emissions cannot be found the contract holder would then fulfill the contracted job.

To ensure the fair reallocation of jobs, as well as to guarantee these are delivered in the most efficient way, the jobs' fulfillment costs must be estimated as accurately as possible. These will be the members' operating costs to deliver such jobs, which the platform algorithm will estimate based on fleet-specific parameters and daily requirements of the delivery of jobs inputted by each of the collaborating members, as described in Section 3.1.

To validate the proposed business model, a financial and economic analysis has been undertaken based on the algorithm results using historic transport operational data. To provide an understanding of the impact of collaboration, the analysis provides a comparison between the 'business as usual' scenario of non-collaborating operators and the form of collaboration determined by the FSLP. It should be noted that the 'business as usual' scenario presents the situation where the individual fleet operations have been optimised (e.g. using an optimisation tool or service), which on average provides a 12.5% (wbcsd, 2016) reduction in costs and distance travelled than when fleets operate without the use of any optimisation tool or service.

Furthermore, it should be noted that the algorithm was in development phase when results were analysed and supported by only a day's worth of data representing 27 fleet operators. This data

was provided by the project partner Routemonkey (Trackm8), which were then extrapolated to cover a whole year. Due to these limitations, the results should be treated with caution. Even so, these illustrate the type of benefits that might, with further analysis and greater amounts of more real-world data, be achievable from FSL.

4.2   Customer segments and relationships

Fleet operators are Freight Share Lab's principal direct customers. Given their competitive nature, and to ensure compliance with competition law, it is necessary for a neutral trustee to facilitate the collaboration between them.

A neutral trustee is an organisation responsible for ensuring the collaborative network will be constructed in such a way that a fruitful long-term, sustainable relationship is established and maintained. Partners in a collaboration agreement (possibly competitors) could provide commercially sensitive data to the trustee organisation, which can maintain the required confidentiality and security of such data but use, according to contractual terms and conditions agreed with the data owners, for fulfilling the purposes of FSL. In this way, compliance with EU competition and data protection laws is provided.

Arguably, the platform is best managed as a cooperative by the FSL members: all terms and conditions, rules of the FSL business, quality and standards shall be agreed in a decentralised manner by the members and profits distributed among them. FSL members would upload contracts they have individually agreed with their customers into the platform, securely and confidentially, for the system to analyse.

In this model, shippers, do not have direct access to the platform, but will benefit from it through sustainable competition among the logistics service providers and lower emissions associated with the fulfilment of their jobs. The relationships, interactions and negotiations between shippers and carriers remain the same. Logistics companies will still need to negotiate and agree contracts with their customers. Where the logistics operators or their customers participate in specific load-sharing, auction, return-load freight exchange platforms, FSL will look to provide a value add for them also: FSL will offer a collaborative relationship by which those contracts awarded through these other platforms can be uploaded into FSL system to see if a better alternative can be found and arranged (i.e. at a lower price and reduced emissions); in effect the FSL platform acts as a 'platform of platforms'.

4.3   Key activities

The definition of the key activities in a collaborative process has been proposed in (Vargas et al., 2013, 2018) based on previous ideas (Alarcón, 2005; Audy et al., 2012; Kilger et al., 2008; Petersen et al., 2005; Ribas and Companys, 2007; Stadtler, 2009; Verheij and Augenbroe, 2006). These activities are: 1) Initiation, 2) Plan Exchange, 3) Negotiation/Revenue Sharing, 4) Execution, 5) Performance Measurement & Revenue Sharing Execution, and 6) Feedback/ Improvement. In this proposal, the benefits of using a combination of decentralised and centralised coordination in each key activity was highlighted. Findings of different European projects proposed centralised coordination being led by a neutral trustee (NexTrust, 2017). A high-level workflow showing the interrelation of these key activities and the key actors involved is presented in Figure 5.
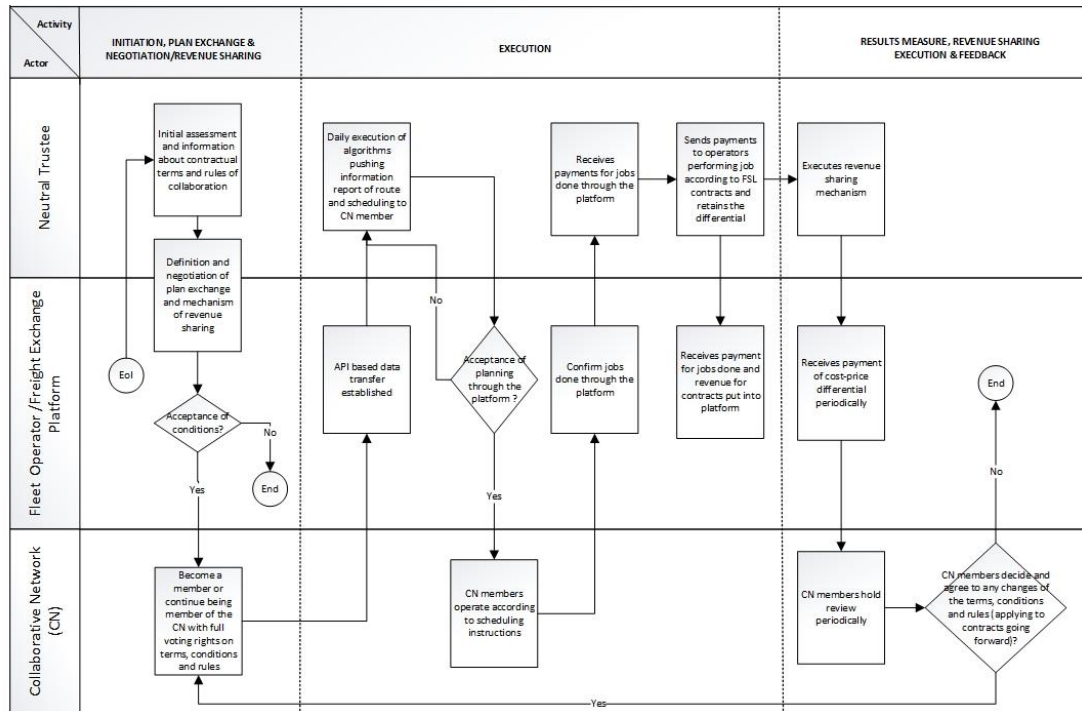
Figure 22: FSL collaborative process workflow

The *Initiation* requires all the partners, including the neutral trustee to agree to collaborate. *Plan exchange and Negotiation/Revenue Sharing* involves defining responsibilities, contracts, joint processes, and mechanisms of revenue sharing among all the partners in the collaboration. The *Execution* is led by the neutral trustee that informs each partner about the optimised routes and schedules and, each partner follows instructions to complete the assigned task. The *Results Measure and Revenue Sharing Execution* are performed by the neutral trustee, as per the agreed contract, where the specific mechanism of revenue sharing was selected. Finally, the *Feedback* is completed among all the partners and it is refined, if necessary, to improve the process and determine if the partners will continue collaborating. A detail of these activities can be consulted in Vargas et al., (2018), including the management of unexpected events (Vargas et al., 2016).

4.4 Cost structure

The business model provides that all savings achieved through the platform will be shared between members, once the costs of running the platform are covered. Costs will be distributed across collaborating members in proportion to the savings they generate, and hence those members that do not participate in any transaction will neither incur any costs during that period nor share any additional revenue generated.

For the proposed business model to be sustainable, the savings achieved through collaboration must be able to cover the platform costs. The platform operating costs were therefore estimated as part of the analysis: a) *Fixed costs* – such as labour and office space; these are fixed for specific ranges based on the number of jobs run through the platform, i.e. more jobs would require more labour and hence more office space; and b) *Variable costs* – the costs associated with running each job through the FSL platform. The cost per job decreases as more jobs are run through the platform and are capped at £0.05 per job.

Although these are highly speculative at this stage, cost assumptions are based on information provided by project partners from their different experiences. Investment costs for setting up

the platform have not been considered at this stage, and, would have to be dealt with at the outset when no revenue from FSL would have been generated to cover them. However, this is under the assumption that the main applications and algorithms would be developed once the Innovate UK project is finalised.

4.5   Revenue streams

The FSL algorithm will reallocate jobs where the total fulfilment price is lower than the cost of fulfilling their own contracted jobs with their own logistics assets. This will guarantee all collaborating members, both the original contract holder and those deployed by the platform, maintain their agreed profit margins, as well as providing them with additional revenue.

Firstly, the platform provides members access to a wider pool of potential jobs - contracted to other members. Contracts are uploaded to the FSLP for other members to fulfil – if they can fulfill them at a lower price and lower emissions than the contract holders' operating costs. Secondly, with profit margins protected for all (10% gross profit margin has been assumed for operating costs for the purpose of the analysis to date), additional revenue is awarded to the original contract holder and those fulfilling the contract from a share of the cost-price differential. The shipper still pays the original contract price but benefits from reduced emissions and sustainable competition between the operators. Therefore, with the proposed business model, collaborating members will have the following net revenue streams: a) *Profit from the contracted job*; b) *Profit from completing other members' jobs; and c) Sharing of cost-price differential* once any platform costs are deducted.

Furthermore, the business model assumes that the price-cost differential is held by FSL, in the so-called FSL 'bank' (this name is used just for hypothetical reasons), for an agreed period, generating interest. Therefore, the amount to be shared depends on the period for which funds are held in the FSL bank, the interest rate, and the costs of running the platform. For the purpose of the analysis, it has been assumed that the savings are held by the FSL bank for one year, with an annual interest rate of 0.5%.

Figure 23 shows the aggregated daily FSL business model proposed revenue for all fleets involved, covering those for which the FSLP identifies an optimised solution through collaboration and those for which it does not: it also covers each of the three full-sharing collaboration scenarios. The 'No Special Arrangements' scenario generates the least cost-price differential, as it is the scenario which provides the least cost-efficiencies and lowest additional capacity compared to members operating individually outside of FSL.
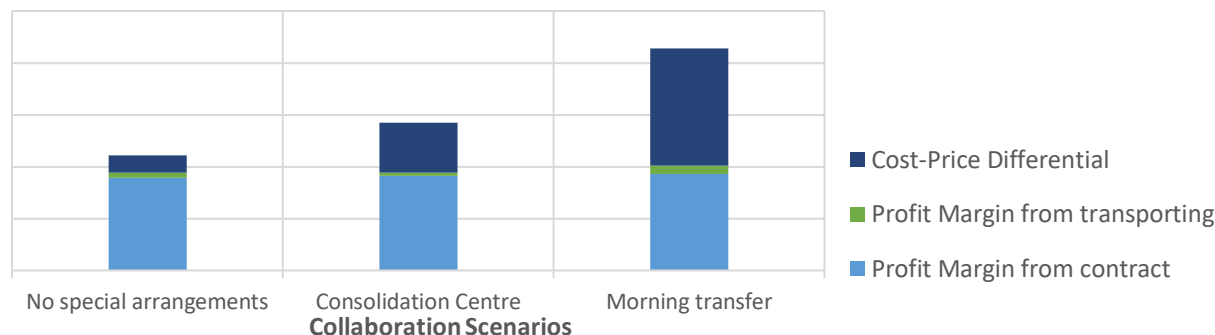

Figure 23- Total daily Revenue Streams with FSL

As can be observed, significant efficiencies can be realised through collaboration, and the increased profits these can generate through the proposed business model are significant.

5 Results

5.1 Efficiencies

Analysis was undertaken on the initial algorithm results, where approximately 6,700 daily jobs were run through the FSLP. Significant commercial benefits can be seen from the FSL collaborative business model, combined with important increases to profits, as shown in Section 4.5. Results have indicated that a high proportion of jobs can be delivered at a lower cost than that of fleets operating independently. Furthermore, the collaboration made further capacity available, with a corresponding increase in the number of jobs that could be delivered in a single day. Table 6 presents results for the three collaboration arrangements scenarios.

Table 6: Efficiencies achieved through the different collaboration arrangements

	No Special arrangements	Consolidation Centre	Morning transfer
% of jobs with savings	48%	63%	72%
% increase of jobs completed per day	3%	1%	5%
Daily mileage reduction	-3,012 km	3,523 km	2,143 km

5.2 Wider socio-economic and environmental benefits

In addition to the private costs borne by logistics operators, their activity imposes externalities on society and the environment. Optimised truck journeys through collaboration will lead to a reduced total distance travelled and reduced number of trucks on the road with consequent reduction in environmental and social costs.

The initial algorithm results, shown in Table 7 and Table 8 have been utilised to quantify the annual change in these external costs and hence, if reduced, offer an understanding of the level of benefits that can be expected through collaboration. The changes were calculated based on reduced mileage, following the UK Department for Transport's WebTAG unit A5-4 and TRL publications for the reduction in emissions.

Table 7: Annual mileage and emissions savings through the different collaboration scenarios

Collaboration Arrangement	Emissions Saved			
	CO2 (tonnes)	PM (Kgs)	NOx (Kgs)	HC (Kgs)
No Special Arrangements	-629	-122	-12	-996
Consolidation Centre	735	143	14	1165
Morning Transfer	447	87	9	708

Table 8: Annual wider economic costs savings through the different collaboration scenarios

Collaboration Arrangement	Other Wider Economic Cost Savings		
	Congestion (k£)	Infrastructure (k£)	Accidents (k£)
No Special Arrangements	-211	-107	-3
Consolidation Centre	247	125	4
Morning Transfer	150	76	2

It can be seen that, although 'morning transfer' leads to the highest cost efficiencies and therefore profits, as shown in Figure 23, mileage reduction is behind that achieved from the consolidation centre scenario, which leads to wider economic cost savings. Meanwhile, 'No Special Arrangements' leads to additional mileage due to the journeys vehicles have to do to get to other fleets' depots, thus generating additional emissions as well as other wider economic costs. At this stage in our analysis, it would seem most appropriate to stipulate that participation in the FSL must be limited to those that are willing to enter into operations that incorporate 'morning transfer' or other special arrangements (e.g. consolidation).

6 Conclusions

The development of the Physical Internet requires multilateral collaboration among logistics asset-owners and operators; horizontal collaboration, potentially between competitors, appears to be a barrier to this. The Freight Share Lab project is seeking to demonstrate that, by engineering a gain share model into a collaboration platform architecture that enables horizontal collaboration, it is possible to break the barriers to collaboration. The hypothesis we are evoking is to say that more practitioners in the freight and logistics sector will be encouraged to participate in such collaboration platforms when it is shown that they provide a clear business case, and a win-win situation exists for all participants; and secondly, that such a collaborative platform can exist without compromising any competition between participants.

This paper has drawn on the experiences of other works in this area and literature which has revealed the barriers and efforts to overcome those barriers to collaboration in the freight and logistics sector. Various elements of business models have been explored. The FSLP architecture and the theory behind it has been explained and adapted from existing optimisation platform architecture. A gain-share business model has been established that will provide the sought-after collaboration in a competitive environment. It will satisfy the commercial imperatives of improving participants' revenue-earning potential and their customers need for access to service providers at competitive rates, with all the sustainability benefits for a clear pathway to zero emissions logistics.

The results from the simulation of hypothetical operations in the FSLP, as shown in this paper, have provided promising results and guidance as to the final commercial proposition for FSL. It is hoped that these results will encourage enough logistics operators to enable us to move from a hypothetical to real-world operational test environment.

The project will seek logistics operators to individually test the FSL algorithm and business model, using their own historic data. If the results prove as positive as early results suggest, the operators will be encouraged to enter a trial, imputing live operational and contract data and performing collaborative operations. Due to the available time for this project to complete, such a live trial will represent a post-project activity on the way to full commercial development of FSL. The central hypothesis can then be tested to see if a demonstration of the potential revenue gains, service coverage, competitive rates and sustainability benefits in the real-world will stimulate even greater collaboration, a key precept of the Physical Internet.

Acknowledgements

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Freight Share Lab: New 'Gain-Sharing' Collaborative Logistics Platform Offering a Stronger Business Case and Accelerating Developments Towards the Physical Internet

Freight Share Lab: New 'Gain-Sharing' Collaborative Logistics Platform and Business Model

Alix Vargas[1], Andrew Traill[1], Carmen Fuster[1] and David Corne[2]

Introduction

Collaboration in the freight industry has the potential to generate significant socio-economic and environmental benefits, and is key to the development of the Physical Internet. Additionally, freight service providers would commercially benefit from the reduced operating costs achieved through the reduction in the number of trucks, mileage, and increased trailer utilisation, from which, assuming perfect competition, customers would ultimately benefit as well.

FSL demonstrates that there is a win-win for logistics service providers and their customers, where "coopetition" can be delivered through a collaboration platform yielding significant commercial benefits for all participants.

The platform developed by the FSL project partners' Heriot-Watt University and Trakm8 PLC, deploys a multi-fleet logistics optimisation and decision support algorithm, managing those freight logistics assets which, when combined, deliver a more efficient and environmentally friendly solution.

The business model developed by Connected Places Catapult ensures that both the original contract holder and those deployed by the FSL platform retain their profit margins and share the differential between the price of the latter and operating costs of the former. Initial results obtained from model simulations with realistic data indicate significant financial benefits for FSL platform members using this 'gain sharing' model, based on game theory.

Freight collaboration business model

The proposed business model aims to address the barriers for collaboration in the freight industry demonstrating there is a win-win for logistics service providers as well as their customers, yielding significant commercial benefits for all participants.

The objective of the FSL platform is to increase competitiveness, efficiency and utilisation, by creating a collaborative ecosystem. The platform will dispose of the collaborating members' jobs and assets inputted into the system and reallocate jobs accordingly to guarantee their most efficient delivery, in terms of operating costs, fleet utilisation and emissions.

Collaboration process activities

The key activities in the collaboration process include:
1. **Initiation** – requires all the partners, including the neutral trustee to agree to collaborate
2. **Plan Exchange** – involves defining responsibilities, contracts and joint processes among all the partners in the collaboration
3. **Negotiation** – agreement from members on plan exchange revenue sharing mechanism
4. **Execution** – led by neutral trustee that informs each partner on instructions & tasks to follow
5. **Performance measurement & revenue sharing execution** – performed by the neutral trustee
6. **Feedback / Improvement** – completed among all the partners to refine and improve process

Collaboration arrangements

Horizontal collaboration between FSL members is the essence of the proposed solution and business model. Each FSL member indicates its preferences (and any associated parameters) for each of the following four collaboration arrangements: a) Full Sharing without special arrangements; b) Full Sharing with morning transfer arrangements; c) Full Sharing with a consolidation site; and d) Partial Sharing with no arrangements. The algorithm will select the most optimised arrangement in line with the users' inputs.

The Full Sharing scenarios are for FSL members who are willing to both undertake other members' jobs as well as handing over some of their own jobs for others to handle, ie: there is full sharing of assets and contracted jobs.

The Partial Sharing scenario assumes some of the FSL members will only leave vehicles at the platform's disposal.

Results

Analysis was undertaken on the initial algorithm results, where approximately 6,700 daily jobs from 27 fleet operators were run through the multi-fleet logistics optimisation.

Fleet operators can find significant efficiencies as well as commercial benefits through the proposed collaborative business model.

In addition to the private costs borne by fleet operators, the use of road vehicles incurs on externalities borne by the wider society. Optimised truck journeys through collaboration will lead to reduced total mileage for the fulfilment of jobs and reduced number of trucks on the road. Road decongestion benefits will arise from not only the reduction of truck mileage, but also from improved traffic levels and hence more efficient driving by other road users.

Total Daily Revenue Streams

	No special arrangements	Consolidation centre	Morning transfer
% of jobs with savings	48%	63%	72%
% increase of jobs completed per day	3%	1%	5%
Daily mileage reduction	-3,012 km	3,523 km	2,143 km

Collaboration arrangement	Emissions saves (anually)				Other wider impact cost savings (annually)		
	CO2 (tonnes)	PM (kgs)	Nox (kgs)	HC (kgs)	Congestion (k£)	Infra-structure (k£)	Accidents (k£)
No special arrangements	-626	-122	-12	-996	-211	-107	-3
Consolidation centre	735	143	14	1165	247	125	4
Morning transfer	447	87	9	708	150	76	2

Conclusion and future work

The proposed business model aims to address the barriers for collaboration in the freight industry demonstrating there is a win-win for logistics service providers as well as their customers, yielding significant commercial benefits for all participants.

The objective of the FSL platform is to increase competitiveness, efficiency and utilisation, by creating a collaborative ecosystem. The platform will dispose of the collaborating members' jobs and assets inputted into the system and reallocate jobs accordingly to guarantee their most efficient delivery, in terms of operating costs, fleet utilisation and emissions.

Future empirical research will be necessary to understand trust issues between different providers and start building up confidence among stakeholders, when demonstration of the potential revenue gains, service coverage, competitive rates and sustainability benefits is available to them. This will stimulate collaboration, which is a key precept of the Physical Internet.

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Sustainable distribution & e-commerce logistics - 10ᵗʰ July 2019 13:30 – 15:00

On-demand transshipment of freight deliveries in urban areas: A physical Internet-enabled multi-mode mobility service

Physical Internet Retail and Distribution Networks - 10th July 2019 13:30 – 15:00

Digital Twin-enabled Synchronization Mechanism for Pick-and-Sort Ecommerce Order Fulfillment

Physical Internet enabled bulky goods delivery and pick up solution in city logistics

Hao Luo[1], Siyu Tian[1], Xuan Yang[1], Xiang T.R. Kong[1,2]

1. Department of Transportation Economics and Logistics Management,
Colleague of Economics Shenzhen University, Shenzhen, PR China

2. Department of Industrial and Manufacturing Systems Engineering, The
University of Hong Kong, Hong Kong

Corresponding author: Hao Luo   address email：luohao403@qq.com

Abstract: *Physical Internet (PI) and city logistics are two novel concepts aiming to render more economically, environmentally and socially efficient and sustainable the way, in which physical objects are transported, handled, stored, realized, supplied and used throughout the world. City logistics is a key enabler to city economy, which has been introduced to cope with the challenges of sustainable cohabitation and development of freight transportation in the city. In the city logistics operation, bulky goods delivery is big challenge since it is difficult to delivery in the "last 100 meters" in the city. This research has been motivated by real-life problem faced by our collaborating company, which is specialized in customized furniture. Following characteristics of customized furniture industry create lots of problems to delivery service providers. In order to mitigate these impacts, the model of Physical Internet enabled Bulky Goods City Logistics (PI-BGCL) is proposed. The meta-heuristic algorithm (Genetic algorithm) has been applied to compare the traditional delivery model and proposed PI-BGCL model. To validate the effect and efficiency of proposed PI-BGCL model, the case study in this paper consists of two parts. The first one is a real-life case study of a customized furniture industry in China, which demonstrates the efficiency and feasibility of the proposed mode. The second one is to validate the effectiveness of proposed algorithms. Experimental design and a set of sensitivity analyses was performed to examine the effects of several key parameters on system performance.*

Keywords: *Physical Internet; bulky goods; city logistics; simultaneous delivery and pick up; backhaul; genetic algorithm*

1   Introduction

City logistics is a key enabler to city economy, which has been introduced to cope with the challenges of sustainable cohabitation and development of freight transportation in the city (Benjelloun and Crainic, 2008) (Crainic and Montreuil, 2016). Since the bulky goods urban delivery mainly distributes the goods of small batches and multiple varities, which are difficultl to delivery in the "last 100 meters" of the supply chain (Morganti and Morganti, 2014). The bulky goods include furniture, household electrical appliances, musical instruments and indoor decorating materials. But they have been experiencing a challenge of intensified market competition, the customization and the innovation of " Industry 4.0".

Nowadays, Montreuil (2011) introduced a solution to Global Logistics Sustainability Grand Challenge, Physical Internet (PI), whose aim is to enable an efficient and sustainable logistics web at the logistics hubs as well as at the end consumer. To achieve this goal, Sallez et al. (2016) have shown that considerable gains can be achieved through the application of the PI by designing PI-containers. The containers have associated activity, which allows the PI-container

to have an active role for its mission and in the PI management and operation. Following the application of the digital internet, PI enabled goods will be sent over an open and global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. And city Logistics providing the final and last segments of the Physical Internet logistics and transportation networks (Crainic and Montreuil, 2016).

Customized furniture is one of the typical bulky goods. Some characteristics of customized furniture delivery bring critical challenges to the logistics service providers. In our previous research (Luo Tian & Kong 2018), the characteristics and painpoint of customized furniture city logistics have been studied and a PI enabled conceptual solution has been proposed. In this research a mathematical model has been proposed to deal with the Physical Internet enabled Bulky Goods City Logistics (PI-BGCL)

The main objectives of this paper are (1) to improve the field of bulky goods city logistics with PI concept. (2) to descript the bulky goods city logistics problem with the PI-BGCL model. (3) to design Genetic Algorithm to solve the problem. (4) to discuss the potential application bulky goods city logistics technology in the viewpoint of academic and industry.

2 Characteristics Bulky Goods Urban Delivery

Customized furniture is one of the typical bulky goods. Some characteristics of customized furniture delivery bring critical challenges to the logistics service providers. Compared to the traditional furniture industry, customized furniture industry has following characteristics:

(1) Order size is quite different. Due to the different sizes of the customers' rooms, the quantity of products contained in each order is different.

(2) Most of the product form is board–shape furniture components and a large number of metal accessories.

(3) All components are make-to-order produced, and the customized furniture produces only one single piece.

(4) Leading time is very long, usually more than 3 months, so it is impossible to predict the delivery time required by the customer when ordering. It is impossible to predict the delivery time required by customers when ordering.

(5) The delivery time window is narrow. There are only two days from the customer's delivery request to the actual delivery request.

(6) Deliver to a designated location. The customer requires all products to be moved to the designated location in the room.

Most of the customized furniture manufactures use the 3rd party logistics service to conduct the door to door delivery service. However, the characteristics of customized furniture industry are critical challenges for the delivery service providers.

This research has been motivated by real-life problem faced by our collaborating company, which is specialized in customized furniture. Following these characteristics of customized furniture industry is a big challenge to the delivery service providers of customized furniture. (1) One shipment order contains multiple product pieces. The loading/unloading and movement into customers house is very time consuming. (2) The long on-site material handling time leads to long waiting time of vehicles. The transportation efficiency is very low. (3) The dimensions of furniture parts are irregular. The space utilization of vehicles is very low. (4) The repeatedly

loading and unloading operation may lead to product damage. Since the furniture is customized, one piece of furniture part damage may lead to a delay of the whole assembly project. Meanwhile, the remanufacturing cost is very high.

3   PI enabled Bulky Goods Delivery solution

In order to solve the problem of bulky goods in urban delivery, especially the pain points identified in customized furniture industry, a PI enabled Bulky Goods Delivery Solution has been propsoed (Luo Tian & Kong 2018). The key componets in the proposed soultion are PI enabled container and PI enabled Vehicle.

The design of PI enabled container are shown in Figur 1. Based on the PI concept, each container can be packing one customer order. Due to the characteristics of customized furniture industry, the product is a board-shape component. The length and width of the component have limited standards. The high dimensions depend on the quantity of component in each order. Therefore, the proposed PI container will have standardized width, length and different height. A data analysis for history order information will be conducted to determine 3-5 container types.
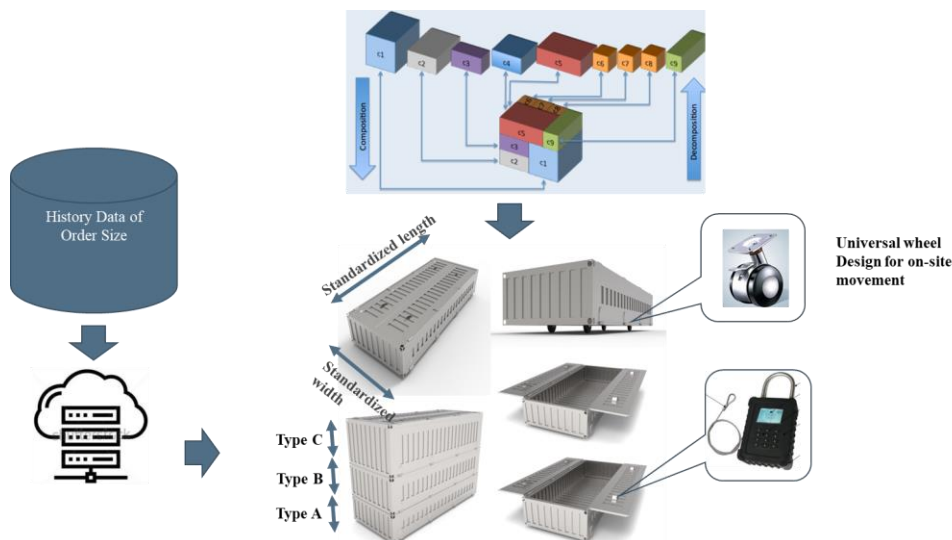
Figure 1: the design of PI enabled container

The design of PI enabled Vehicle are shown in Figur 2.In order to improve the transportation efficiency, the PI containers on one truck will be dropped on each customers' destination, one by one in a round trip. Meanwhile, the empty container will be collected. Therefore, the aim of the PI enabled vehicle design is to achieve autonomic container loading/unloading on the customer destination without forklift. Figure 4 shows the concept design of proposed PI vehicle. The vehicle-mounted loading/unloading mechanism consists of a shiftable frame, two supporting wheels with electric motor and hydromantic system.
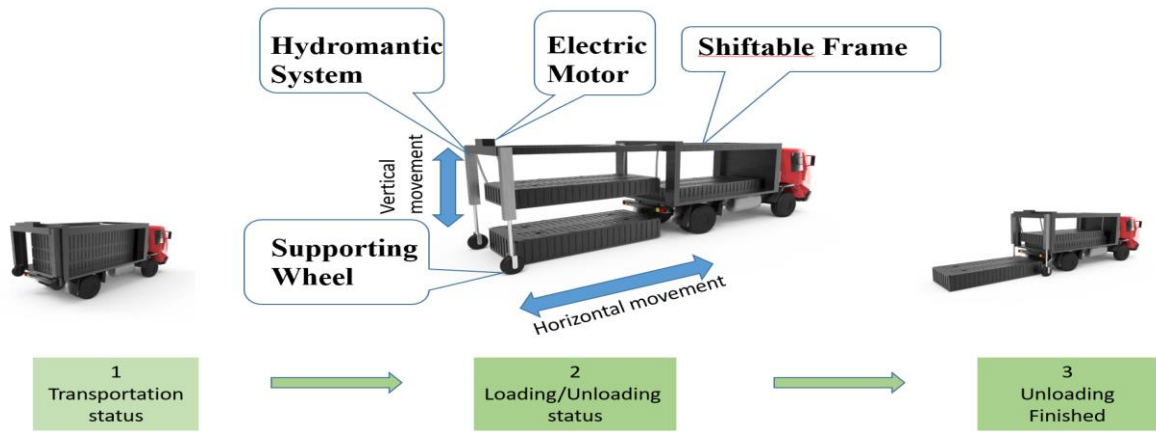
Figure 2: the design of PI enabled Vehicle

4 Problem Description

Figure 3 shows the comparison of traditional delivery process and improved delivery process based on PI-BGDS. In this case, there are 6 delivery points (Customer A, B, C, D, E and F) and 1 product warehouse in the factory. In the delivery process, one truck can load at most 3 customer orders and delivery the orders one by one in a milk run route. The transportation time between each delivery point is about 1 hours. When the PI-Vehicle arrive each delivery point, the unloading time and material moving time from PI-Vehicle to customer's house is about 3 hours.

4.1 Traditional Delivery Mode

The upper part of Figure 3 shows the traditional delivery process. In first round delivery, the normal truck loads the products of customer A, B and C at the factory. One material handing operator goes together with the truck driver. When they arrive the delivery point A, the material handing operator conducts the unloading and movement work. The truck has to wait at the delivery point, until all the material handling operation is finished. They go to the next delivery point together. When all of the delivery tasks are finished, the empty truck goes back to factory directly. Then, they can start the next delivery trip of customer D, E and F.

In traditional mode, the vehicle is used to deliver merchandise to customer. The set of delivery vertices is given by *D={1,…,m}*. All the trip starts and ends at same distribution center. The set of distribution center is given by vertex 0. The truck must come back to distribution center in the allowed time$[t_0, t_e]$. All the location of distribution center and customer is known. All the trucks are identical. The rated capacity of each vehicle is Q. The bulky goods have three types {*v,2v,3v*}. The demand of each vertices *di* is known. In the distribution process, the loading amount of the trucks should not pass the rated capacity. Each delivery vertex can be visited only once. One truck only completes one route. The influence of the traffic is ignored. The ultimate goal is total profit per minute during the period which equals the total revenue minus total costs then divided by the time. the total revenue equals piece rate multiplied by delivery demand, and the total costs can be divided into two parts. First part is petrol fee, equals to the petrol fee per hour multiply distribution time. The second part is fixed vehicle fee, which means the cost of invoking a vehicle per day.

4.2   Physical Internet enabled Delivery Mode

The lower part of Figure 3 shows the Physical Internet enabled delivery mode. The customer orders are reloaded in the PI container. In the first round, the truck loads the PI container A, B and C at the factory. When truck arrive each delivery point, the PI container can be landed by the vehicle-mounted unloading system and go the next delivery point immediately. When all PI-container A, B and C are delivered. The PI-Vehicle driver continues to delivery point F, E and D to pick up 3 empty PI containers back.

In this mode, the vehicle is used to pick up the empty containers and delivery containers to customer. All the trip starts and ends at same distribution center. The set of distribution center is given by vertex 0. The truck must come back to distribution center in the allowed time $[t_0, t_e]$. All the location of distribution center and customer is known. All the trucks are identical. The rated capacity of each vehicle is Q. The demand of each vertices di is known. And according to their volume, the demand of each vertex will be packaged into containers. The bulky goods have three types $\{v,2v,3v\}$. The size of the PI-container is devided into three basic type: the volumn of S container is v, the volumn of M container is $2v$ and the volumn of L is $3v$. In the pick-up and distribution process, the loading amount of the trucks should not pass the rated capacity. Each pick-up vertex and delivery vertex can be visited only once by a same vehicle. After merchandise is delivered, the driver will pick up empty containers at vertex i. If the number of empty containers is larger than the number of containers that distribute the goods, there will be special vehicles (PI-vehicle) to recover the remaining empty containers after all the goods are delivered. The set of pick-up vertices which are brought back by delivery vehicle is given by $P=\{1,...,n\}$, the set of remaining pick-up vertices is given by $P'=\{n+1,n+2...,2n\}$. the set of delivery vertices is given by $D=\{1,...,m\}$, All vertices completed by delivery vehicle is given by $V=P\cup D$. One truck only completes one route. The influence of the traffic is ignored. The ultimate goal is total profit per minute during the period which equals the total revenue minus total costs then divided by the time. the total revenue equals piece rate multiplied by delivery demand, and the total costs can be divided into petrol fee and fixed vehicle fee. The components of both costs are made up of two parts, the one part is used to delivery and pick up empty container simultaneously, and the other cost is used to pick up remaining empty container.
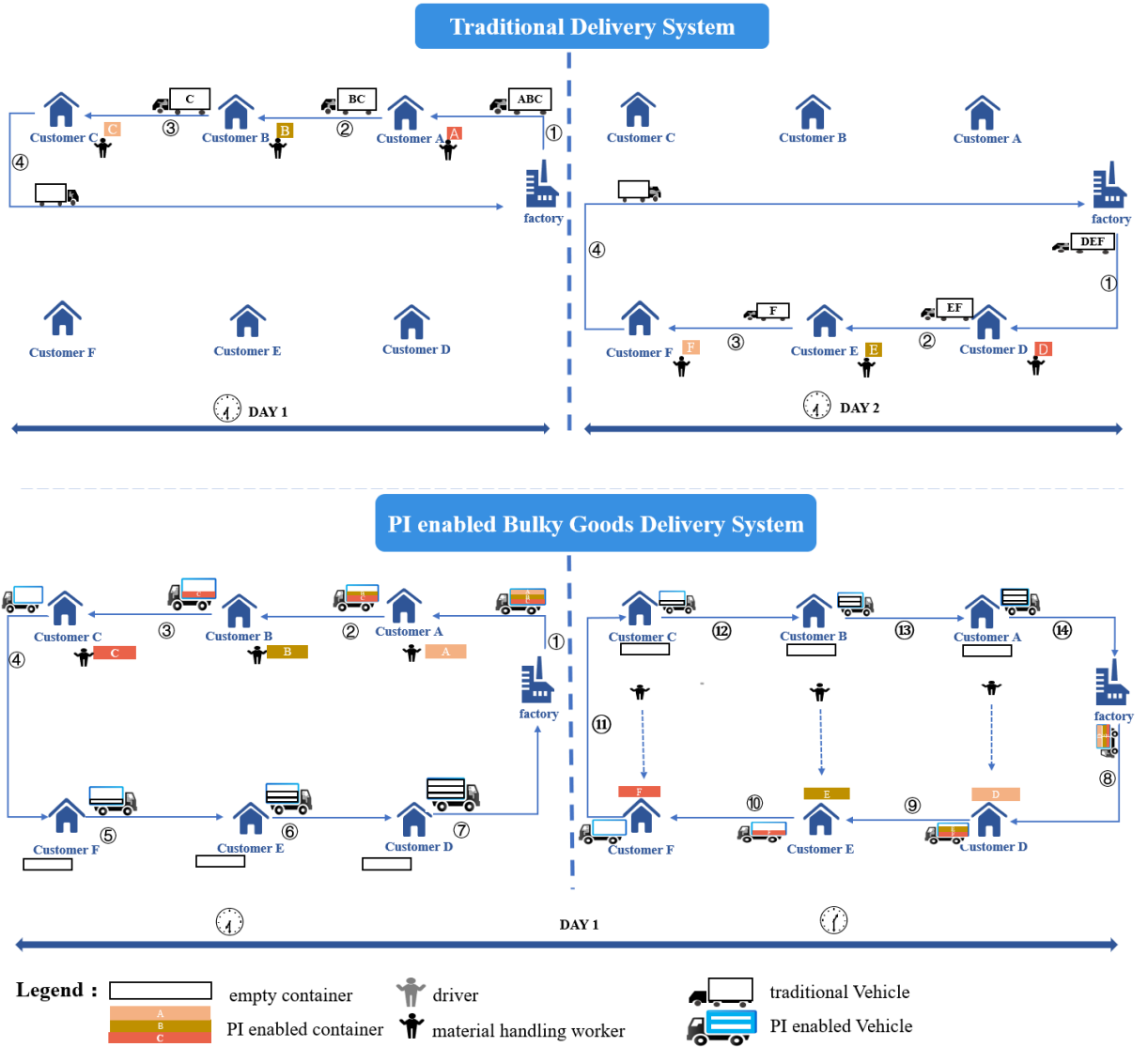
Figure 3: Illustrating comparison urban distribution between Traditional Delivery Mode and PI enabled Delivery Mode

5 Mathematical Model

5.1 Notations definition:

5.1.1 Notations

N	total number of customers which need to pick up empty container by delivery $P=\{1,...,n\}$
N'	total number of customers which has remaining containers need to pick up separately $P'=\{n+1,...,2n\}$
M	total number of customers which need to delivery merchandise $D=\{1,...,m\}$
V	all the vertices by delivery vehicle $V=P\cup D$
K	the set of vehicle's number, $K=\{1,2,...k\}$
T	number of days of the period

Q	the rated capacity of truck
i,j,f,g	customer vertices, distribution center $i=0$
$[t_0, t_e]$	the time window of distribution center
t_{ij}	the travel time from vertex i to j
L_i^k	driver's waiting time of vehicle k arrives at vertex i, which equals to the service time of material handling worker at vertex i.
$d_i^{k,r}$	the delivery demand of vehicle k at vertex i, $r \in \{S, M, L\}$
$q_i^{n,r}$	the pick up remaining empty container demand of vehicle n at vertex i
$P_{i,j}^{r,k}$	load of vehicle k of resource r after leaving vertex i before visiting vertex j
β	the petrol fee of each vehicle per minute
δ	the fixed cost of each vehicle k
α	logistics service fee for each item

5.1.2 Variables

$$x_{ij}^{kl} = \begin{cases} 1, \text{if } arc(i,j) \text{ is traversed by vehicle } k \text{ on day } l \\ 0, \text{else} \end{cases}$$

$$y_i^{kl} = \begin{cases} 1, \text{if vehicle } k \text{ pick up or delivery container at vertex } i \text{ on day } l \\ 0, \text{else} \end{cases}$$

To formulate two models, the following assumptions are made.

1) The customer's location is known. And the demand of each vertices di is known at each vertex i which obeys a random probability distribution.

2) The types of the distribution quantity and empty container quantity of each vertex are composed of different size types.

3) Each merchandise are three types, and the size of the PI-container is devided into three basic types $\{S,M,L\}$.

4) All the trip starts and ends at same distribution center.

5) All vehicles are of the same type. A vehicle can carry up to three different sizes of customer orders.

6) The waiting time of each vehicle is equal to the working time of the material handling worker.

7) The quantity of pick up empty container today is equal to the previous day's delivery demand (in the PI-BGCL model).

8) All empty containers on that day must be picked up.

5.2 Traditional Delivery model

Objective:

$$\max \left\{ \frac{\alpha \sum_{l=1}^{T} \sum_{i,j \in D} \sum_{k \in K} x_{ij}^{kl} d_i^l - (\beta \sum_{l=1}^{T} \sum_{k \in K} \sum_{i \in D} \sum_{j \in D} x_{ij}^{kl} t_{ij} + \delta \sum_{l=1}^{T} \sum_{k \in K} \sum_{i \in D} x_{0i}^{kl})}{\sum_{l=1}^{T} (\sum_{k \in K} \sum_{i \in D} \sum_{j \in D} x_{ij}^{kl} t_{ij} + \sum_{k \in K} \sum_{i \in D} L_i^{kl})} \right\} \qquad (1)$$

Subject to:

$$\sum_{k \in K} \sum_{i \in D} y_i^{kl} = 1 \qquad\qquad \forall l \in T \qquad (2)$$

$$\sum_{k \in K} \sum_{j \in D} x_{ij}^{kl} = 1 \qquad\qquad \forall i \in D; \forall l \in T \qquad (3)$$

$$\sum_{i,j \in D} x_{ij}^{kl} - \sum_{i,j \in D} x_{ji}^{kl} = 0 \qquad\qquad \forall k \in K; \forall l \in T \qquad (4)$$

$$\sum_{j \in D} x_{0j}^{kl} = \sum_{j \in D} x_{j0}^{kl} \leq 1 \qquad\qquad \forall k \in K; \forall l \in T \qquad (5)$$

$$\sum_{i \in D} \sum_{j \in D} x_{ij}^{kl} d_i^l \leq Q \qquad\qquad \forall k \in K; \forall l \in T \qquad (6)$$

$$t_0 \leq \sum_{i \in D} \sum_{j \in D} x_{ij}^{kl} t_{ij} + \sum_{i \in D} L_i^{kl} \leq t_e \qquad \forall k \in K; \forall l \in T \qquad (7)$$

the objective function (1) maximizes total profit per minute during the period which equals the total revenue minus total costs then divided by the time, and the total costs including petrol fee, fixed cost of vehicle. Constraints (2) guarantee that a distribution task can only be assigned to one vehicle in day l. Constraints (3) guarantee that each vertex is served only once. Constraints (4) guarantee each vertex is visited by the same vehicle. Equalities (5) ensure that each vehicle starts at and returns to the depot at the end of its route. Constraints (6) guarantee during the distribution process the weight does not exceed capacity Q. Constraints (7) guarantee the total working times of each vehicle including travel time and service time of the vehicle are within the time window of distribution center.

5.3 Physical Internet enabled Delivery model

Objective:

$$\max \left\{ \frac{\alpha \sum_{l=1}^T \sum_{i,j \in D} \sum_{m \in K} x_{ij}^{ml} d_i^{ml} - (\beta \sum_{l=1}^T \sum_{m \in K} \sum_{i \in V \cup P'} \sum_{j \in V \cup P'} x_{ij}^{ml} t_{ij} + \delta \sum_{l=1}^T \sum_{m \in K} \sum_{i \in V \cup P'} x_{0i}^{ml})}{\sum_{l=1}^T \sum_{m \in K} \sum_{i \in V \cup P'} \sum_{j \in V \cup P'} x_{ij}^{ml} t_{ij}} \right\} \qquad (8)$$

Subject to:

$$\sum_{k \in K} \sum_{i \in V \cup P'} y_i^{kl} = 1 \qquad\qquad \forall l \in T \qquad (9)$$

$$\begin{aligned}
&\sum_{m \in K} \sum_{i \in V \cup P'} \sum_{j \in V \cup P'} x_{ij}^{ml} t_{ij} = \\
&\sum_{k \in K} \sum_{i \in V} \sum_{j \in V} x_{ij}^{kl} t_{ij} + \qquad\qquad \forall n,k \in K; \forall l \in T \qquad (10) \\
&\sum_{n \in K} \sum_{f \in P'} \sum_{g \in P'} x_{fg}^{nl} t_{fg}
\end{aligned}$$

$$\sum_{k \in K} \sum_{j \in V} x_{ij}^{kl} = 1$$
$$\qquad\qquad\qquad \forall i,j \in V; \forall f \in P'; \forall l \qquad (11)$$
$$\sum_{n \in K} \sum_{g \in V} x_{fg}^{kl} = 1 \qquad\qquad\qquad\qquad \in T$$

$$\sum_{i,j \in V} x_{ij}^{kl} - \sum_{i,j \in V} x_{ji}^{kl} = 0$$
$$\qquad\qquad\qquad\qquad \forall n,k \in K; \forall l \in T \qquad (12)$$
$$\sum_{f,g \in P'} x_{fg}^{nl} - \sum_{f,g \in P'} x_{gf}^{nl} = 0$$

$$\sum_{j \in V} x_{0j}^{kl} = \sum_{j \in V} x_{j0}^{kl} \leq 1$$
$$\qquad\qquad\qquad\qquad \forall n,k \in K; \forall l \in T \qquad (13)$$
$$\sum_{g \in P'} x_{0g}^{nl} = \sum_{g \in P'} x_{g0}^{nl} \leq 1$$

$$t_0 \leq \sum_{i \in V} \sum_{j \in V} x_{ij}^{kl} t_{ij} \leq t_e$$
$$\qquad\qquad \forall i,j \in V, \ \forall f,g \in$$
$$\qquad\qquad P', \forall n,k \in K; \forall l \in T \qquad (14)$$
$$t_0 \leq \sum_{g \in P'} \sum_{g \in P'} x_{fg}^{nl} t_{fg} \leq t_e$$

$$\begin{aligned}
&\sum_{k \in K} \sum_{i,j \in P} x_{ij}^k d_{il-1} = \\
&\sum_{n \in K} \sum_{f,g \in P'} x_{fg}^n q_{fl} + \qquad\qquad \forall n,k \in K; \forall l \in T \qquad (15) \\
&\sum_{k \in K} \sum_{r \in R} \sum_{i,j \in P} x_{ij}^k (P_{i,j,l}^{r,k} - P_{0,i,l}^{r,k} + d_{il})
\end{aligned}$$

$$\sum_{i \in V} d_i^{kl} \leq Q \qquad\qquad \forall i \in V, \forall k \in K; \forall l \in T \qquad (16)$$

$$q_f^{nl} \leq Q \qquad\qquad \forall f \in P', \forall n \in K; \forall l \in T \qquad (17)$$

$$\sum_{r \in R} x_{ij}^{kl} P_{i,j}^{r,k} - \sum_{r \in R} x_{0i}^{kl} P_{0,i}^{r,k} + d_i^{kl} \leq Q \qquad \forall i,j \in V, \forall k \in K; \forall l \in T \qquad (18)$$

$$\sum_{r \in R} x_{ij}^{kl} P_{i,j}^{r,k} \leq Q \qquad\qquad \forall i,j \in V, \forall k \in K; \forall l \in T \qquad (19)$$

$$\sum_{r \in R} x_{fg}^{kl} P_{f,g}^{r,n} \leq Q \qquad\qquad \forall f,g \in P', \forall n \in K; \forall l \in T \qquad (20)$$

the objective function (8) maximizes total profit per minute during the period which equals the total revenue minus total costs then divided by the time, the total revenue equals piece rate multiplied by delivery demand, and the total costs including petrol fee, fixed cost of vehicle. Constraints (9) guarantee that a distribution task can only be assigned to one vehicle in day l. Constraints (10) guarantee that the total traval time consists of two parts, the one part is the time of delivery and pick up empty container simultaneously, and the other is the time of pick up remaining empty container. In addition, the bottom m means the total number of vehicles in use which equals the number of vehicle k plus n. Constraints (11) guarantee that each vertex is served only once. Constraints (12) guarantee each vertex is visited by the same vehicle. Equalities (13) ensure that each vehicle starts at and returns to the depot at the end of its route. Constraints (14) guarantee the total working times of each vehicle including travel time and pick up remaining empty time of the vehicle are within the time window of distribution center. Equalities (15) express that total amount of delivery demand in the previous day equals to the total quantity of pick up empty containers today. Constraints (16) (17) (18) guarantee during the pick up empty container and distribution process the weight does not exceed capacity. the total amount of demand on delivery process on day l is less than the maximum capacity of the vehicle by constraints (16). the amount of pick up empty container by delivery process at vertex i is less than the maximum capacity of the vehicle by constraints (17). The amount of pick up remaining empty container at vertex i is less than the maximum capacity of the vehicle by constraints (18). Consistency with respect to resource and load variables is guaranteed by constraints (19) (20).

6 Solution Methodology

Based on each of the above introduced formulations, A meta-heutistic Genetic algorithm (GA) is proposed to compare feasible routing solution of traditional delivery model and the PI-BGCL model, which is in order to mitigate the impacts of bulky goods in urban delivery. And algorithm rule is used to deal with constraint and objective.

Geneticl Algorithm, as a population-based optimization method (Salhi and Petch, 2007). it starts from a randomly generated initial population of solutions. The main steps that solve the problem are decribed as follows:

Step 1: Initialise five algorithm parameters, namely the number of populations (Pop), the number of generations (Gen), crossover probability (P_c), mutation probability (P_m), the number of iterations in GA ($Iter$). the initial solution is randomly generated.

Step 2: The fitness of a chromosome is evaluates as follows: $f(x) = \frac{1}{F(x)}$. Where $F(x)$ is the total cost of a chromosome.

Step 3: Randomly generate an initial population of *Pop* chromosomes (solutions) and find out the best chromosome Chm_{best}.

Step 4: Let *Gencur* = 1. Repeat Steps 5-8 until *Gencur > Gen*.

Step 5: Perform the roulette wheel method to select parent chromosomes for reproduction.

Step 6: Apply the modified two-point crossover operator with crossover probability P_c to produce new offspring.

Step 7: Apply the single-point mutation operator with mutation probability P_m to perturb the structure of selected offspring.

Step 8: Let *Gencur = Gencur* + 1 and updating *Chmbest* if necessary.

Step 9: Return the best solution Chmbest with the minimum total cost T_{cost} and total time T_{time} (including transportaion time and service time) of delivery container (and pick up empty container in the PI-BGCL).

Step 10: Return T_{cost} within a period (day *l=1: T*) to calculate the objective function $Profit_{min}$. First, calculate the total revenue $T_{revenue}$ on day *l*. The total profit T_{profit} on day *l equals* $T_{revenue}$ minus T_{cost}. Finally, the objective function $Profit_{min}$ is calculated by T_{profit} over T_{time}.

7 Numerical study

In this section a numerical study has been conducted to evaluate and compare performance between the traditional delivery mode and PI-BGCL. In order to make the simulation results more realistic, the parameter as follows are changed to compare two model results.
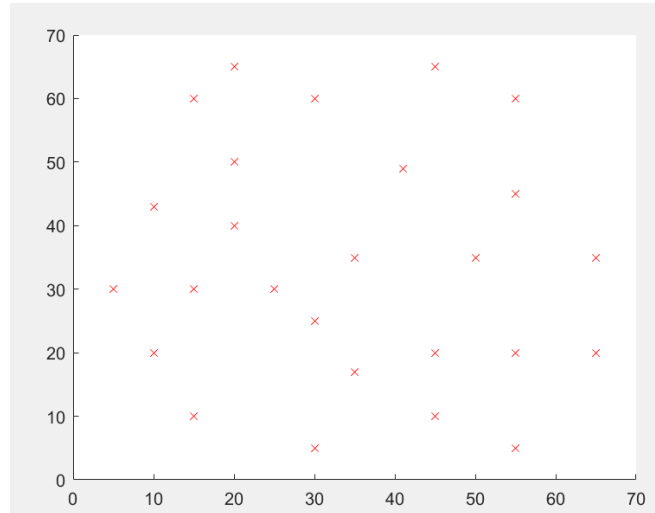
Figure 4: Location of customers in test problem

The locations of the 30 customers in *figure 4* are randomly generated using a procedure prensented by solomn (1987). This procedure generates locations grouped around a certain number of centers. The demands of the period *T* are eatablished randomly and follows a normal distribution [150, 20]. The several variable paremeters of the model are showed (Table 1) as follow:

Table 1 : The Variable Parameters of the model

Variable parameters	Value
Logistics service fee for each item *(α)*	*20 RMB / item*
The fixed cost of each vehicle *(σ)*	*300 RMB / vehicle*
The petrol fee of each vehicle per minute *(ß)*	*0.05 RMB / minute*
The time window of distribution center *[t_0, t_e]*	*[0,840] (minute)*
The rated capacity of truck *(Q)*	*100 items*
The number of populations *(Pop)*	*100*
The number of generations *(Gen)*	*300*
Crossover probability *(Pc)*	*0.8*
Mutation probability *(Pm)*	*0.3*

Table 2 : Compare the experimental results of traditional delivery model and PI-BGCL

		day 1	day 2	day 3	day 4	day 5	day 6	day 7	average
	Quantity of delivery	147	156	157	155	134	163	177	155.6
	Time (minute)	655.2	719.4	717.8	715.1	563.6	767.9	769.6	701.22
	Number of vehicle	2	2	2	2	2	2	2	2.00
Tradition-al model	Total revenue	2940	3120	3140	3100	2680	3260	3540	3111.43
	Total cost	620.5	619.6	620.5	619.2	623.3	619.3	618.8	620.17
	Total profit	2319.5	2500.4	2519.5	2480.8	2056.7	2640.7	2921.3	2491.3
	Total profit per minute	3.54	3.48	3.51	3.47	3.65	3.44	3.80	3.55
	Time (minute)	146.3	193.5	170.4	212.9	137.1	190.2	196.4	178.1
PI-BGCL model	Number of vehicle	2	2	2	2	2	2	2	2.00
	Total revenue	2940	3120	3140	3100	2680	3260	3540	3111.4

Total cost	620.5	621.5	619.5	621.4	620.2	619.4	620.2	620.4
Total profit	2319.5	2498.5	2520.5	2478.6	2059.8	2640.7	2919.8	2491.1
Total profit per minute	15.86	12.91	14.80	11.64	15.02	13.89	14.87	14.14
%	4.48	3.72	4.22	3.36	4.12	4.03	3.92	3.98

Table 2 presents the experimental results of traditional delivery model and PI-BGCL model were generated. The line *Quantity of delivery* of the period *T*, are eatablished randomly and follows a normal distribution [150, 20]. the quantity of pick up empty container next day is equal to quantity of delivery today. By the way, the delivery demand of each customer on day *l are* randomly generated, which consist of three size (*v, 2v, 3v*). The line *Time in the traditional delivery model* including transportation time and the vehicle waiting time (equals handling worker's service time), the line *Time in PI-BGCL* is made up of the transportation between pick up empty container by delivery and ipck up remaining empty container. The line *Total cost of two models* shows the minimum total const concluding transportation cost and vehicle fixed cost. The line *Total profit per minute* shows maximum total profit per time of two models.

According to the experimental results of meta-heuristic in Table 2, it can be seen that the PI-BGCL result is better than traditional delivery model. The numbers of vehicle which are identical in two models, play an important role both in the traditional delivery model and PI-BGCL model. It is obvious that the several empty container picked up by vehicle in PI-BGCL are not uesd extra vehicle. That means the vehicle fixed cost of PI-BGCL is not more than traditonal model. The time of the PI_BGCL are far less than traditional delivery model, which means PI-BGCL solution greatly save time and improve efficiency. The last line shows the total profit per minute of PI-BGCL model is far more than traditional delivery model.

8   Conclusion

In this study, the bulky goods delivery problem in a customized furniture industry has been addressed. The problems are characterized in 4 aspects, heavy workload of material handling, unclear responsibility for operators, high risk of product damage and complicated human and vehicle resource planning. In order to solve the problem a PI enabled Bulky Goods City Logistics (PI-BGCL) solution is proposed. The propose system is driven by some key PI concepts, including design of standard container size and PI-Vehicle. In order to clarify the application of the proposed system further, a case study of bulky goods urban delivery in customized furniture industry is conducted. To maximize the total profit per minute of PI-BGCL, the meta-heuristic is developed to compare the experimental results between traditional delivery system and PI-BGCL.

This study has made several contributions: (1) to improve the field of bulky goods city logistics with PI concept. (2) to descript the bulky goods city logistics problem with the PI-BGCL model. A Physical Internet enabled Bulky Goods City Logistics (PI-BGCL) solution is proposed, especially which apply to customized furniture industry is identified. (3) the case study in the customized furniture company indicates that the proposed solution can improve the efficiency of transportation by designing the PI-Container and PI-Vehicle. (4) to discuss the potential application bulky goods city logistics technology in the viewpoint of academic and industry.

Several research problems need further investigation. Future studies will focus on making the proposed solutions more practical. How to generalize the results of such a small sample to a broader context will become the next step for our research and development. And the sensity analyse will be studied on next work.

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Hyper-connected Megacity Logistics: Multi-Tier Territory Clustering and Multi-plane Meshed Hub Network Design

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

Abstract: In this paper, we present a dynamic approach for designing a hyper-connected network based on the multi-plane logistic structure proposed by Montreuil, Shannon, et al. (2018). Possible hub candidates are selected based on geographical locations and historic demand volume, and a heuristic solution for large-scale hub location problem (up to 5000 nodes) is presented to reflect different consolidation preference. Moreover, we construct an end-to-end framework for network configuration assessment and update through routing and simulation, allowing optimization of the whole system over comprehensive performance indicators.

1   Introduction

The parcel logistics industry, as old as this industry is, remains soaring as a result of internet commerce and worldwide trade. On the other hand, the trend also imposes challenges to the industry, pressing for a more reliable system that can offer multiple service levels and tackle with high demand stochasticity.

Currently, most of parcel logistics systems are constructed according to the standard hub-and-spoke network topology, where the term hub denotes a central sorting center (see O'Kelly and Miller, 1994). Although convenient in terms of daily operations and management, this structure suffers from low efficiency in the sense that it is vulnerable to demand peaks and valleys, also unable to prioritize products with the different time limit.

The hyper-connectivity concepts underpinning the Physical Internet (see Montreuil, 2011) aims at transforming the current hub-and-spoke network topology to a logistic web topology based on multi-plane meshed networks interconnecting hubs adapted to each plane (Montreuil, Meller, and Ballot,2013). Compared with the standard hub-and-spoke network, decentralization of the hyper-connected network enables more flexible and adaptable operations based on parcel pickup/delivery locations and service offering.

This paper is positioned as an extension of the works of Montreuil, Shannon, et al. (2018), and it targets a network design that enables max service capability at efficient overall cost via a combination of geographical data analysis and mathematical optimization techniques. The remainder of the paper is organized as follows. In Section 2, we introduce the general idea of the network structure proposed by Montreuil, Shannon, et al. (2018). In Section 3, we present our methods on hub candidate identification. The territory clustering is also included as a

necessary step for the identification. In Section 4, we propose an iterative solution for hub location problem with given locations of hub candidates and historic flow data. We also provide an integrated approach for updating the network configurations through routing system.

2   Multi-plane Parcel Logistic Web

The four-tier pixelization of the area covered by the logistics service includes zones, local cells, urban areas, and the overall region (Montreuil, Shannon, et al., 2018). A zone is the most basic tier that the overall region consists of, and it varies in size depending on the managements' estimation of demand. For example, it can be a residential apartment complex or several floors in a sky-rise building in the business area. It can be viewed as a cluster of customers based on geographical location and demand. These zones can be clustered into local cells, and local cell themselves be clustered into areas (see Figure 1).
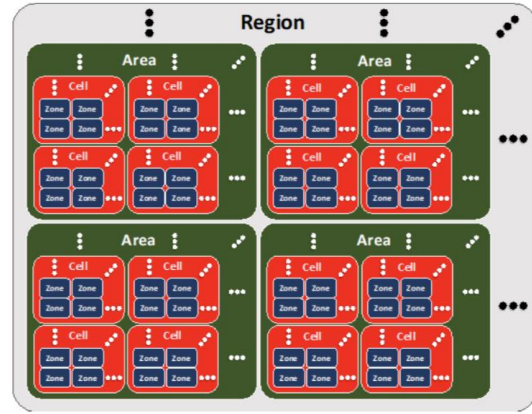
Figure 1: Four-Tier Pixelization of Service Area from Montreuil, Shannon, et al., 2018

To enable more efficient parcel logistic service corresponding to the four-tier pixelization, Montreuil, Shannon, et al. (2018) present a multi-plane logistic structure, each representing a sub logistics element with different capabilities. As shown in Figure 2, there are four tiers of planes: Plane 0 is the inter-P/D network linking pickup and delivery points; Plane 1 is the inter-zone network linked by access hubs; Plane 2 is the inter-cell network linked by local hubs; and Plane 3 is the inter-area network linked by gateway hubs. Furthermore, from the hub connection perspective, the hyper-connected network characterizes multiple connections between zone and its adjacent access hubs, multiple connections between access hub and its adjacent local hubs, and also multiple connections between local hub and its adjacent gateway hub (see Figure 3, and also Figure 4 for current dominating hub-and-spoke network connections as a contrast).
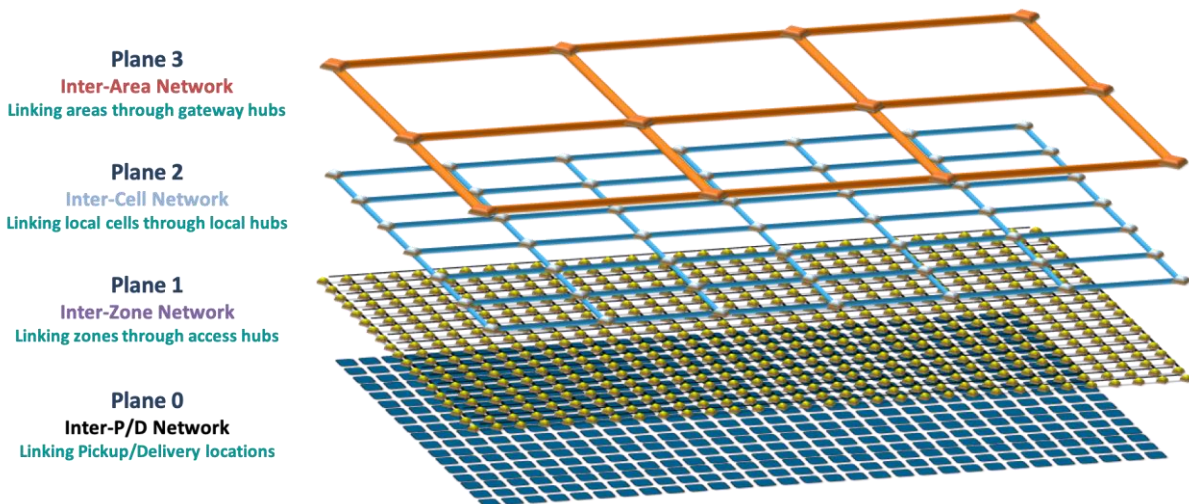
Figure 2: Urban Parcel Logistic Web from Montreuil, Shannon, et al. (2018)

well. For example, we could possibly add more planes to allow parcels to flow from city to city or even country to country. In this paper, we shall focus on intra-city network design, i.e.,

the four-plane network within the urban area, and assume that the zones and gateway hubs are already fixed. Still, the ideas and approaches presented in this paper could be easily applied to a broader scale.
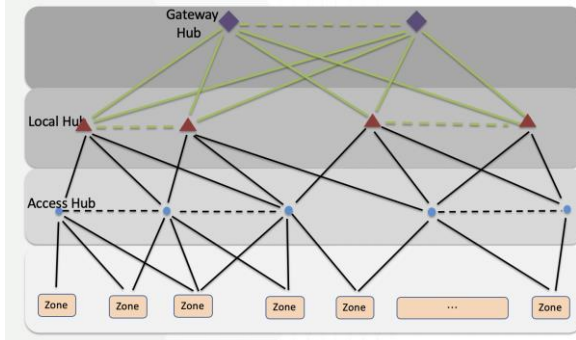
Figure 3: Conceptual Representation of Hyper-connected Network
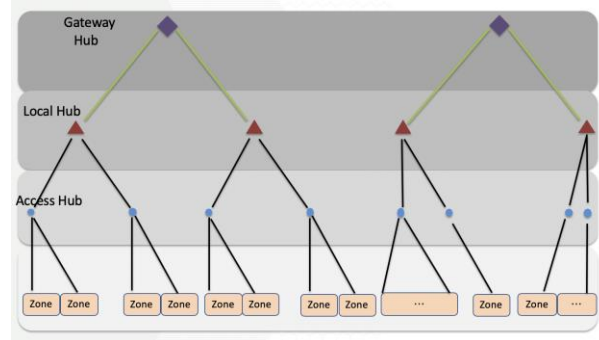
Figure 4: Conceptual Representation of Hub-and- connected Network Spoke Network

3 Identify Hub Candidates

3.1 Access Hub Candidates

When mapping the pixelized illustration of the service area to the hyper-connected logistics web (see Figure 6), ideal access hub candidates (yellow dots) lie on the intersection of the zones (rectangles). However, the zones in real-world practices, as the smallest logistic unit, are most likely to be in the shape of polygons. In this case, we could consider the vertices shared by multiple polygons as a rough estimate of the intersection point of the zones, and treat them as the ideal access hub candidates. Moreover, any two vertices with a distance below some certain threshold can be merged into one "access hub candidate" if a relatively small number of candidates is preferable (see Figure 7).
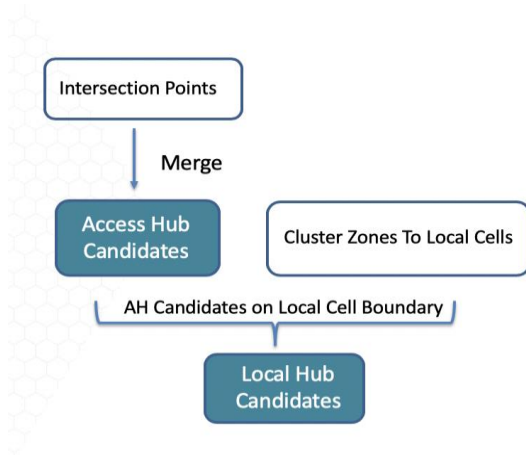
Figure 5: Outline for Hub Candidates Identification
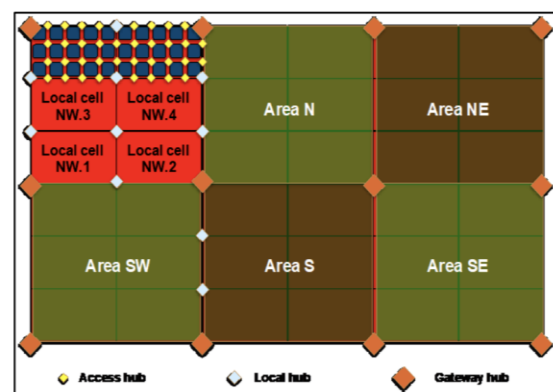
Figure 6: Logistic Web Mapped on Pixelized Urban Area from Montreuil, Shannon, et al. (2018)
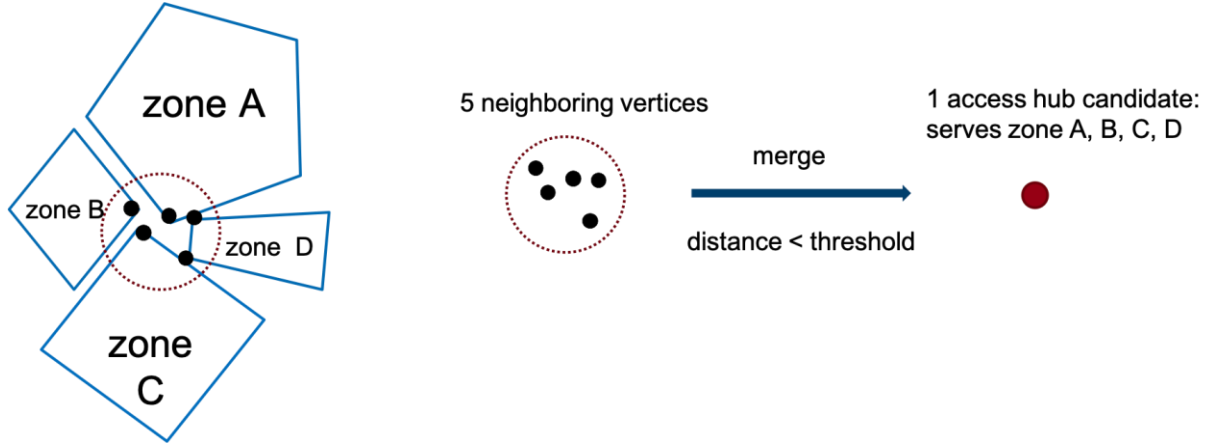
Figure 7: Intersection Point as Access Hub Candidates

3.2 Clustering Analysis: Define Local Cell

As an intuitive illustration, a local cell is depicted as a rectangular cluster covering 3×5 zones in Figure 6. If we assuming the size and demand are equal in each zone, then it is natural to design local cells to be with an equal number of zones, as illustrated in Figure 6. However, in most cases, the zones are different both in size and in demand. As a consequence, the potential benefits we seek from the hyper-connected network such as robustness against stochasticity will be dismissed under an imbalanced design. Therefore, we aim to achieve a clustering that (roughly) balances the demand between different groups.

Obviously, one can apply a classical clustering method, K-means for example, directly to group the zones; and as a result, a cluster would contain neighboring zones that are close to each other. However, as we have previously stated, demand balance should also be taken into consideration while doing clustering. Therefore, inspired by the greedy approach in monotone sub-modular function maximization proposed by Mirzasoleiman et al. (2015), we present a greedy algorithm for identifying clusters as follows.

$$max_{S \subset J} f(S) = \sum_{i \in I} \text{gain}(i) - \beta \sum_{j \in J: y_j = 1} \left(\sum_{i \in I: x_{ij} = 1} D_i - \frac{\sum_{i \in I} D_i}{|S|} \right)^2 \tag{1a}$$

$s.\ t.$

$$\sum_{j \in J} x_{ij} = 1 \quad \forall i \in I \tag{1b}$$

$$\sum_{j \in J} y_j = |S| \tag{1c}$$

$$x_{ij} \le y_j, \tag{1d}$$

$$x_{ij},\ y_j \in \{0,\ 1\} \quad \forall i \in I, j \in J \tag{1e}$$

where I is the set of zones, J is the set of potential local cell centers, and S is the selected set of local cell center. The demand for each zone i is denoted by D_i, and β denotes the hyper-parameter used to penalize the imbalance in demand. The binary variable x_{ij} indicates whether zone i is assigned to local cell center j or not, and the binary variable y_j indicates if the hub candidate j is selected as a local cell center. To determine the gain function in Eq. (1a), let d_{ij} be the distance from the center of zone i to the hub candidate j, and the gain from current assignment is defined as:

$$\text{gain}(i) = \max\left(0, \text{distance cutoff} - \min_{j \in J} d_{ij}\right) \tag{2}$$

where the distance cutoff is the maximum allowed distance between zone i and its assigned hub candidate. Moreover, the imbalance in demand between each local cell is in the form of mean square error, which is the last term in Eq. (1a):

$$\sum_{j\in J:y_j=1} \left(\sum_{i\in I:\, x_{ij}=1} D_i - \frac{\sum_{i\in I} D_i}{|S|} \right)^2 \tag{3}$$

Next, we conduct the clustering analysis via greedy selection algorithm. Let S initially be an empty set. In each iteration, we aim at finding one hub candidate j from J which maximizes the function value of f in Eq. (1a), and then add this point j into S. In summary,

$$j = \text{argmax}_{j\in J}\big(f(S\cup\{j\}) - f(S)\big) = \text{argmax}_{j\in J} f(S\cup\{j\}) \tag{4}$$

$$S:= S\cup\{j\} \tag{5}$$

Similar to ideal access hub locations, ideal local hubs should also lie on the intersection of local cells, with each local hub serving multiple local cells. Therefore, after selecting local cells through the above clustering analysis, we set the local hub candidates to be those access hub candidates that lie on the intersection of local cells.

Furthermore, the techniques for clustering zones as local cells can also be extended to a multi-tier setup. For example, we can apply the above process to cluster local cells as urban areas, and even cluster urban areas as some broader regions, if needed.

4   Network Design Optimization

In this section, we present a flow optimization model for selecting hubs out of all the hub candidates identified through the process we discussed in the previous section. To solve the flow optimization problem, we construct a graph with all hub candidates as nodes and their connections as edges.
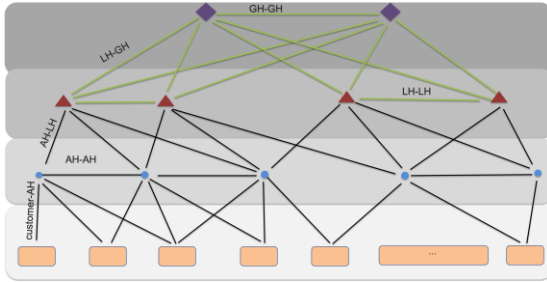
Figure 8: Global v.s. Local Edges   *Figure 9: Vertical v.s. Flat Edges*
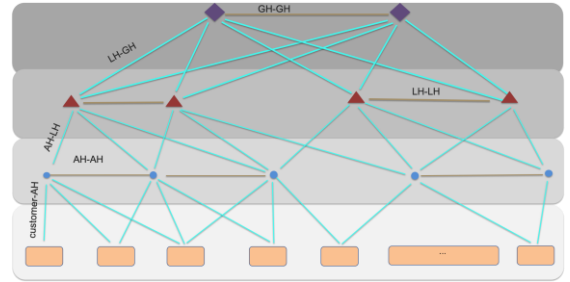
Based on different criteria, we will classify the edges in the network into two groups, as illustrated in Figure 8 and Figure 9.

- Based on vehicle usage, we divide the edge into global edges and local edges. Local edges contain the edges between a customer and an access hub, between access hubs, and between an access hub and a local hub; while global edges are between local hubs, between a local hub and a gateway hub, or between gateway hubs. Hence, in practice, small vehicles like motorcycles and small vans are commonly used for local edges, and the transportation on the global edges usually rely on large vans and trucks (see Figure 8).
- Based on the utilization of hyper-connection, we have vertical edges and flat edges. A vertical edge (blue in Figure 9) connects nodes in different tiers, and a flat edge (brown

in Figure 9) connects two hubs within the same tier. So preferably, when pickup and delivery locations are close enough, in the hyper-connected network, flat edges should be fully utilized, since directly sending all packages to hubs at higher layer not only slows down delivery, but also increases the capacity pressure for hubs at a higher layer as well.

Additionally, for the flow optimization model, there are two types of flow for the network within urban area level.

- Intra-city flow: this is the flow from a customer within an urban area to another customer within the same urban area. The flow between source and destination can be viewed as a *(customer, customer)* pair.
- Inter-city flow: the package either originates outside the urban area and the destination of which is within the area, or it originates from a customer within the area, and the destination is outside the urban area. From the perspective of network design, these flows can be viewed as either *(gateway hub, customer)* or *(customer, gateway hub)* pair.

With the above classifications, next we discuss the problem of determining hub locations.

4.1 Hub Location Problem

Hub location problem is a classic topic in the area of integer programming, and has been studied extensively (one can see Farahani et al., 2013 for a good review of the topic). In our study, given the number of nodes and connection variables in the network, it is infeasible to seek an exact solution, and thus most heuristic approaches employ the Benders decomposition technique. However, most large network solved via Benders decomposition contains no more than 3000 nodes (for example, one can see the paper of Fischetti, Ljubić, and Sinnl, 2016). On the other hand, adding the effect of the economy of scale to the hub location model, as first proposed by O'Kelly and Bryan (1998), results in a prohibitively large number of variables, which also poses an obstacle in finding solutions. Therefore, we propose a novel, iterative approach to the hub location problem by solving a weighted shortest path problem for each zone. The weight on the edges are adjusted in each iteration to reflect current preferential attachment, and they decrease exponentially every time the edges are utilized because of the effect of the economy of scale. We will describe our approach for the remainder of this section.

Let N be the set of customer nodes, and K the set of hub candidate nodes, including access hub candidates, local hub candidates, and fixed gateway hubs. The union of N and K is the set of all the nodes in the network, denoted as V, and note that N and K do not overlap. In each iteration, given a customer (i.e., an origin zone), we solve the following shortest path problem:

$$\min \ \sum_{i,j \in N} \sum_{v \in V, u \in \delta(v)} f_{ij}(u,v) \cdot \mathrm{dist}(u,v) \cdot \mathrm{cost}(u,v) \tag{6a}$$

$$s.t.$$

$$\sum_{k \in \delta(i)} f_{ij}(u,k) = \sum_{k \in \delta(i)} f_{ij}(k,u), \quad \forall \, i,j \in N, k \in K, u \in V \tag{6b}$$

$$\sum_{k \in \delta(i)} f_{ij}(i,k) = Demand(i,j), \quad \forall \, i,j \in N \tag{6c}$$

$$\sum_{k \in \delta(i)} f_{ij}(k,j) = Demand(i,j), \quad \forall \, i,j \in N \tag{6d}$$

Our objective function in Eq. (6a), similar to most hub location problems, at the network planning phase, is to identify hubs from the set of hub candidates over the hub-customer links and the inter-hub links. The constraint (6b) follows the conservation of flow at each hub, and constraints (6c) and (6d) require that all outflow from zone i must route through its hub first and all inflow to zone j must pass its hub first.

The major innovative part in our approach is that in each iteration, the weight of previously used edges are updated to reflect consolidation preference. More specifically, in each iteration the weight is calculated as follows.

$$\text{weight}(u,\ v) = \min(\gamma \cdot \text{weight}(u,\ v),\ \beta) + \delta \tag{7}$$

where β is the consolidation threshold, δ is the hop penalty, and γ is the cost decay factor, which promotes reusing edges/consolidation of flow. Note that smaller β promotes the reuse of previous edges, and larger δ promotes fewer hops on each path.

Moreover, we could also set different proportional weight on different types of edges. Here we define two consolidation ratios according to vehicles usage and flat edges utilization:

- global consolidation ratio $= \dfrac{\text{cost on global edges}}{\text{cost on local edges}}$
- vertical consolidation ratio $= \dfrac{\text{cost on vertical edges}}{\text{cost on flat edges}}$

Note that in definitions above, the exact number of weight on edges are not required. Instead, it is crucial to use the ratio itself as an agent to reflect the desired usage of different types of edges. Higher global consolidation ratio promotes more global flow, while higher vertical consolidation ratio promotes more usage on vertical edges.

4.2 Network Validation and Update

The objective of the hub location model described above is to minimize the flow cost, which is not a very representative performance indicator in practice. To address this problem, we introduce a simulation system to assess the quality of the network produced by the optimization model. On the other hand, the hyper-parameters in the iterative model needs some fine-tuning, so we need to build a Bayesian optimization model to learn the function mapping between different weight parameters and more comprehensive performance indicators provided by the simulation system. The Bayesian method is commonly used when no exact functional form for integrated parameter evaluation is available. It proceeds by maintaining a probabilistic belief and designing an acquisition function to select the next point to query, learning a surrogate model over time, as described by Shahriari et al. (2016). Overall, this end-to-end optimization scheme allows for large-scale, in-the-loop models to directly optimize the whole system for target performance indicators.

In the following experiment, we aim at tuning two parameters: the global consolidation ratio and the vertical consolidation ratio. For simplicity purpose, the consolidation threshold β and the hop penalty δ will be fixed at 0.1 and 5 for all tested networks. Our target is to minimize the total time (in minutes) of delivery lateness in the system. In each iteration, the Bayesian optimization model selects different combinations of the global consolidation ratio and the vertical consolidation ratio. As illustrated in Figure 10, the Bayesian method shows a clear decreasing trend in terms of the total lateness time.
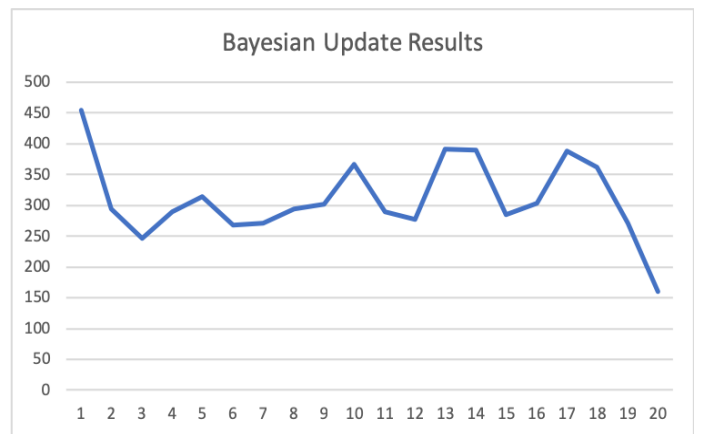
Figure 10: The Resulting Total Lateness per Iteration

5   Summary

To improve efficiency and flexibility in logistic service, this paper develops the methodology of designing a hyper-connected network. We first conduct a clustering analysis to identify possible hub candidates by using a greedy algorithm to balance the demand in different zones, and then propose a novel, iterative approach to solving large-scale hub location problems. Furthermore, to fine-tune the hyper-parameters in our iterative model, we build a Bayesian optimization model and demonstrate the effect of Bayesian techniques in terms of updating network configurations according to specific performance indicators.

6   Acknowledgements

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Hyperconnected Logistics for Farm-to-Table Platforms

Optimizing High-Value Product Availability in Hyperconnected Retail Networks

Jinyong Yim, Shahab Derhami, and Benoit Montreuil

H. Milton Stewart School of Industrial & Systems Engineering, Georgia Institute of Technology, Atlanta, USA

Corresponding author: jinyongyim@gatech.edu

Abstract: This paper addresses the optimization of dealer replenishment decisions in planning their assortment for high-value substitutable products so as to maximize product availability of dealers in hyperconnected retail networks. To achieve this, we formalize the problem as a discrete optimization model, and provide exploratory empirical results based on a Monte Carlo simulation for a case study of a leading manufacturer of recreational vehicles. Then, we show that the proposed model achieved sales increase by 30% in a given network while keeping the same inventory level as the current business model. Emphasizing availability rather than inventory, we present the contribution of this paper in assortment planning, inventory transshipment, customers' substitution behavior, and product availability. We conclude the paper with a call for further research under Physical Internet-enabled settings such as aiming universal hyperconnectivity in transportation, distribution, production and supply.

1   Introduction

Incomplete product availability deems inevitable in retail networks for reasons such as uncertain demand, forecast errors, budget, and space-related limitations. It results in the customers purchasing a substitute product when a satisfactory alternative is available in stock (Fitzsimons, 2000; Gruen et al., 2002; Campo et al., 2004) or lost sales if none of the available products meets the customer's expectations (Derhami and Montreuil, 2019). In either case, customer satisfaction suffers through in the latter case, it suffers more drastically, and both the product manufacturer (brand) and the retailer incur direct and indirect costs associated with lost sales. This along with the customer-centric marketing strategies that attempt to provide the customers with their desired products within a satisfactory time in any location, force retail networks to employ smart innovative approaches to prevent or at least reduce incomplete product availability.

Retail centers offering high-value substitutable products such as cars, recreational vehicles, high-end electronics, luxury clothing and jewelry usually employ inventory transshipments or on-demand priority orders from distribution centers, depots or manufacturing facilities to satisfy the demand for out-of-stock products. This is mostly because on one side the sales profit justifies the cost and hassles of a transshipment and on the other side customers in such markets may be willing to wait up to a reasonable time to receive their desired product (Montreuil et al., 2019). Today, such retail networks are rapidly moving towards hyperconnected distribution networks where the flow of information and goods between multi-party retail centers, distribution centers and manufacturer allow efficient utilization of inventory across the network (see Figure 1). In such environment, in-stock availability does not fully reflect product

availability in a retail center because other resources such as manufacturer, depot, and inventory of other retailers can be exploited on-demand to satisfy customer demand. This makes the assortment planning decision more challenging because, in addition to stock, dealerships ought to account for the available products through the network to maximize their sales.
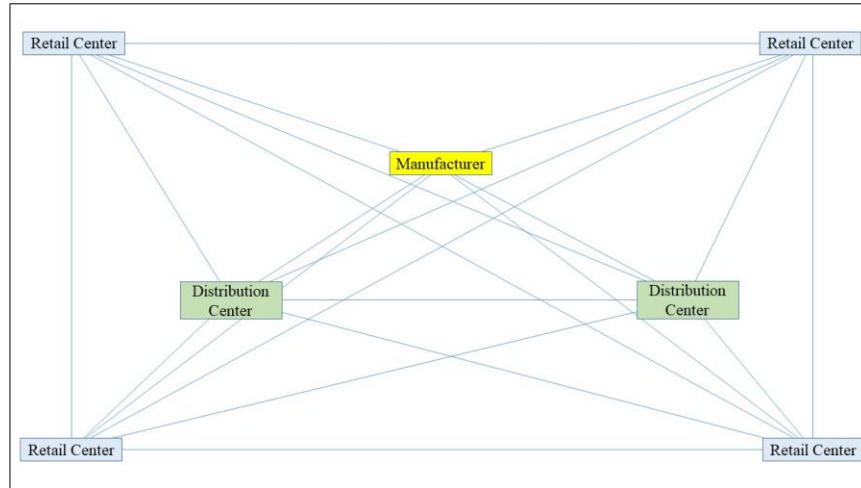
Figure 1: Illustration of a Hyperconnected Retail Network of High-Value Product Manufacturer

Montreuil et al. (2019) proposed a new approach to estimate product availability for an interconnected network of dealerships. They defined a new Key Performance Indicator (KPI) termed Product Availability Ratio (PAR) that measures the readiness of a dealership to satisfy upcoming customers by taking into account product demand share estimates, product substitution probability, and network availability of products.

In this paper, we develop a mixed integer program using the PAR model proposed by Montreuil et al. (2019) to find the optimal replenishment orders in the context of dealerships placing frequent replenishment orders under stochastic demand and customer substitution. Our model determines the set of products that a group of interconnected dealerships should replenish to maximize their product availability and consequently, customer satisfaction. It simultaneously solves the assortment plan for all dealerships in the network and therefore considers the interactions and effects of dealer orders on one another. The proposed model differs from the conventional assortment planning problem in that it concurrently accounts for product substitution, the inventory transshipment policies employed frequently by dealerships to satisfy the demand for an out-of-stock product, and the willingness of customers to wait to receive their desired product. The simulation results for a case of recreational vehicles show that the proposed model can achieve 30% sales increase while maintaining the same inventory level.

The remainder of the paper is structured as follows. Section 2 reviews pertinent papers, describes the gap in the existing literature and explains the contribution of this paper. In section 3, we briefly present the PAR estimation model developed by Montreuil et al. (2019) and describe the mathematical formulation of our optimization model. Section 4 presents the simulation results of a case study, and section 5 provides concluding remarks and avenues for further research.

2 Literature review

In a customer-centric retailing environment taking into account product availability for high-value high-variety products, determining what to store where is a key decision. Extensive research on assortment and inventory decisions in retailing have been conducted to solve this

problem. Pentico (1974) demonstrated a one-dimensional assortment planning problem regarding the sequence of customer arrivals under stochastic demand. Then, Pentico (1988) extended his research to a two-dimensional assortment planning problem that allows product substitution while it is not the case in the one-dimensional assortment planning problem, using an Economic Order Quantity (EOQ) model under deterministic demand. Ryzin and Mahajan (1999) analyzed a category-based assortment problem using a multinomial logit model (MNL) to describe the consumer choice process. Chong et al. (2001) presented an empirically-based modeling framework using a nested MNL model to address the complexity of managing a category assortment. Gaur and Honhon (2006) proved that products should be equally spaced using a locational choice model to address customer demand under a single-period assortment planning. This paper as contrasted with the above papers, investigates a product availability maximization focused multi-dimensional network based assortment planning problem taking in account estimated demand share of each product and customer substitution probability.

One key component for the assortment planning problem in our study is customer's substitution behavior. Numerous studies focused on stock-out-based substitution behavior whereby customer decision depends on the products available in stock at the time of her visit to the store. Kok and Fisher (2007) implemented a case study of a supermarket chain to observe the substitution behavior and demand for products in each store. Honhon et al. (2010) developed a dynamic programming algorithm for the optimal assortment and inventory levels in a single-period problem with stock-out-based substitution. However, relatively little is studied on dynamic substitution taking into account all the available products in the network as potential resources so as to best meet stochastic demand.

Inventory transshipment is exploited as an alternative and complements to dynamic substitution in this research, as a retailer may exploit alternative sources for the demanded product and for substitutes depending on the lead time acceptable by the customer. Inventory transshipment has long been identified as a key leverage in the literature. Zhao et al. (2008) analyzed the optimal production and transshipment policy for a two-location make-to-stock queueing system. Fang and Cho (2014) showed how inventory decisions change when transshipment of excess inventory is allowed by studying a cooperative game among multiple companies. Wee and Dada (2005) developed a formal model for transshipping inventory in a retail network using the stock either from a warehouse or from another retailer that has excess stock. In this paper, we extend by assuming that all retailers may take advantage of inventory transshipment, and that they cooperate to maximize network-wise product availability for all customers visiting any dealership in the network, while insuring satisfying retailer-specific availability.

In recent years, more studies have been conducted on product availability to better satisfy uncertain demand. By smartly deploying products in the network inventory, sales increase while keeping the same inventory level is made possible. Chiang (2008) showed how customers' stock-out based substitution can make an impact on product availability when both a supplier and its retailer behave to optimize their own profit. Ervolina et al. (2009) proposed a mathematical optimization model to manage product availability in an assemble-to-order supply chain with multiple customer segments by a case study. In our research on product availability optimization, we benefit by comparing the simulation results by the proposed-model-based orders and the actual dealer orders for a case of recreational vehicles.

Physical Internet plays a key role in facilitating fast and efficient order replenishment and inventory transshipment in the context of this research. Recent studies have demonstrated how the new concept of Physical Internet enables to shift toward much more distributed hyperconnected transshipment. Montreuil B. (2011) emphasized live open performance

monitoring of all Physical Internet actors and entities as one of the key characteristics to define the Physical Internet vision, which focuses on key performance indices of critical facets such as speed, service level, reliability, safety, and security. Exploiting real-time inventory identification between retail centers and fast replenishment, we evaluate the new KPI termed PAR in hyperconnected retail networks in this study. Hakimi et al (2012) and Sarrai et al (2014) showed by simulation that the Physical Internet-based transportation reduces 20-32% of the total traveled distance in a case of an open logistics web in France. In this study, considering the customer's acceptable waiting time that facilitates nearer transshipments through hyperconnected transportation, we attempt to find the best fitting combination of inventory deployment for all retail centers in the network.

This paper contributes to the multi-dimensional assortment planning literature for high-value products in that inventory transshipment between dealerships and customers' willingness to wait for their desired product are considered throughout the hyperconnected network. On top of that, this research proposes a novel approach that optimizes product availability under the Physical Internet-enabled hyperconnected retail networks, and investigates the correlation between the product availability of dealerships and the corresponding successful sales.

3   Methodology

In this section, we first present the components of the PAR model developed by Montreuil et al. (2019) for product availability estimation in an interconnected network of retailers. Then, we describe our proposed optimization model to solve the assortment planning problem with the objective of maximizing product availability while considering the possibility of inventory transshipment.

3.1   Product availability ratio (PAR)

We consider product availability ratio as a key measurement to assess the readiness of retail centers to satisfy the upcoming customers. Considering a hyperconnected network of dealerships, it uses stochastic demand shares, and accounts for possible inventory transshipment as well as customers' willingness to accept a substitute product and to wait some time so as to receive a satisfactory product.

The fundamental components utilized to compute the PAR are (a) inventory at each dealer, (b) substitution matrix from substitution product to demanded product, (c) product transfer time from a dealer to another, (d) daily product demand share at each dealer, and (e) the proportion of customers willing to wait for the desired product. Components (a), (b), and (c) are inputs to the model while components (d) and (e) are derived from experimental results, as described in Derhami and Montreuil (2019) and Montreuil et al. (2019). The PAR computation starts with truncating the original substitution matrix of products by given thresholds based on the assumption that none of the customers would purchase any substitute product whose substitution level for the desired product is below a certain threshold (Montreuil et al., 2019). The threshold for each product is also input to the model. It varies according to the main characteristics of the product and its retailing price. In general, it may be assumed that customers who want a more luxurious and costly item might be pickier, so their expectations relative to the fitness of a substitute product for it to be satisfactory would be higher than if they would be wanting less costly items (Montreuil et al., 2019). The substitution matrix truncating process is expressed below:

$$F_{pp'} = f_{pp'} \; if \; f_{pp'} > t_p, else \; 0 \qquad\qquad \forall p, p' \qquad\qquad\qquad (1)$$

where $F_{pp'}$ is the considerable substitution of product p' for demanded product p, $f_{pp'}$ is the original substitution fitness of product p' for demanded product p, and t_p ($0 \leq t_p \leq 1$) is the threshold for considering substitution for a client-demanded product p. When product p' is not available now at the dealer d visited by the customer, then its transfer time form its current dealer d' to dealer d must be taken into consideration. So we transform the considerable substitution matrix into a time-based substitution matrix as follows:

$$S_{pdp'd'\tau} = F_{pp'} \; if \; p_{dd'} \leq \tau, else \; 0 \qquad \forall p, d, p', d', \tau \tag{2}$$

where $S_{pdp'd'\tau}$ is the time-based substitution fitness of product p' from dealer d' in time τ as a substitute for demanded product p to dealer d, and $p_{dd'}$ is the transfer time (in days) of a unit of product from dealer d' to dealer d. Now considering the existing inventory at each dealer, we get the best considerable availability for all possible demands from each product p, each dealer d, and each customer waiting time τ as follows:

$$A_{pd\tau} = \max_{p'd'}(S_{pdp'd'\tau} * i_{p'd'}) \qquad \forall p, d, \tau \tag{3}$$

where $A_{pd\tau}$ is the time-based best considerable product availability for product p at dealer d in time τ, and i_{pd} ($i_{pd} \in \{0,1\}$) is the existing inventory state of product p at dealer d. The PAR is then computed by taking into consideration the estimated demand shares per product per dealer, and the customers' willingness to wait for their desired product, as formally expressed below:

$$PAR = \sum_{\tau} v_{\tau} \sum_{pd} d_{pd} A_{pd\tau} \tag{4}$$

where v_{τ} is the share of the customers' willingness to wait for their desired product until time τ and d_{pd} ($0 \leq d_{pd} \leq 1$) is the expected demand share of product p at dealer d in the region, and $\sum_{pd} d_{pd} = 1$.

3.2   Product availability optimization model

We here address the problem of maximizing the product availability ratio of all dealerships by deciding which product to order in the context that each dealer takes into account the product substitutions and exchanges within the network. Hence, all dealers can take advantage of the network inventory so as to maximize the availability of a customer-targeted product at her selected dealer, as a surrogate to minimizing unsatisfied customers and lost sales. We hereby formalize this problem through introducing a PAR optimization model.

3.2.1 *Input parameters*

$a_{pp'}$:Product substitution availability of product p' for product p (1 if product p' is substitutable for product p, 0 otherwise), $a_{pp'} \in \{0,1\} \; \forall p, p'$

d_{pd} :Expected demand share [0,1] of product p at dealer d in the region, $\sum_{pd} d_{pd} = 1$

i_{pd} :Current inventory of product p at dealer d, $i_{pd} \in \{0,1\} \; \forall p, d$

m_d :Maximum dealer portfolio size for dealer d

$s_{pdp'd'\tau}$:Substitution fitness of product p to dealer d offered by product p' from dealer d' in time τ

v_τ : Expected share $[0,1]$ of customer's willingness to wait for her desired product until time τ, $\sum_\tau v_\tau = 1$

3.2.2 Variables

$A_{pd\tau}$: Availability of product p at dealer d in time τ

$F_{pdp'd'}$: 1 if product p' from dealer d' is the offered substitution for product p to dealer d, 0 otherwise

I_{pd} : 1 if product p is in the inventory of dealer d, 0 otherwise

O_{pd} : 1 if product p is ordered by dealer d, 0 otherwise

3.2.3 Objective function

The objective is to maximize the total weighted product availibilty of dealers given the expected share of customers willing to wait up to a specific time for a satisfactory product, and the expected demand share of product p at dealer d in the region. It can be expressed as:

Maximize: $PAR = \sum_\tau v_\tau \sum_{pd} d_{pd} A_{pd\tau}$ (5)

3.2.4 Constraints

$$I_{pd} = O_{pd} + i_{pd} \qquad \forall p, d \tag{6}$$

$$\sum_p I_{pd} \leq m_d \qquad \forall d \tag{7}$$

$$F_{pdp'd'} \leq 1 - a_{pp'} I_{p'd} \qquad \forall p, d' \neq d, p' \tag{8}$$

$$F_{pdp'd'} \leq I_{p'd'} \qquad \forall p, d, p', d' \tag{9}$$

$$\sum_{p'd'} F_{pdp'd'} \leq 1 \qquad \forall p, d \tag{10}$$

$$A_{pd\tau} = \sum_{p'd'} s_{pdp'd'\tau} F_{pdp'd'} \qquad \forall p, d, \tau \tag{11}$$

$$F_{pdp'd'} \in \{0,1\} \qquad \forall p, d, p', d' \tag{12}$$

$$I_{pd} \in \{0,1\} \qquad \forall p, d \tag{13}$$

$$O_{pd} \in \{0,1\} \qquad \forall p, d \tag{14}$$

By constraint set (6), the total sellable inventory becomes eqaul to the sum of the order and the current inventory. Constraints (7) restrict the portfolio size for each dealer. By constraints set (8), the offered substitution product p' from dealer d' can be chosen for demanded product p at dealer d only if there is no substitutable product p' at dealer d; these constraints are made for this optimization model to represent the actual dealer behaviors such that dealer does not consider inventory transshipment from other dealers if it has a substitutable product in its stock for demanded product. By constraints (9), product p' at dealer d' can be a substitute for demanded product p to dealer d only if product p' is in the inventory at dealer d'. Constraints (10) ensure that only one product from all products at all dealers can substitute for demanded product p at dealer d. By constraint set (11), product availablity of product p at dealer d in time

τ is computed such that the binary variable $F_{pdp'd'}$ selects the best time-based substitution to enable the maximum product availability. Constraints (12), (13), and (14) ensure that those variables are binary.

4 Case study

The case company, specialized in recreational vehicles including off-road vehicles and snowmobiles, currently operates with more than five hundred dealers in North America and is one of the top manufacturers in this industry. Dealers are businesses distinct from the manufacturer. Many dealership businesses operate a single dealer site, while some operate a few dealer sites. When facing a demand by a customer for a product not in its inventory, a dealer has the capability of investigating whether alternative sources within a satisfactory distance have the demanded product or a substitute one in stock, and to engage in transshipping a product from another source (e.g. dealer). The baseline for this experiment has each dealer deciding independently upon its inventory replenishment decisions without formally considering the substitution and transshipment options, and ignoring product availability ratio performance.

In order to test the performance of the proposed optimization model in this case study, a simulation-based experiment has been designed in a way that dealers are allowed to make an order on a daily basis and that with fast-replenishment the ordered products are delivered by early next morning before the dealers begin to operate. Seventeen dealerships in one state and 102 products of a certain category of vehicles are selected for this experiment. The simulation period is set to six business days in a given week in year 2018, and overall regional demand is set to be stemming around four customers daily, each demanding a specific product. The dealer visited by a customer is randomly identified, based on estimated dealer demand share within the region. The product demanded by the customer at the dealer is also randomly identified based on the given expected demand share per product per dealer. Each day the dealerships order products to replace those sold. A scenario is generated to correspond to a 6-day week of specific customer demand. In this paper, we provide exploratory results based on a twenty-scenario experiment.

We use Monte Carlo simulation as shown in Figure 2 to investigate the performance of our proposed methodology with the baseline approach. The 20 scenarios by simulation are generated using MATLAB software while the PAR optimization model is run using a developed Java software, exploiting the CPLEX optimization software package. In each scenario of the simulation, each customer visits one retail center, expresses her demanded product, and states how long she is willing to wait for receiving a satisfactory product. If the retailer can provide a satisfactory product (i.e., the product whose substitution level for the demanded product is above the threshold) either by its own inventory or by inventory transshipment from other retailers within the time that the customer is willing to wait, then a successful sale occurs. Otherwise, the retailer loses the sale. After the available substitution product searching process, as marked with the blue dotted line in Figure 2, is finished, the retailer makes an order at the end of the day by different order policies that are explained in the next paragraph. Then, all this process is repeated for the assigned simulation period, and the resulting scenario is generated.

We design different three order policies for dealerships to evaluate the performance between the current business model of the case company and the proposed model. The three alternatives for the experiment are:

1. Actual dealer order of the case company during the simulation period

2. Single dealer focused PAR optimizing order
3. Hyperconnected network-based PAR optimizing order
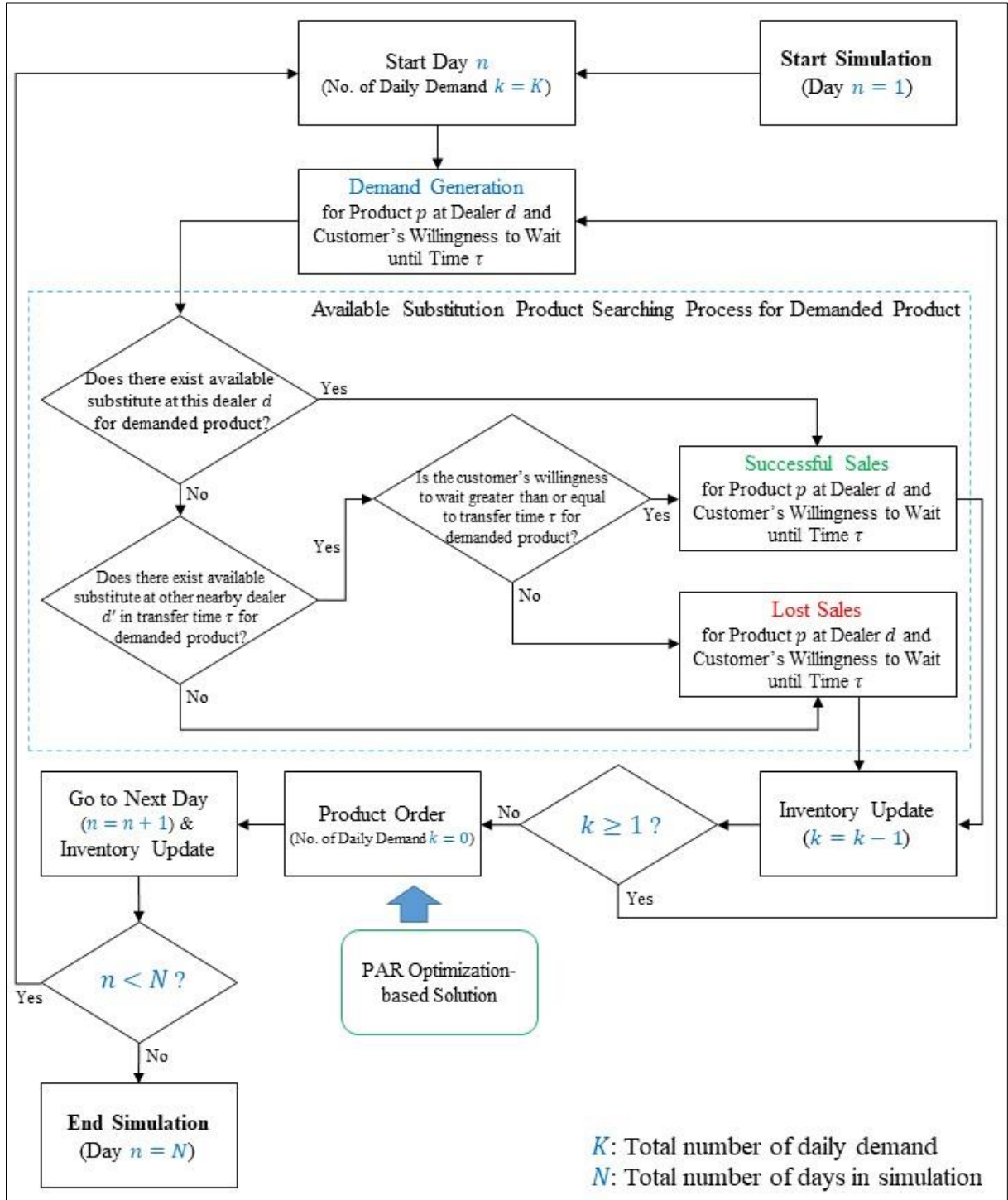
Figure 2: Diagram of Simulation Model Generating Hyperconnected-Dealer-Network-based Scenarios

Note that alternative 1 corresponds to the company's current typical operation so the actual dealer orders during the simulation period are identified: dealers make orders independently and locally, not considering customers' substitution behavior nor the potential of inventory transshipment. Alternative 2 is designed to evaluate the single dealer focused product

availability whereas alternative 3 is the proposed operation scheme discussed in section 3. In alternative 2, dealers consider customers' substitution behavior but do not take into account the potential of product transshipment, while dealers consider all the three factors in alternative 3. We generate the initial inventory for alternatives 2 and 3 based on single dealer focused PAR optimization and hyperconnected PAR optimization, respectively but keep the inventory level the same as alternative 1.

Demand shares of products are forecast daily using exponential smoothing, adjusted so the total of estimated shares always equals one. We used the historical sales log data of the case company in the given region and the expected lost sales ratio in order to estimate the realized demand shares (Derhami and Montreuil, 2019), which become data input to product demand share forecast.

4.1 Quantitative analysis

To evaluate how much improvement our developed method can make on dealers' performance and provide better insight, we numerically and graphically analyze the experimental results.
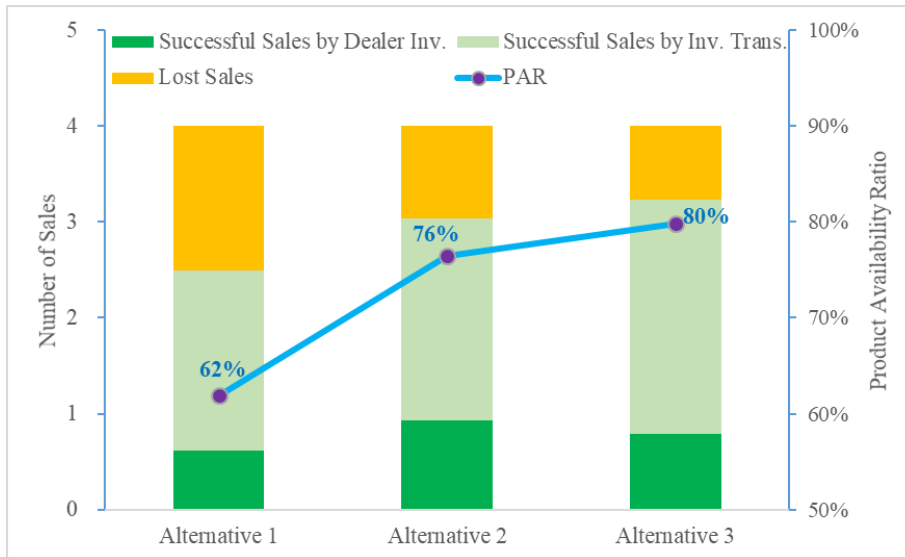
Figure 3: Daily Average Successful Sales and Lost Sales along with PAR

Figure 3 shows the resulting daily average successful sales and lost sales, along with the daily average PAR result from the 20 scenarios generated by each alternative. Maintaining the same dealer inventory size at retail centers as alternative 1, alternative 2 and 3 result in significantly higher PAR than alternative 1. This can be interpreted as dealers having significantly higher chance to meet uncertain customer demand in alternative 2 and 3 than in alternative 1. Since dealers in alternative 2 always attempt to maximize their own PAR without taking into consideration the potential of the network-driven product transshipment, even though it is allowed, the average daily PAR improvement is restricted. Exploiting hyperconnected-network-based PAR optimization, alternative 3 increases PAR by 29% in contrast to baseline alternative.

The sales results derived from customer demands indicate that dealers can make more sales under the PAR optimization policy. Exploiting alternative 2 and 3, the average daily sales increase by 22% and 30% as contrasted with baseline alternative 1. Interestingly, the successful sales made by the dealer's inventory rather than the inventory of other dealers is higher in alternative 2 than those in alternative 3. This is due to the fact that in alternative 2, dealers always attempt to be ready for the next visiting customers as best as possible with their own

inventory by maximizing their standalone product availability. In contrast, alternative 3 enables the best total average daily sales as it better deploys products in the network and consequently, results in more inventory-transshipment-based sales. The average daily lost sales ratio of each alternative resulting from the 20 scenarios is 38%, 24%, and 19%, respectively for alternatives 1 to 3.
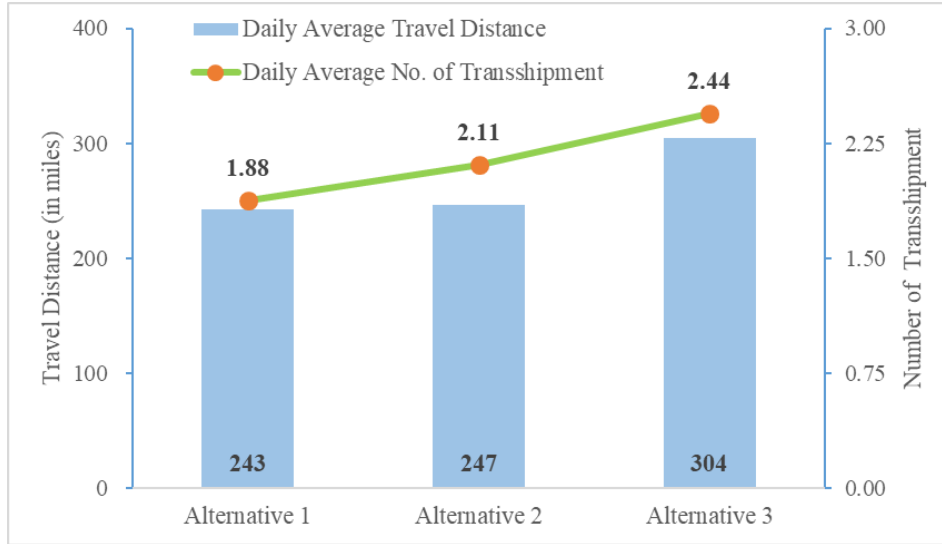
Figure 4: Daily Average Number of Transshipment and Corresponding Travle Distance

Figure 4 presents the daily average number of transshipment occurrence and the resulting daily average travel distance. As expected from the result shown in Figure 3, the most travel for product transshipment occurs in alternative 3 so as to best meet the customers' demand by employing the network inventory. Also, a higher number of transshipments occur in alternative 2 than in alternative 1 as in the region there is inventory of more PAR-contributing products in alternative 2 and thus this contributes to meeting uncertain demand to some degree. However, the total traveled distance differs only slightly between alternative 1 and 2. This is because in alternative 2, a few big dealers with higher inventory are ordering some highly substitutable products, which become available for transshipping to other relatively small dealers, whereas the product transshipments in alternative 1 occur more randomly and thus, result in a greater traveled distance per unit of product transshipment.
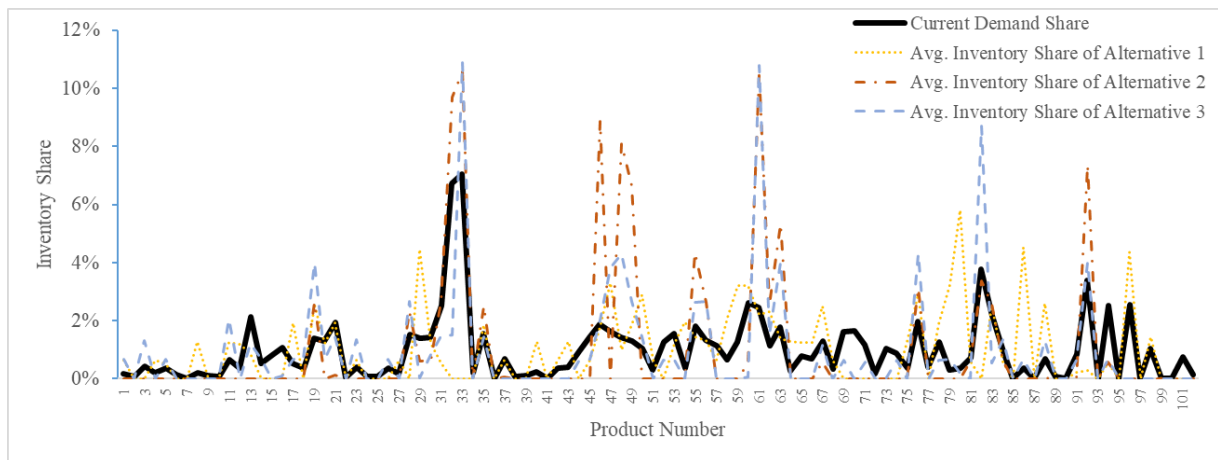
Figure 5: Daily Average Network Inventory Share

Figure 5 shows the share of the average network inventory per product for each alternative, compared with the current demand share per product in the region. There are some significantly

higher inventory shares than the current demand shares for certain products in alternatives 2 and 3, while inventory shares over 6% for any product do not exist in alternative 1. This is due to the fact that keeping more of highly substitutable products contributes to enabling high PAR, thus it ends up in alternatives 2 and 3 with ordering more of those products than their demand shares. This does not happen in alternative 1 that does not consider production substitution when ordering replenishments. Because of product substitution, alternatives 2 and 3 show similar high inventory share patterns for certain highly substitutable products such as products 32, 33, 61, and 63. However, they significantly differ in other highly substitutable products, including products 46, 48, and 49. This is because in alternative 3, dealers consider the potential of inventory transshipment when they place an order, and consequently do not order too many of them if the products are stored at other nearby dealers, whereas the potential of inventory transshipment is never considered in alternative 2.

5 Conclusion

In this paper, we address the optimization of dealer replenishment decisions in planning their assortment so as to maximize the Product Availability Ratio (PAR) defined by Montreuil et al (2019). We formalize the problem as discrete optimization model capable of tackling PAR optimization for a hyperconnected network of dealers offering a wide-variety portfolio of substitutable high-value products. We provide exploratory empirical results based on a Monte Carlo simulation for a case study of a leading manufacturer of recreational vehicles.

By switching the emphasis from inventory to availability, the paper originally contributes to the literature associated with assortment planning, inventory transshipment, customers' substitution behavior, and product availability. Importantly, the paper takes into account inventory transshipment among dealerships and customers' willingness to wait to receive their desired product.

The paper provides insights on how such an advanced hyperconnected system can benefit all retailers in the network by increasing readiness to respond to customer demand, and inducing sales growth and customer satisfaction growth. The simulation results notably show that our developed model can achieve 30% sales increase while keeping the same inventory level by smartly determining the set of products for a group of interconnected dealerships. This is mainly because the proposed model induces the network inventory shares match to the network-based product demand shares, while adjusting to take into consideration the fact that certain products are satisfactory substitute to several others.

In regard to further research, more meaningful results can be obtained in future work by further investigating the exploitation of non-dealer external resources in the model such as depots, warehouses and production facilities so as to concurrently maximize the hyperconnected network-based PAR performance and overall sustainability. In addition, there should be deeper investigation of the gains in PAR, sales, profitability and sustainability performance enabled by Physical Internet hyperconnectivity. Notably, the reduction of required inventory to achieve high PAR given faster and cheaper hyperconnected transportation and distribution, with digitally transmitted real-time information and smart deployment optimization. There is also potential to be explored relative to production and supply, by feeding dealers directly from factories and suppliers instead of only relying on inventoried products.

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Hyperconnected Showcasing-Based Retail and Distribution of High-Value Products

Jisoo Park[1,4], Benoit Montreuil[1,2,3,4], Iman Dayarian[1,5],

1. Physical Internet Center
2. Supply Chain and Logistics Institute
3. Coca-Cola Chair in Material Handling and Distribution
4. School of Industrial and Systems Engineering,
Georgia Institute of Technology, Atlanta, U.S.A.
5. Culverhouse College of Business, University of Alabama, Tuscaloosa, U.S.A.

Corresponding author: jisoopark@gatech.edu

Abstract: *Although e-commerce has transformed the way products are manufactured, transported, and sold, the pure e-commerce context is not appropriate for high value goods. In these industries, products are not strictly purchased online and the role of offline retail stores remains important as it is crucial for the customers to experience the product prior to the purchase. In fact, in some industries, having the possibility of testing the products could be a deciding factor. In the omnichannel supply chain era, showcasing is then emerging as one of the forthcoming key retailing factors. A showcasing value optimization model for hyperconnected showcasing centers, which maximizes showcasing value with respect to binary variables that represent which models are showcased is developed. The goal is to ultimately best represent the portfolio of products with features that customers expect to experience. Numerical results from our case study suggest that the showcasing value can be optimized to create a more efficient and effective showcase, with 20.4% increase on average across all 17 dealers. We also reiterate that for the model to be sustainable, Physical Internet and highly efficient, interconnected networks, are required.*

Keywords: *Showcasing; Retailing; Merchandising; Hyperconnected Distribution; Physical Internet; Product availability; Optimization; Mixed Integer Programming*

1   Introduction

Online retail has been accelerating ever since the rise of the e-commerce sector, with many customers willing to buy products without having physically seen, touched, and experienced them. However, for some industries, customers prefer to gain sufficient in-person experience with products before making their purchase decision, and thus the purely online setting is not appropriate. An example of such markets are high-value substitutable product markets like cars and recreational vehicles where products often have high values, carry in various models, and getting a first-hand experience of the product prior to purchase is one of the deciding factors for the customers. Vehicle dealerships are well aware of the importance of letting the customers touch, feel and experience the products to increase the chance of a successful sale but are often faced with spatial, financial, and supply chain related limitations that cause incomplete product availability frequently occur in retail centers. Factors such as demand uncertainty and forecast errors, seasonality, high holding costs, broad product mix, limited production capacity, long order-to-delivery times, and storage space limitations contribute to incomplete product

availability in high-value product markets making it practically difficult to provide in-person experience to customers for all products and often lead to stock-out-based lost sales.

On the other hand, unlike markets that deal with the daily demand of customers like grocery stores, customers in high-value product markets are usually inclined to wait up to some acceptable time to receive their desired product. This along with high marginal profit and frequent occurrences of incomplete product availability persuades the retail centers to use inventory transshipment from other retailer centers or from the firm's distribution facility to satisfy demands for out-of-stock products. However, the customers who have not experienced some influential features that are found only in out-of-stock products, may not be able to realize their desired product among the firm's product portfolio or be willing to wait and accept a transshipment. This results in feature-out-of-experience-based lost sales which are different from stock-out-based lost sales. In the former case, the retailer can persuade most of the undecided customers that are willing to wait to realize their desired product by providing them the chance of experiencing different features of the products in-person. This requires the retail canters to consider feature availability or showcasing in their stores in addition to product availability.

It is important to make the distinction between stocked items in inventory and showcased items; having a product in inventory does not necessarily mean that the product is showcased. In fact, an optimized showcase may differ from an optimized inventory. Simply put, the inventory insures high availability of product. A product-availability-ratio (PAR) oriented inventory model measures and maximizes product model availabilities for a dealer's portfolio at any given time. The PAR takes the substitution phenomenon into account: whenever a model is not available due to a stockout situation, customers may take a similar available model for equal or lesser value. Given financial and space constraints, smart inventory management optimizes product availability, so as to essentially maximize the probability that a client wanting a given model will be satisfied with the inventory available to the dealer. This takes into consideration inter-model substitution fitness, the customers' preferred delivery time window distribution, and the stock exchange potential from other dealers and the manufacturer.

Whereas in inventory management, having multiple units of a given product on hand may help to satisfy heavy demand, in showcasing, this would be done only to enable multiple clients to touch and try the same product at the same time in the dealership. In fact, the main goal of showcasing optimization is to demo as many features in each category, given spatial and budget constraints; the showcasing value does not increase from displaying the same feature multiple times in the same showcase. Showcasing optimization takes feature similarities into consideration. However, showcasing and PAR models differ in terms of the criteria considered and the substitution or similarity values. More specifically, the showcasing model focuses on the product features and their feature similarities while PAR looks at products and their substitutability. Thus, it is important for the dealers to optimize both the showcase and the PAR, the former for meeting consumers' expectations prior to the purchase, and the latter for immediate sales since some customers might be reluctant to wait for shipments.

Motivated from a case of recreational vehicles, this paper investigates the assortment planning problem from the showcasing perspectives in a network of dealerships that owned independently or managed centrally by a firm and distribute recreational products. Dealerships do not sell the showcased units except for end-of-season clearance or for renewing the product freshness. When a client purchases a product, he gets a unit of the purchased product shipped from a fulfillment center to the client's location within the desired time window. The firm

deploys its stock of products in the hyperconnected network of fulfillment centers, dynamically adjusting the overall quantity of stock in the network and the location of each product unit, aiming for each product to be deliverable efficiently within the various time windows expected to be requested by clients. We use the context of a recreational vehicle manufacturer and its thousand-dealer network across North America as a testbed.

2 Literature Review

The Physical Internet vision, which enables the logistics network to be hyperconnected and thus allows for the full implementation of the showcasing only model, has been proposed as a possible solution to the much called for supply chain revolution to meet the increase in customer's expectations in a sustainable way in modern world (Montreuil, 2011; Montreuil, 2012). The Physical Internet aims to create a sustainable, global, and interconnected logistics network that is analogous to the way information is transferred, handled, and stored in the digital internet (Montreuil, 2011; Montreuil, et al., 2012). The difference between the digital world and the physical world is well-acknowledged by the authors, but the focus is on standardization and interconnectivity that can be implemented in the physical world. Although the Physical Internet is a relatively new concept, it has been gaining significant attention globally from both academia and the industry, with topics ranging from city logistics to business models (Pan, et al., 2017; Crainic & Montreuil, 2016; Montreuil, et al., 2012). Its application in enabling efficient fast-response hyperconnected omnichannel supply chains is key to the widespread deployment of the showcasing model (Montreuil, 2017).

Visual merchandising can be defined as "the art and science of presenting products in the most visually appealing way" for retail stores to "[communicate] with the customers" (Ebster & Garaus, 2015). The authors have studied ways to promote sales through visual merchandising and appropriate design of store space. They accentuate the physical store environment as it can not only provide the customers with important information about the products and entertain them in the process, but also sell products to them, leading to sales. The authors provide a detailed guideline of how to design and present the store to derive such influences, such as customer paths, shelving, etc. but much of these details are not relevant to our discussion of a showroom. However, their argument that a purchase is contingent on a product being visible, tangible, and accessible is one of the key drivers of our study – in store product displays, or the showcase, will have a significant impact on sales.

Ebster and Garaus devote a chapter on using senses as a means to communicate with the customers, noting that high-pleasure and high-arousal store experience will encourage a more satisfactory shopping experience for the customers. Similarly, the four significant dimensions of store atmosphere had been defined as early as the 1970s as visual (sight), aural (sound), olfactory (smell), and tactile (touch) (Kotler, 1973-1974). This idea of sensory channels and their effect on consumer purchase decision and product choice were later reiterated by other scholars such as. McGoldrick (McGoldrick, 2002).

Another chapter in Ebster et al.'s work is in experiential store design, which is encouraging a memorable shopping experience. This concept also dates earlier as Schmitt has shown the need to shift in marketing approach to focus on providing consumers with enjoyable experiences, outlining five different kinds of strategic experiential modules including sensory associations, affective experiences, and physical experiences (Schmitt, 2015). In fact, with this rise of the era of experience economy companies should view the source of revenue as the consumption of experiences rather than products and functions (Pine II & Gilmore, 1998). It can thus be inferred that a showroom that provides customers with the experiences they

expect once they purchase the product will best serve their needs, and the importance of providing them with the sensory, affective, and physical experiences for the products they desire is highlighted.

Studies have long acknowledged the impact of assortment planning on retailers' sales and profit, as outlined in Kok's extensive review of published work on assortment planning (Kök, et al., 2009). Kok et al. define the objective of assortment planning as to "specify an assortment that maximizes sales ... subject to various constraint" and show that a majority of existing studies are on the analytical formulation of the model and on demand estimates that are required for the formulations. The similarities in the concept then becomes obvious, as the goal of the showcasing optimization model is to select the set of products to be displayed as to maximize variety and meet customer demands, and thus maximizing the retailer's revenues.

Thus, the consequences of an ineffective showcase also mirror those of an ineffective retail assortment — if the selected set does not meet customers' expectation and fail to provide value, then the sales is jeopardized. An effective showcase displays not only the products customers expect to see, reflecting their demands, but also a variety, as is the case in assortment planning problems (Hoch, et al., 1999). Thus, the showcasing optimization model needs to maximize product variety to increase the chance of displaying the products customers desire for a greater number of customers, as well as to enhance customer's perception of variety which has a positive influence on store choice and customer purchase (Hoch, et al., 1999; Arnold, et al., 1978). The notion of customers' perception of variety is further explored by Hoch, as they outline the perception of variety is driven by a measure of dissimilarity between different products based on the number of different attributes (Hoch, et al., 1999). Nevertheless, at the heart of assortment planning is not only selecting the product set, but also determining the appropriate inventory levels for the products in that set. In the showcasing optimization model, inventory management is not a factor, especially in the context of hyperconnected logistics that eliminates the need for retail store inventory.

3 Showcasing Portfolio Optimization

3.1 Measuring Showcasing Value

We define the showcasing value as the measure of how much a showroom displays features that customers desire to experience before purchasing an item. The parameters and variables required to calculate the showcasing value are as follows:

- P is the set of all products that can possibly be showcased in a showroom by, and p is a product within that set.
- Each product is characterized by its features from different feature categories. Let C be the set of all feature categories, and c be a category within that set.
- Similarly, be the set of features within feature category F, $c \in C$ and f a feature within that set.
- Binary parameter δ_{fp} equals 1 if feature $f \in F_c$ of category $c \in C$ is a part of product p, or takes a value between 0 and 1 if a similar feature to f is a part of product p. That is, parameter δ_{fp} indicates how representative product p is to showcase feature f. Obviously, if feature f is part of product p then δ_{fp} equals 1, otherwise, it takes of a value between 0 and 1, depending on the level of similarity of f to the corresponding feature in p.
- w_c is the showcasing weight of a feature category that represents how some feature categories hold a greater importance for the customers to experience in a

showroom than other feature categories, between 0 and 1. For feature categories that are more important
all categories is 1, or $\sum_c w_c = 1$.

- d_{fc} is the expected demand share for a feature within a category, between 0 and 1. The demand share value estimates how likely a customer would like to purchase a product with that feature, and thus how much the customers would like to see the feature showcased. For each feature, the showcasing value contributed by that specific feature is multiplied by the corresponding demand share for the feature. Thus, the showcasing value does not simply measure how well a variety of features are showcased – it rather measures how well the showcase portfolio represents what the customers expect to see, as most customers visit the showroom with features in mind for purchase. The resulting showcase then is more likely to give an overall showcasing experience satisfactory for all customers. The sum of $d_{fc,}$ across all features within a category is 1 for every category, or $\sum_c d_{fc} = 1 \ \forall c \in C$.

- Y_{fc} is the showcase value for feature f in category c, which describes how well the feature is showcased in the given portfolio. If the exact feature is showcased by a product in the portfolio and thus the customer has a full exposure of the feature, then $Y_{fc} = 1$. If the exact feature is not showcased but the customer can still gain partial value by being exposed to a similar feature that is showcased, Y_{fc} is between 0 and 1. If the feature is not showcased and none of the similar features are showcased such that the customer cannot gain partial experience of the feature even through similar features, then $Y_{fc} = 0$. For some categories, customers will always want to see the exact feature. In such cases Y_{fc} is a decision variable which is 0 if the feature is not showcased and 1 if it is. When a feature similar to the desired feature can give some value to the customer when showcased, Y_{fc} will be between 0 and 1, the value being higher if the similarity is higher.

The showcasing value then can be modeled as follows:

$$Showcasing\ value\ \Gamma\ = \sum_{c \in C} \sum_{f \in F_c} d_f Y_f \tag{1}$$

3.2 Showcasing Optimization

The objective function is then written as the maximization of equation (1) from the previous section with respect to Y_f with the following constraint sets:

$$Y_f \geq \delta_{fp} X_p \tag{2}$$

$$Y_f \leq \sum_{p \in P} \delta_{fp} X_p \tag{3}$$

$$U_f \leq 1 - (Y_f - \delta_{fp} X_p) \tag{4}$$

$$\sum_{p \in P} X_p \leq m \tag{5}$$

$$\sum_{p \in P} c_p X_p \leq m \tag{6}$$

$$U_f \in \{0,1\} \tag{8}$$

$$X_p \in \{0,1\} \tag{9}$$

$$Y_f \geq 0 \tag{10}$$

Constraint set (2), (3) and (4) guarantee that variable Y_f for a given feature in each category will be a positive value between 0 and 1 and thus contribute to the showcasing value if and only if a product with the feature in the category is showcased. Moreover, customers will benefit from the product that best represents the desired feature, and thus Y_f takes the maximum value possible. Binary variable X_p is 1 if product p is showcased and 0 otherwise. This variable then is multiplied by δ_{fp}, the feature representivity for feature f of category c that is a part of product p. Parameter δ_{fp} is 1 if the exact feature f is a part of p, between 0 and 1 if a similar feature is a part of product p, and 0 otherwise. Thus, $\delta_{fp} X_p$ represents the value a specific feature within a category adds to the overall showcasing value when a product with that feature is displayed, taking the feature representativeness into account. Another assumption is made here as if multiple products with partial feature representativeness are showcased, then max $\delta_{fp} X_p$ will take the maximum value, which means the customer benefits from the feature most similar to the desired feature. When multiple products are showcased and these products represent any feature that is similar to a particular feature f, then customers will gain utility only from experiencing the feature that best represents the desired feature. Constraint (6) ensures that the given dealer cannot showcase more products than the maximum number m. To keep the total expense of the showcase within the budget, constraint (7) is included so that the given dealer cannot spend more than the budget B to showcase the products. Constraints (8), (9) and (10) give the type and domain of the variables of the model.

Then the goal is to maximize showcasing value for a dealer through deciding which products to showcase given physical and budgetary constraints. The assumption is that higher showcasing value means lower chance of a customer not purchasing the product because desired features were not showcased.

4 Experimentation

4.1 Numerical Example with a Dealer

This section illustrates a numerical example of the model with data collected from the industry. Specifically, it is from a company that manufactures and distributes recreational vehicles, focusing on a particular type of such vehicles. The showcase for seventeen dealerships, referred to as dealer 1, dealer 2, etc., in a state in the United States is considered, as it was the site for pilot testing.

Table 1: Showcasing Weight of Feature Categories

Feature Category	Weight (%)
Color	13.6
Engine	9.1
Platform	18.2
Seat Capacity	13.6
Segment Industry	45.5
Sum	100

In table 1 we provide a list of key categories of product features that contribute to the showcasing value, as well as the corresponding showcasing weight w_w for each feature category, based on the weight given for each category for demand share calculations.

These feature categories are defined as key categories of product features that customers want to physically touch and feel on a product in the dealership in order to differentiate correctly between products and to gain sufficient confidence that an ordered product will satisfy their needs and meet their expectations.

The demand share for each feature f, or d_f, was translated from the demand share for a product p for year 2018. Based on the historical sales data for a one-year period, the demand for a feature

was estimated by multiplying the product demand matrix (which shows the demand share for each product for each month) and the product-feature matrix (which shows whether the feature is a part of the product or not). Exponential smoothing was then used with the ratios from the sales data to calculate estimated demand share for each feature in year 2018. Table 2 shows an example of the demand share used for calculating the showcasing value.

Table 2: Demand Share for Features in Category Seat Capacity

Feature	Demand Share (%)

2 Seats	36.0
3 Seats	23.9
4 Seats	11.8
6 Seats	28.4
Sum	100

To further illustrate how the current showcasing value is measured, dealer 13 is taken as an example. Assuming the current stock is equivalent to the showcase, Fig. 1 below is a visual representation of the current showcase and the features represented by the products with this showcase.

Alpha2   Beta2

Beta11   Gamma6

Figure 1: Current showcase for dealer 13, assuming that the inventory is the showcase

Because this showcase is not optimized, the products represent the same or similar features in a number of cases (eg. Alpha2 and Gamma6 both feature the color which corresponds to the color "Red", and three out of four vehicles are 2 passenger seats). With the current showcase, the showcasing value for dealer 13 is 48.8%. The features for all categories considered are shown in the table 3.

Table 3: Features for the current showcase for dealer 13

Category	Alpha2	Beta2	Beta11	Gamma6
Color	Red	Blue	Black	Red
Engine	1000 Twin Cylinder	1000 Twin Cylinder	Turbo	Pro 100
Platform	A2	A2	A2	A3

Seating	2	2	2	3
Segment Industry	Recreational	Sport-1	Sport-2	Utility

With the model we propose, the showcasing value for the same dealer was maximized, with the optimized showcase shown in Figure 2.

Figure 2: *Optimized showcase for dealer 13, assuming that the inventory is the showcase*

Alpha12   Beta10

Gamma9   Gamma20
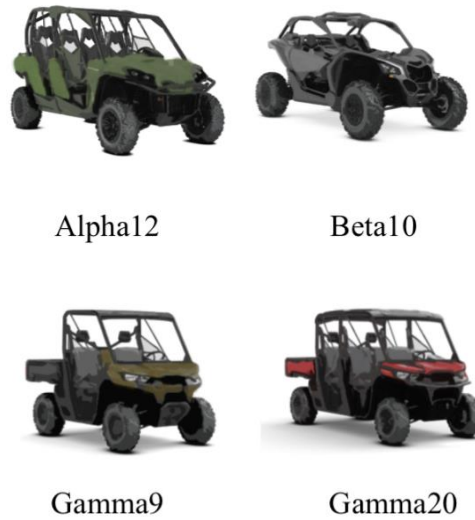
This optimized showcase offers a more variety of features for customers to experience, especially the more demanded features when possible. For example, compared to the current showcase that displays only two features in the category passenger seats (2 and 3), the optimized showcase displays all four features available in the category.

Table 4: *Features for the optimized showcase for dealer 13*

Category	Alpha12	Beta10	Gamma9	Gamma20
Color	Green	Grey	Brown	Red
Engine	1000 Twin Cylinder	Turbo	Pro 80	Pro 100
Platform	Alpha6	D38	B5	B15
Seating	4	2	3	6
Segment Industry	Multi	Sport-1	Utility	Utility Multi

4.2 Numerical Example with All Dealers

When the current showcasing values are measured for all dealers in the state, the average showcasing value is 62.3%. Dealers with either an efficient showcase, or higher budget and

maximum number of vehicles to be showcased display relatively higher showcasing values. When the proposed optimization model is applied to all seventeen dealers, the average of the optimized showcasing value increased to 82.7%.

Because the budget was part of the constraint of the optimization model, the new budget for the optimized showcase is never higher than the current budget. In fact, we saw a decrease in the average required budget to achieve the maximum showcasing value across all dealers.

Table 5: Showcasing value and budget for all dealers

Dealer Number	Current Showcasing Value	Optimized Showcasing Value	Current Budget (USD)	Optimized Budget (USD)
1	42.9%	77.6%	80296	78396
2	64.3%	86.2%	131994	122194
3	31.9%	43.3%	37298	35998
4	39.2%	60.2%	51397	51397
5	96.6%	100.0%	635068	622468
6	77.6%	98.1%	327081	324283
7	94.9%	99.5%	466376	472776
8	35.3%	82.2%	128995	103495
9	88.3%	98.5%	349082	348282
10	59.9%	87.4%	127992	127893
11	70.6%	84.6%	110494	108494
12	34.8%	42.7%	33198	32498
13	56.8%	82.2%	123495	103395
14	91.4%	99.1%	399079	395479
15	68.1%	91.7%	164391	164091
16	43.7%	77.6%	86696	78496
17	62.1%	94.8%	273889	216989
Average	62.3%	82.7%	207460	199213

5 Conclusion

In this paper we described the key decisions, objectives, and constraints in dynamically optimizing the showcasing portfolio of each dealer, then we contrasted baseline vs optimized portfolios in terms of showcasing value, dependent on budget decisions. The showcasing value aims to measure how well each feature is represented in a given dealer's portfolio. The

showcasing value optimization model for hyperconnected showcasing centers then maximizes the sum of all the feature representivity for a given dealer, weighted by expected demand for that demand and then by the importance of the category to showcasing. The model is formulated as a mixed-integer programming model, with binary variables that represent which models are showcased, and concurrently the features showcased. With the empirical application of the model, it shows that the data-driven model can be solved efficiently for industry cases. The results illustrate that the showcasing value can be optimized significantly given certain conditions are met with an increase of 20.4% in showcasing values on average across all 17 dealers. With efficient decision support systems for optimizing showcase, the showcasing model can allow to take full advantage of the fast replenishment from hyperconnected networks in the Physical Internet world, benefiting retailers, manufacturers and customers. Indeed, optimized showcasing can be implemented in practice only if the supply chain is agile enough with a short lead time to deliver the products to the customers within the time frame they expect, from sources ranging from fulfillment centers, warehouses and factories.

The implication on the downstream supply chain of the manufacturer to support the fast and reliable availability of products demanded at the showcasing dealers across the market territory is then clear. In traditional settings, a higher level of inventory is oftentimes kept in dealers, distribution centers, and fulfillment centers minimize the possibility of lost sales. Dealerships would also keep what they think is the best showcase to meet customers' needs. Once the customers gain confidence in their decision from their visit to the showcase they would make a purchase directly from that retail store. However, with the advancements in the Physical Internet, the independent dealers, OEM distribution centers and fulfillment facilities will be hyperconnected; as these facilities now share all the information and networks, with fast replenishment, products available in one of the facilities would be available in all other facilities in the network within a short time frame. Such flexibility and end-to-end visibility across the supply chain means that products could now be delivered from any point to the customer within an acceptable period of time. In-store inventory is then not a necessity anymore, transforming the role of dealerships from retail stores to showcasing centers. In this context, the importance of having a showcase that meets customers' expectation is now greater than ever. To successfully induce the client to make a purchase, the showcase would need to help the customers understand the options by letting them experience the features, especially the ones they desire. We thus accentuate the role of showcasing as one of the forthcoming key retailing models in the omnichannel supply chain era, together with the opportunities offered by the emerging Physical Internet.

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Urban logistics and parcel distribution - 10th July 2019 15:30 – 17:30

Parcel lockers for the pickup and delivery problem with transshipment in Hyper-connected City logistics

Chaojie Guo[1], Russell G. Thompson[1], Greg Foliente[1]
1. The University of Melbourne, Melbourne, Australia
Corresponding author: chaojieg1@student.unimelb.edu.au

Abstract: *The concept of Hyperconnected City Logistics (HCL) suggests an open and shared system associate with multi-modes transportation to meet the challenges of City Logistics (CL). A new application of Parcel lockers is suggested in this paper which is to be used as transhipment hubs besides the current popular utilization as ship/reception lockers. Transhipment could be easily processed through parcel lockers rather than building new specific transfer hubs which are cost consumption and normally away from demand nodes. We formulate the model from the perspective of Pick-up and Delivery Problem with Transhipment and Time-Window (PDPTTW) and propose Combine Saving heuristic for solving the PDPTTW. The heuristics has been evaluated by a set of examples and show a good performance.*

Keywords: *Hyperconnected City Logistics, Parcel lockers, Pick-up and Delivery Problem with transhipment, Combination Saving heuristic.*

1 Introduction

Growth in ecommerce has exploded the freight transport demands of both Business to Customers(B2C) and Customers to Customers(C2C) in urban areas. The new challenges for CL are not only the increasing numbers of parcels but also the high level of delivery service as well as the emphasis on environmental and societal requirements. To minimize travel distance and save travel time, various pick- up nodes and delivery nodes are encouraged to be combined in one vehicle trip to finish the job requests in hours rather than days especially in urban areas. The operation of CL is more complex than ever before. Hyperconnected City Logistics is an innovative concept to deal with the challenges which proposes an integrated, open and shared urban logistics network(Ballot, Montreuil et al. 2014, Crainic and Montreuil 2016). It enables a flexible transport system where job exchanging, flow merging as well as assets sharing could be new options for carriers through horizontal collaboration(Ballot, Montreuil et al. 2014). Under this concept, transhipments will be more frequently happened to enable collaboration. Therefore, the PDPTTW will be more highly suggested than the Pick-up and Delivery Problem with Time-Window (PDPTW) in HCL.

Open transfer hubs have been highly recommended as important elements which have the mission to enable the interconnection of multi-segments(Montreuil, Meller et al. 2010, Crainic and Montreuil 2016). Several initiatives have been explored to design the internal structure for such transfer hubs(Ballot, Montreuil et al. 2013, Meller, Montreuil et al. 2013, Walha, Bekrar et al. 2014). However, directly use some existing facilities may be more achievable than

building new ones. The recently popular parcel lockers around residences and business centres give alternative options for transhipment. The well-known utilization of parcel lockers is to ship/collect parcels by shippers/receivers, and has been successfully used in more than 20 countries(Deutsch and Golany 2018). This utilization is contributing to the elimination of unsuccessful deliveries as well as reducing delivery costs(Iwan, Kijewska et al. 2016). As far as we know, the utilization of parcel lockers is an interaction terminal between shippers and carriers or between carriers and receivers only till now. However, the parcel lockers have more potential for cost saving and efficiency improving in HCL. In this paper, we suggest another utilization of parcel lockers where they act as open transfer hubs for multi-segment connection. It means parcels could be temporarily stored in the parcel locker at the end of one segment carried by one carrier and collected by another carrier to continue the next segment.

From the perspective of optimization, the PDPTTW has drawn attention in recent years and has shown more value of cost saving(Oertel 2001) than the classic PDPTW. However, the studied transfer hubs in current models are normally separated from the pick-up and delivery nodes and involving very limited numbers owing to the computing complexity. In our model, transfers could be processed with the pick-up and delivery at the same time as long as there is an available parcel locker, rather than go to the specific transfer hubs. The disbursed location of parcel lockers can allow easy accessibility and more opportunities for transhipment.

2   Literature review

Under the concept of HCL, we identify two issues which should be examined here including the solution approach of PDPTTW as well as the meaning of parcel lockers.

2.1   Solution approach for PDPTTW

The PDPTTW is a well-known NP-hard problem(Shang and Cuff 1996, Kerivin, Lacroix et al. 2008, Takoudjou, Deschamps et al. 2012, Rais, Alvelos et al. 2014). The PDPTTW was first introduced by Shang and Cuff (1996) as a special case of the classical PDPTW where transfer between different vehicles is allowed in certain transhipment nodes. Contrary to the well-studied PDPTW, there are limited work exploring the PDPTTW. Besides inherited the NP-hard feature of PDPTW(Savelsbergh and Sol 1995), the PDPTTW is much more complex owing to the various transfer options(Qu and Bard 2012). It has been generally formulated using MIP models(Shang and Cuff 1996, Mues and Pickl 2005, Thangiah, Fergany et al. 2007, Cortés, Matamala et al. 2010, Qu and Bard 2012, Rais, Alvelos et al. 2014, Vornhusen, Wang et al. 2014, Hincapie-Potes and Lesmes-Ramirez 2018). Several MILP formulations are proposed as well for certain scenarios(Oertel 2001, Kerivin, Lacroix et al. 2008, Masson, Ropke et al. 2014). In terms of the solution approach of PDPTTW, a number of exact methods(Mues and Pickl 2005, Kerivin, Lacroix et al. 2008, Cortés, Matamala et al. 2010, Masson, Ropke et al. 2014, Rais, Alvelos et al. 2014, Vornhusen, Wang et al. 2014) have been explored however the solving ability is limited by the data size because of the complexity of the problem. Meanwhile, some heuristic methods have been applied(Shang and Cuff 1996, Oertel 2001, Mitrović-Minić and Laporte 2006, Gørtz, Nagarajan et al. 2009, Qu and Bard 2012, Takoudjou, Deschamps et al. 2012, Masson, Lehuédé et al. 2013, Masson, Lehuédé et al. 2013, Masson, Lehuédé et al. 2014, Danloup, Allaoui et al. 2018). A more detailed review of solution methods for PDPTTW is found in Danloup, Allaoui et al. (2018). From the current works, we find the dominant method to describe and develop the transhipment nodes into the PDPTW is to split the transhipment nodes into two parts – an inbound transfer vertex and an outbound transfer vertex(Cortés, Matamala et al. 2010, Qu and Bard 2012, Takoudjou, Deschamps et al. 2012, Masson, Lehuédé et al. 2013, Masson, Lehuédé et al. 2013, Masson, Lehuédé et al. 2014, Masson, Ropke et al.

2014). It can be noticed that the number of transhipment nodes in tested examples are normally limited to 1 and the location is separated from pick-up and delivery nodes in most current PDPTTW models. Shang and Cuff (1996) and Rais, Alvelos et al. (2014) attempt that transfer could occur at any node and solve the model for a limited data set. A summary of solution approach for the PDPTTW can be found in Table1.

From the review above, we could conclude that the existing works associated with solution methods for PDPTTW are restricted by the number of transhipment hubs. Further, the restriction is even stronger in some examples. We will address this gap in this paper.

Table 1: summary of solution approach for PDPTTW

Ref.	Method		Nb of P&D nodes	Nb of TH nodes	Location of TH.	
					Separate	Other
Shang and Cuff (1996)	Heuristic	Insertion	9	9		Any P&D nodes
Oertel (2001)	Heuristic	Tabu	43	2	*	
Mues and Pickl (2005)	Heuristic	Column Generation	140	1	*	
Mitrović-Minić and Laporte (2006)	Heuristic	Insertion	200	4	*	
Kerivin et al. (2008)	Exact method	Branch and cut	10	1	*	
Gørtz et al. (2009)	Heuristic		--	--	*	
Cortés et al. (2010)	Exact method	Branch and cut	12	1	*	
Qu and Bard (2012)	Heuristic	GRASP+LNS	50	1	*	
Takoudjou et al. (2012)	Heuristic	VND	50	1	*	
Masson et al. (2013a)	Heuristic	ALNS	198	5		Any D nodes
Masson et al. (2013b)	Heuristic	Insertion	--	--	*	
Masson et al. (2014a)	Heuristic	ALNS	198	5		Any D nodes
Masson et al. (2014b)	Exact method	Branch and cut and price	89	2		Any D nodes
Vornhusen et al. (2014)	Solver	Cplex	18	1	*	
Rais et al. (2014)	Solver	Gurobi	14	14		Any P&D nodes
Danloup et al. (2018)	Heuristic	Genetic Algorithm	50	1	*	

* GRASP	*Greedy Randomized Adaptive Search Procedure*	*LNS*	*Local Search Based method*
VND	*Variable Neighbourhood Descent*	*ALNS*	*Adaptive Large Neighbourhood Search*
P&D	*Pick-up and Delivery*	*TH*	*Transfer hub*

2.2 Studies for Parcel Lockers

Parcel lockers have begun to attract attention in recent years for their efficiency and convenience in last mile delivery. Several studies investigate the attitudes of e-commerce users towards parcel lockers in last mile delivery(Morganti, Seidel et al. 2014, Iwan, Kijewska et al. 2016, de Oliveira, Morganti et al. 2017). From the simulation test results, Punakivi, Yrjölä et al. (2001) argue that the reception box could contribute to an operation cost reduction of up to 60 percent which shows great potential of parcel lockers in last mile delivery. Conceptual development of how smart lockers used in hyperconnected network to facilitate the pick-up and delivery have been given by Faugere and Montreuil (2017). They propose an optimization model to design the smart locker bank with a suitable size. An optimization model is proposed by Sitek and Wikarek (2017) considering that parcel lockers provide alternative options for delivery point. Deutsch and Golany (2018) propose a 0-1 integer linear model to explore the parcel lockers' location problem.

As far as we know, the current focus of the utilization of parcel lockers is on the smart collection box. There is no proposal and research work regarding parcel lockers being used as transfer hubs in PDPTTW networks.

3   Problem definition

As discussed before, HCL is far more flexible than traditional logistics networks owing to a large number of opportunities for jobs exchange by transhipment. We define the PDPTTW model the same with that depicted in Shang and Cuff (1996) as they proposed transhipment were allowed at any pick-up/delivery node. Besides, we should pay attention to the transhipment capacity at parcel lockers as the space of each parcel lockers is usually limited.

This PDPTTW can be notated by a graph G (N, A) with N denotes the node set and A denotes the arc set. The node set N includes a set of job requests as well as a depot denoted as o. Each job request associated with a pair of nodes - p_n and d_n, denote the pickup node and the corresponding delivery node respectively. Each node p_n/d_n has a service time window $[e_n, l_n]$. Which should be noticed is that, when there is a parcel locker in shipper/receiver's node, the face to face service can be replaced by parcel lockers, therefore, both customers and carriers do not have to attend the interaction but finish the interaction through parcel lockers instead. One obvious benefit is that the service time window will be not that restricted and can be extended for the reason that it just needs an earliest time for pick up node and a latest time for delivery node of each job request in reality. With this consideration, the model will extend the time window automatically where there is a parcel locker in the node. Let T (T $\subseteq (p_n \cup d_n)$) be the set of transhipment nodes with parcel lockers available for transfer. The arc set A includes all feasible links between nodes. The capacity of each parcel locker is C. The objective is to minimize the cost of travel distance as well as the number of used vehicles.

4   Solution approach

The idea of combination saving was first proposed by Clarke and Wright (1964) which is one of the most famous heuristics for the VRP. We developed the Combination Saving I (CSI) and Combination Saving II (CSII) heuristics for the PDPTW and the PDPTTW respectively.

4.1 CSI for the PDPTW

The procedure of CSI shows as follows:

Step 1: initial solution
Generate an initial set of routes: a set of initial routes are generated with one job request per route. e.g. route r: $o - p_n - d_n - o$.

Step 2: route combination without transhipment (CNT)
For any two routes, using Insertion Method* to combine them into a new route.

Step 3: routes set update
The most saving new route from all the possible combined new routes will be a new route. Delete the choosed two routes and add the new one.

Step 4: repeat step 2 until there is no feasible combination.

* Insertion Method

This Insertion Method is inspired by the famous Insertion Heuristic in VRPT(Solomon 1987), the difference is the target which is going to be inserted is not a single node but a trip combined by several nodes. Therefore, Insertion Method here associated with two entire routes denoted by R_1 and R_2 (in order to have a brief description, depot node is descluded from R_1 and R_2 here). We need to insert all nodes of R_2 into R_1 and make sure constraints including the nodes sequence in R_2 as well as time windows of nodes in both R_1 and R_2 not be violated. Let's denote the numbers of nodes in R_1 and R_2 are N_1 and N_2 respectively. For the first node n_2^1 of R_2, there are $N_1 + 1$ potential positions could insert. The set of insertion positions denoted as P_1. When n_2^1 inserted at position p ($p \in P_1$), check the time window for n_2^1 as well as the rest nodes of R_1 (nodes following n_2^1 to the end). The checking detail can be found in Solomon (1987). Keep all feasible routes and the corresponding inserted position. For the following nodes of R_2, there are $N_2^I + N_1 - p + 1$ potential positions could insert where N_2^I is the number of nodes of R_2 has already been inserted into R_1 and p is the inserted position of the last inserted node. Execute check time window and keep all feasible routes as well as the corresponding inserted position. Do node insertion till all nodes of R_2 are inserted into R_1. Finally, choose the shortest distance route as the combined new route.

4.2 CSII for the PDPTTW

CSII allows transhipment between routes. In CSI, the combination happens like this - one route is inserted into another single route (CNT). In CSII, we will introduce another type of combination – combination with transhipment (CWT). Where one route is inserted into another two routes, therefore, a transhipement will happen in a cross node which divides the inserted route into two parts. The procedure of CSII shows as follows.

Step 1: initial solution
Generate an initial set of routes: a set of initial routes are generated with one job request per route. e.g. route r: $o - p_n - d_n - o$.

Step 2: route combination
Step 2.1: executive CNT. Keep the most cost saving solution and total saving value denoted as saving1.
Step 2.2: executive CWT*. Keep the most cost saving solution and total saving value denoted as saving2.
Step 2.3: compare saving1 and saving2, keep the maximum one and update route set.
Step 3: repeat step 2 till no feasible combination.

* CWT

- Choose: choose three routes R_1, R_2, R_3 (in order to have a brief description, depot node is descluded from $R_1, R_2 \ and \ R_3$ here), the task is to insert R_1 into R_2 and R_3. Before insertion, it must be make sure that R_1 includes at least one node with parcel lockers so that transhipment is available in this route.
- Divide: if there is already a transhipment node in R_1, then this transhipment node is still the only cross node and divide R_1 from here (see Figure1.1). Also should check that there is enough transhipment capacity in this cross node. If there is no transhipment node in R_1, then each node with a parcel locker with enough transhipment capacity could be a cross node for division (see Figure1.2). One notice is that both the after divided parts must contain at least two nodes respectively, as there is no need to transhipment for an empty vehicle.
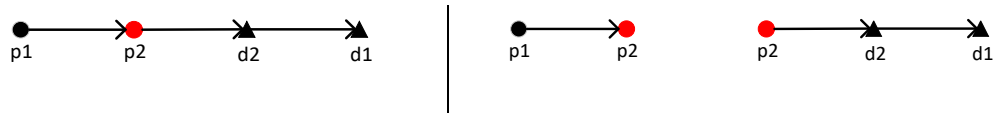
Figure 1.1
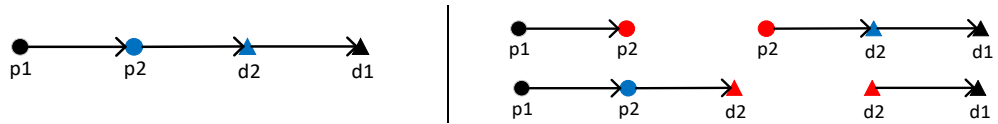
Figure 1.2

- Insertion: for every possible division, insert the after divided two parts in to R_2 and R_3. Each division has two possible groups of insertion (shows in Figure 2). Keep the most saving one.
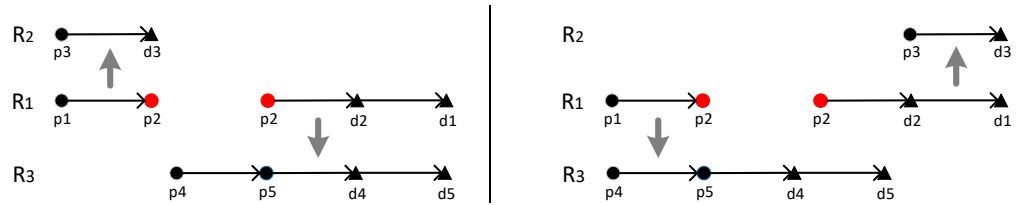
Figure 2

Circles denote pick-up nodes. Triangles denote delivery nodes. Red nodes (including circles and triangles) are transhipment nodes. Blue nodes (including circles and triangles) are nodes where their is a parcel locker.

5   Results and Discussion

For computational results analysis, we used python 3.6 to develop and code for both CSI and CSII. All the programs run on a HP desktop with an Intel core i7 2.70 GHz processor and 16GB RAM. The performance of CSI and CSII was evaluated through three types of data examples: a. example from Shang and Cuff (1996). b. examples from the PDPTW benchmark given by Li and Lim (2003). c. repaired job requests of Li and Lim (2003)'s benchmark example.

- Result of example from Shang and Cuff (1996)

Table 2. Resluts of example from Shang and Cuff (1996)

	Travel time	No. vechicles	Tardiness
Shang and Cuff (1996)	45.8	4.1	1.12
CSI	20.75	7	0
CSII	17.4	5	0

In the sample from Shang and Cuff (1996), travel time between two nodes are given instead of giving travel distance which we will use more frequently in the following evaluation. As travel time and travel distance are linear correlation. We use the travel time as the criteria for evaluation in this sample as well. The result shows that total travel time has been decreased and no delay from both CSI and CSII. However, with a small increase of vehicle number. This data set includes 9 nodes associated with 159 job requests, which means a large number of job requests share the same nodes even the same arcs. It is not a very common scenario in CL in reality. Therefore, we use data sets of the PDPTW benchmark examples from Li and Lim (2003) to have a further test as nodes in those examples are separated with each other.

- Resluts of the PDPTW benchmark examples

We use 10 100-cases with random distribution nodes to evaluate CSI and CSII. We still assume that transfer could occur at any node and extend the time window correspondingly when using CSII for the PDPTTW owe to the benefits of no attendance service by parcel lockers. In order to make the known variables in the two scenarios keep the same. We extend the time window when using CSI as well. The capacity of parcel lockers is assumed to be the same with capacity of vehicle given by the examples. The compute results show in Table 3. Besides, Figure 3.1-3.2 display the routes of one benchmark example (lr110) given by CSI and CSII to give a clearer understanding. There are 5 examples show better results (considering both distance and number of vehicles) by **CSII** than **CSI**.

Table 3. Resluts of the benchmark examples comparision

	Benchmark		**CSI**		**CSII**		
	Distance	Route Nb.	Distance	Route Nb.	Distance	Route Nb.	Transfer Nb.
lr101	1651	19	1233	12	1235	11	2
lr102	1487	17	1255	10	1243	10	1
lr103	1292	13	1074	7	1034	7	3
lr104	1013	9	944	7	988	6	3
lr105	1377	14	1180	10	1150	10	2
lr106	1252	12	1084	9	1077	8	2
lr107	1111	10	1037	8	1064	8	4
lr108	969	9	848	5	912	6	3
lr109	1209	11	1110	9	1140	10	6
lr110	1159	10	969	7	1001	7	3
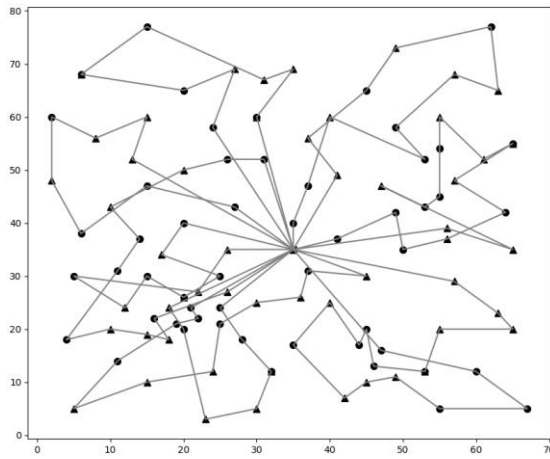
Figure 3.1 Result of **CSI** (lr110)   Figure 3.2 Result of **CSII** (lr110)
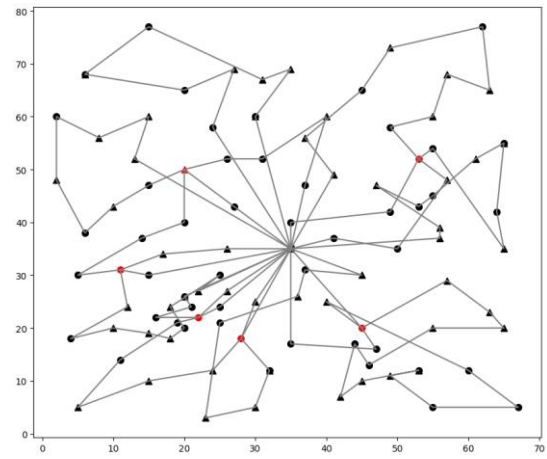
- Results of repaired job requests

It can be noticed that pick-up and delivery nodes of one job request are normally clustered in the same area in data sets of Li and Lim (2003) even in the random distribution nodes cases. The travel distance of each job request is quite limited. In fact, the freight transport in urban areas are usually pick-up from one zone and delivery to another zone rather than centred in the same zone. Therefore, we repair the nodes of their data sets in order to disperse the origin and destination nodes of the same one job request. The rule when doing nodes repair is that choose the farthest node (delivery node) from the first node (pick-up node) in the current nodes set, pair them as a new job request. Remove them from the current node set. Then repeat. We randomly choose 5 10-job requests examples, 5 20-job requests examples, 5 30-job requests examples as well as one 50-job requests examples to test. Assume all job requests share a uniform time window [0, 200]. The results show in table 4. Similarly, Figure 4.1 - 4.2 display the routes of one example (10-2) given by CSI and CSII to give a clearer understanding. It can be found that among the tested 21 examples, **CSII** performs better than **CSI** in 18 examples, one example achieves a same result by both **CSII** and **CSI**, and **CSI** gives better result in two examples.

Table 4. Resluts of repaired job requests examples comparision

	CSI		**CSII**		
	Distance	Route Nb.	Distance	Route Nb.	Transfer Nb.
5-1	569	3	462	2	1
5-2	545	3	520	3	2
5-3	429	2	424	2	2
5-4	368	2	338	2	1
5-5	246	2	246	2	0
10-1	404	2	385	2	1
10-2	499	3	407	2	2
10-3	400	2	383	2	2
10-4	431	2	425	2	1
10-5	365	2	323	2	1
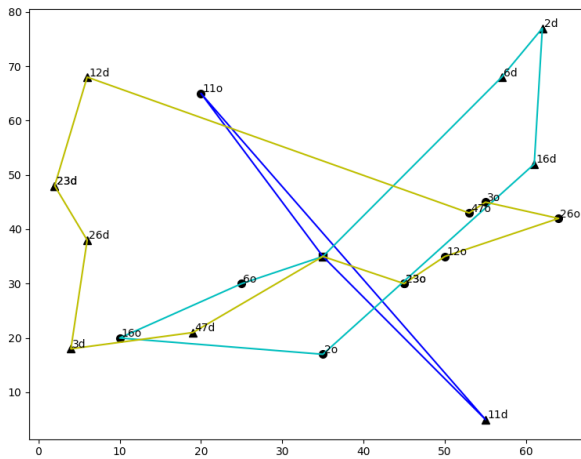
Figure 4.1 Result of **CSI** (10-2)
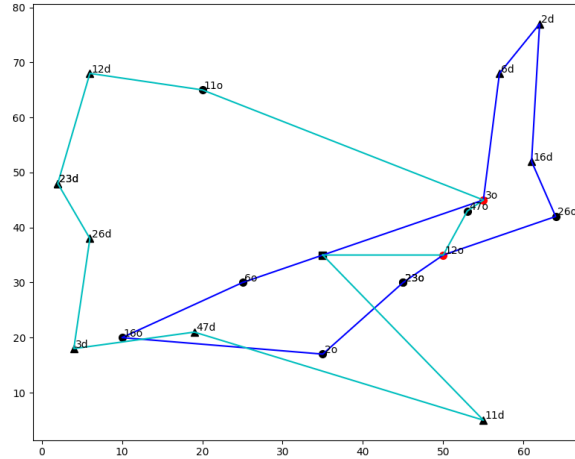
Figure 4.2 Result of CSII (10-2)

6 Conclusion

This paper is an initiative to propose a novel utilization of Parcel lockers to implement the concept of HCL. From the general picture, it has been frequently suggested that horizontal collaboration is the way to benefit city logistics in many decisions (economical, technical, environmental and societal). From the operation perspective, it has been evaluated that transhipment could contribute to the PDPTW. However, no work has made a link of the two sides. We suggest parcel lockers to be the medium to fill this gap. We formulate the model from the perspective of PDPTTW which is an attractive optimize problem draws attentions in recent years. In the proposed model, parcel lockers are used as not only the ship/reception boxes for customers but also the transhipment hubs for carriers. This new utilization for parcel lockers provides a practical and easily achievable opportunity for transhipment realization in pick-up and delivery routes. Further, they are also the important hubs where trips sharing occurs in HCL. Regarding to the computing complexity of PDPTTW, we propose a Combination Saving heuristic (**CSII)** to enable the PDPTTW model solved with unlimited transhipment nodes and test it through three types of examples including both small and large data sets. The solution approach shows a good performance till now. And from the different comparisons, it can be concluded that **CSII** works better than **CSI** especially in examples when origin and destination of jobs requests are dispersed.

In the next stage, our work will talk about more on collaboration oppertunity. Multi-modes sharing is another important objective following this work under the concept of HCL. Furthermore, financial costs including Parcel Locer fees(incorporating capital as well as operating costs) would need to be considered in future modelling.

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On the Potentials and Dilemmas of Cooperative/White-Label Deliveries based on Selected Austrian Demonstration Cases

Matthias Prandtstetter[1], Benjamin Biesinger[1], Bin Hu[1], Pamela Nolz[1], Martin Reinthaler[1], Jürgen Zajicek[1], Alessandra Angelini[2], Georg Hauger[2], Matthias Steinbauer[3], Johannes Braith[4], Reinhold Schodl[5], Sandra Eitler[5]

1. AIT Austrian Institute of Technology, Vienna, Austria
2. Technische Universität Wien, Center of Transportation System Planning, Vienna, Austria
3. Variocube GmbH, Linz, Austria
4. StoreMe GmbH, Vienna, Austria
5. Fachhochschule des bfi Wien, Vienna, Austria

Corresponding author: matthias.prandtstetter@ait.ac.at

Abstract: One of the main pillars of the Physical Internet (PI) is cooperation. One possible form of cooperation in freight transportation is bundling. As soon as bundling is in focus, we have to think about locations where this bundling might take place, which are, normally, hubs. So, the main idea would be that different freight carriers meet at a specific hub and exchange their freight according to some (clever) planning such that redundancies in trips are overcome. E.g., instead of two carriers serving regions A and B, they cooperate such that the first carrier only has to serve region A and the other one only has to serve area B. Even though the general idea is quite clear, details are sometimes more complicated. In this paper, potentials and dilemmas related to cooperative delivery models based on the observations made in selected Austrian case studies are outlined.

Keywords: white-label deliveries, cooperation, hub, parcel distribution, parcel lockers

1   Introduction

The main concepts of the *Physical Internet* (PI) (Montreuil, 2011) are easy to understand: cooperate and collaborate. However, there are many pitfalls to overcome in order to establish "the" PI. As recent efforts show (cf. contributions to the IPIC conference series) extensive research has been carried out specifically aimed at contributing to the realization of the PI in the transport system. However, there are a lot more works which are not specifically targeting at the PI itself but at concepts and developments which are building the basis of the PI considering the transportation network, cf. Markvica (2019). Not so obvious, but nevertheless important, work "at the basis" is provided when having closer looks at the organization of transportation and logistical processes, cf., among others, Veeraraghavan and Scheller-Wolf (2008), Pérez Rivera and Mes (2016). Finally, there are even some best practices (e.g., the ETC Gateway Services or Brabant Intermodal Joint Venture) which are demonstrating the potential of the PI in real-world settings, cf. Putz and Prandtstetter (2015). Nevertheless, "the" PI is not yet applied on a large scale.

The contribution of this paper is twofold: On the one hand, the paper presents four selected Austrian demonstration cases of developments in the logistics sector which are fully in-line with the PI concepts (although they are not targeted to be PI developments). On the other hand,

potentials and dilemmas are extracted as observed at exactly these four presented best practice examples.

The remainder of the paper is organized as follows: In the next section, we will shortly outline the four selected Austrian research and application projects building the basis of this study. Then, some cooperation models in the freight transportation sector will be explained, including the currently hot-topic of white-label distribution. In Section 4, the potential of the presented cooperation models will be discussed while Section 5 will focus on the dilemmas associated therewith. Section 6 will summarize the paper with conclusions.

2   Selected Austrian Demonstration Cases

The work presented herein is based on the observations and conclusions drawn in the four Austrian research and application projects EMILIA, GrazLog, KoopHubs and alBOX. In the following, we will present the four main contributing projects in more detail.

2.1   EMILIA

The EMILA (Electric Mobility for Innovative freight Logistics In Austria) project mainly focused on the integration of electric vehicles into logistics operations. The main application areas were a) parcel delivery and b) distribution of goods from groceries. In the field of parcel deliveries, the main focus was laid on establishing a city hub which is fed by a large(r) (conventional) truck and which was used as a distribution base for (cargo) bike logistics. The distribution of groceries mainly focused on a dynamic distribution concept where customers are guaranteed to receive their last-minute order within the next X minutes.

In the city hub scenario, the main challenge was to solve a classical vehicle routing problem, i.e., which parcel to deliver along which tour in which order. However, additionally, a two-echelon problem was required to be solved since in some cases a direct distribution of some parcels by the trucks serving the city hub might be more efficient (e.g. because of less cargo handling). Furthermore, the parcel deliveries of the trucks to the city hub (for further fine distribution by the cargo bikes) need to be synchronized with the cargo bikes as the storage space at the city hub is (strongly) limited (Nolz et al., 2018). The city hub of the EMILIA project has been established in 2016 and successfully operated by DPD throughout the project runtime (and beyond), cf. Nolz et al. (2017), Nolz et al. (2018).

The use case focusing on the deliveries of goods from groceries was different in that sense that most of the orders were known in advance by the groceries. However, some last-minute orders had to be fulfilled within the next X minutes. This implies that pre-planned tours had to be dynamically adapted. Contrary to the parcel deliveries, the groceries could be picked-up at any cooperating store meaning that maybe only small detours are necessary (Nolz et al., 2017).

2.2   GrazLog

The GrazLog project focuses on the implementation of a common consolidation center for all deliveries towards the inner city of Graz, Austria. The main idea is to apply bundling on the very last mile such that only a limited number of (parcel) carriers has to enter the pedestrian zones. In particular, this means that all delivery services are redirected towards the consolidation center where all parcels are collected and resorted such that finally only dedicated vehicles enter the pedestrian zones at specific times. Due to the applied bundling, the number of vehicles entering the pedestrian zones can be reduced. In addition, the first delivery rate can be significantly increased since on the inbound site of the consolidation center the opening hours are kept quite generous (e.g. 7am-7pm). On the outbound site, delivery tours are planned

according to the time windows specified by the recipients. Due to the (relatively) small area to be served by the consolidation center direct communication with the recipients is possible.

2.3   KoopHubs

In contrast to the GrazLog and EMILIA projects, the KoopHubs project is focusing more on the social potential of a city hub. Instead of providing a consolidation center solely, the city hub concept is extended in that sense that additional services (e.g., coffee shop, workshop, exchange platform, etc.) are offered at the city hub. These additional services shall convert the pure logistical atmosphere of the city hub towards a social meeting point.

2.4   alBOX

The alBOX project is giving prior attention on the parcel delivery and logistical processes within the parcel distribution. The main idea is to implement white-label pick-up station/parcel lockers in urban and rural areas using this infrastructure as delivery points for all parcel services. Costumer can receive their parcel from the parcel locker. Obviously, the mentioned pick-up stations have to be equipped with the corresponding technologies which are mainly tamper-proof lockers and a terminal for un/locking the depositing boxes.

Within this project, two pick-up stations are installed: one parcel locker in an apartment building in the densely populated 5th district of Vienna (AUT), the other one at the public town square in a small village on the Austrian countryside. During the usability check (acceptance study) and in a continuous dialogue-process data is generated. Based on the received data, customized services are provided (e.g. cross-selling, use of the parcel locker for sharing activity within the community) and the efficient flow of goods, services and information is designed.

The main focus of alBOX is laid on investigating how the acceptance by the users (costumer, parcel services etc.) differs and which business models are profitable and accepted by the different user groups.

3   Cooperation Models

As already outline in the Introduction, cooperation is one of the key concepts of the PI. Of course, cooperation has also to be applied in the context of last-mile deliveries. In this context, we distinguish mainly two cooperation areas: The first one is related to the actual last-mile transport while the second one is related to the transshipment.

3.1   Cooperative Distribution

It is well known, that in parcel logistics the (very) last-mile is the actual expensive part of the transport chain (Boyer et al., 2011). This is, among others, reasoned in the fact that bundling effects are not so large for last-mile deliveries. Even more, the efficiency is heavily dependent on the density of the customers (Boyer et al., 2011). Therefore, one goal should be to increase customer density along the last-mile. This can be achieved through cooperation and collaboration.

- **parallel distribution**
  In the parallel distribution setup, the main concept is that two (or more) carriers are using a hub as interchange point of e.g. parcels (or goods in general). At the hub, they exchange parcels such that each carrier increases the customer density along his tour(s). This is basically achieved by the idea that the original (large) area is split into two and one supplier is serving all customers (from both suppliers) in the first area while the

second supplier serves all other customers (from both suppliers) in the other area. The main challenge with this setup is to find the optimal split of the large area.

- **singular distribution**

  In the singular distribution setup, all carriers bring their goods to the hub but only one carrier is then delivering all goods in the whole area. Obviously, the customer density is increased along the last-mile delivery and therefore efficiency is increased too. However, the supplier servicing this area must provide enough capacity. Further, all suppliers delivering only to the hub have to pay for the last-mile delivery.

- **white-label distribution**

  In white-label distribution, the setup is quite similar to singular distribution but the last mile, i.e. the deliveries after consolidating at the hub, are done by a third-party provider, i.e. a company which is none of the freight carriers delivering parcels to the hub (e.g. municipal services). The charming part of this cooperation model is that competition among parcel suppliers is still fair since positive marketing effects (e.g. through labeled cars driving around) are not existent for all operators. The white-label service might be paid by the original suppliers, by the recipient and/or by the municipality (or other public bodies).

Although many variations of cooperation models can be classified according to these three main classes, it is also necessary to talk about the cooperation model with respect to the hub/consolidation center itself:

- **cooperative hub**

  The hub could be operated by all utilizing freight carriers. Costs have to be shared accordingly. Obviously, this setup is, however, the most challenging one as decision making has to be achieved via compromises and therefore (a lot of) negotiations.

- **single-operator hub**

  In this model, only one of the freight carriers is operating the hub while all others are just "customers" to the hub. This setup will be very likely chosen in combination with the singular distribution setup. Like the singular distribution setup, the other suppliers have to pay for the services and the provided infrastructure.

- **white-label hub**

  In the white-label hub setup, the hub is operated by a third-party provider and all freight carriers are customer to it.

Note, that even though some combinations of hub and distribution setups are common in practice (e.g. singular hub and singular distribution; white-label hub and white-label distribution), any combination of cooperation models is possible.

4 Potentials

When coming to the point of potentials, it can be stated that cooperation always is related to (new) opportunities and therefore high potentials are involved. However, to be more precise, let us investigate a small thought experiment: Under the assumption that two carriers cooperate for the very last mile in an area. Let us further assume that both carriers have approximately the same geographical distribution area of parcels to deliver. Then, the obvious approach would be to split the area into two regions A and B and the first carrier delivers all parcels (from both carriers) to region A while the second carrier delivers all parcels to region B. Obviously, both carriers have benefits as the customer density is significantly increased leading to more stops in less time/distance and therefore a higher (monetary) benefit. High cost-effectiveness is further achieved by the decrease of transport and handling time as well as time-efficient

planning of overall resources (personal, vehicles, infrastructure). That is, from a pure business economic view, we are facing a win-win situation. However, and we think that the real potential is contained herein, we have to consider the macroeconomic view as well.

As already stated, for both carriers the distance traveled is significantly reduced which can be directly transferred into an estimation of greenhouse gas emission reductions (under the assumption that conventional delivery vehicles are incorporated). Furthermore, the number of vehicles on the road (and of course also searching for parking spots) is reduced which has a positive effect on the transportation system (high level of service) as well as the livability in the region, too. In addition, one has to keep in mind that due to the increased customer density especially economical unviable regions such as rural areas are becoming more interesting for parcel suppliers leading (on a long term) to improve service quality and gain high vehicle utilization.

To sum this up, we conclude that cooperation in (very) last-mile delivery leads to a win-win-win situation and – from this point of view – should be fostered.

5 Dilemmas

Although the benefits gathered through bundling as explained in the previous section are enormous, one has to keep in mind that there are also some drawbacks and challenges related with cooperative and especially white-label logistics. In the following, we list experiences and observations obtained in various research projects:

- Especially in case of parcel distribution, we made the experience that (almost) all carriers are willing to deliver parcels of other carriers (if the service is paid). However, the willingness to give its own parcels for services with another carrier is rather low. The main reason mentioned is that service quality cannot be guaranteed. Complaints are, however, not stated towards the delivering carrier but to the original carrier instructed by the shipper.
- Service quality as negotiated with the customers (the actual senders of the parcels) cannot be guaranteed unless a strong legal contractual set of agreements has been agreed on. However, this set of agreements has to be negotiated on a bilateral basis among all cooperating carriers. Obviously, this might be quite challenging.
- A further aspect related with cooperative services is the transfer of liability. Obviously, it is necessary to document all transfers on a full basis. Especially in case of damages or losses it is essential to trace the causer. Nevertheless, it is very likely that the primary carrier (which is the contract partner of the shipper) is associated with the loss. This bad image was already discussed in the first point.
- Analogously, complaints related to the service (e.g. lateness, damage, etc.) will most probably addressed to the primary freight carrier and not to the last-mile distributor. Full tracking and tracing is necessary to identify the responsible carrier for the actual degraded service.
- The freight carriers (or at least some of them) are not (or only reduced) visible on the road (due to long haul services only) which leads to a decreased marketing. This might lead to additional costs with respect to advertising.
- Whenever cooperation of competing companies is part of a business model the question arises whether price agreements are undertaken which, obviously, have negative effects on the final customer (e.g. the price is increased, or the service quality is decreased). Therefore, the competition authority has to approve the cooperation(s). Due to current

rapid developments in the parcel service market, it is very likely that many and maybe long-lasting examinations and evaluations have to be performed.

- Complex optimization approaches are necessary in order to make sure that equity and fairness among the freight carriers is given. This is especially the case, when the distribution among the cooperating carriers is not obvious, e.g., one area with high demand and another area with low demand.

- In case of business models where the hub might be used as a final deposit address (and the end customer has to pick-up the parcel at the hub personally), it is not sure that the positive effect of reduction of greenhouse gas emissions is still given. Although the first delivery rate can be significantly increased (to the maximum of 100% if all parcels are delivered to the pick-up station only), all recipients have to drive to the pick-up station in the worst case. This results in a hub-and-spoke-like approach which finally leads to more greenhouse gas emissions than a classical delivery tour. However, we have to keep in mind that for those recipients where the first delivery would have not been successful, the greenhouse gas emissions are reduced. More detailed examinations with respect to this (potential) impact will be carried out throughout further experiments in the alBOX project.

6 Conclusions

As outlined above, there are potentials but also challenges of cooperative and especially white-label distribution concepts. The final question is, however, whether the opportunities and potentials are higher than the risks and drawbacks. As two of the four mentioned projects are going to apply the discussed cooperative delivery models in real-world settings, we expect to get valuable input data on that topic for further investigation. As a first estimation, we have to state that most of the dilemmas mentioned are related to topics like trust, legal framework and distortion of competition (especially towards medium and small carriers).

With respect to (forbidden) market arrangements, one has to access, however, the ratio of additional costs (e.g. due to (quasi) monopoly positions) over saved costs (e.g. due to positive bundling effects). If this ratio is below 1, i.e. the savings are higher than the extra costs, the overall impact would still be positive. Especially due to the climatic situation of our planet and the need to meet the climate goals as agreed on in various global climate conferences, one has to think twice whether even a ration above 1 is a show-stopper.

Finally, we want to highlight that the proposed concept of cooperative (very) last-mile deliveries is a win-win-win situation, i.e. all cooperating carriers (cost and time saving) as well as customers (added value) and environment (reduction of greenhouse gas emissions) are experiencing positive effects. Nevertheless, one big question still remains upright, which is "Why is the willingness to cooperate so low?". Although we have no answer to this question, we think that the main challenge (for cooperative deliveries as well as the PI as a whole) is trust among competing companies. Therefore, we think that further work related on "how to overcome confidence issues" is of high importance and the PI community should intensify efforts to drive forwards on this topic within the next years.

Acknowledgements

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Parcel Lockers for B2B Distribution in Central Business Districts

Russell Thompson[1], Lele Zhang[2], Michael Stokoe[3] and Hadi Ghaderi[4]

[1]Department of Infrastructure Engineering, The University of Melbourne, Parkville, Australia
[2]School of Mathematics and Statistics, The University of Melbourne, Parkville, Australia
[3]Sydney Coordination Office, Transport for NSW, Sydney, Australia
[4]Department of Business Technology and Entrepreneurship, Swinburne University of Technology, Hawthorn, Australia
Corresponding author: rgthom@unimelb.edu.au

Abstract: E-commerce has led to more small parcels being shipped between businesses in metropolitan and CBD areas. Courier routes in large metropolitan areas are inefficient due to the long stem distances and prevalence of courier companies only operating from a single depot.
This paper presents a model for estimating the benefits in terms of reduced distances travelled by courier vans when a shared system utilising parcel lockers is used for CBD based deliveries. The model was used to predict the savings in distances travelled by courier vans when operating in a shared system utilising parcel lockers. Substantial savings in travel distances were estimated that would reduce vehicle operating costs as well as improving sustainability.

Keywords: Parcel lockers; couriers; hyperconnected city logistics; multiple modes.

1 Introduction

Parcel lockers provide many benefits for last kilometre deliveries. This paper describes the development of tools for designing and evaluating networks of shared parcel lockers for Business-to-Business (B2B) courier deliveries to Central Business Districts (CBDs). Using principles associated with the physical internet such as shared and collaborative networks this paper describes how various modes (including walking and bikes) can be integrated to reduce the financial and environmental costs of delivering and collecting parcels.

E-commerce has created many challenges for urban distribution systems. Businesses in CBDs often request delivery of small consignments at diverse locations. The growth in parcel deliveries to offices and retailers in CBDs, with traditional delivery modes, is leading to more traffic congestion in central city areas. Increased pedestrianised areas, competition for parking spaces and disruption due to construction activities is creating substantial efficiency and sustainability challenges for couriers.

City planners are increasingly looking to design cities for "people and places" and less for cars/vehicles. Construction traffic is one of several disruptors and in the scheme of things it has a short-term impact in a particular location. While the challenges for effective management of urban freight are increasingly dynamic and complex, the applications of collaborative transport and logistics promise enormous benefits in tackling the inherent efficiencies exist in distribution of goods in cities. In particular, in the light of rapid growth in the implementation of data analytics and Internet of Things (IoT) practices within transportation context, the opportunities for development of sustainable and cost-effective city logistics models which benefit from shared resources are limitless. Given the soaring demand for such approaches, this paper proposes a model to evaluate the savings in terms of distance travelled by courier vans when a system of shared parcel lockers is utilised for CBD based deliveries.

2   Hyperconnected city logistics

Hyperconnected City Logistics (HCL) is an emerging concept based on the physical internet that involves improved management of goods in urban areas using transfer facilities such as loading docks and parcel lockers (Crainic and Motreuil, 2016). HCL consists of an integrated network of consolidated containers, transhipment nodes and delivery means using a shared network of nodes, that can include Urban Consolidation Centres (UCCs) and Cross Docking Centres (CDCs) as locations for shared parcel lockers.

Information requirements for designing HCL networks include determining the:
(i)   ideal location, size and function of nodes,

(ii) capacity: in terms of types of vehicles servicing nodes, and

(iii) equipment for transferring containers.

The information requirements for network operations relate to developing schedules (frequency and timing) to coordinate transport services.

3   Parcel lockers

Parcel lockers are traditionally associated with e-commerce as a viable alternative to home deliveries for B2C consignments. The Benefits, particularly in reducing futile home deliveries are welcome by couriers and can be substantial (Iwan et al., 2016). E-commerce, especially B2B, continues to grow at increasing rates, and there is a need to develop more efficient and sustainable processes to cater for the rising levels of demand and provide high levels of service. Parcel lockers provide a flexible option for transferring goods between different modes within the courier process of B2B deliveries and they can provide substantial financial savings for carriers as well as social and environmental benefits (Thompson and Taniguchi, 2015).

The supply of parcel lockers relates to the location of banks as well as the number and size of lockers within them. Models are required to determine the best location for locker banks including sites near offices and shops. To maximize the potential of parcel locker systems for improving the efficiency and sustainability of last kilometre freight it will be important that open systems are created where lockers can be shared by multiple logistics organizations. Shared parcel locker systems allow integrated multi-modal B2B logistics networks to be created.

Parcel lockers provide an opportunity to transfer goods between modes and logistics partners. Trucks and vans can be used to carry parcels to locker banks and these can then be picked up by couriers to delivery to the final customers within a precinct or area of the CBD. Walking and cycling can often be more productive in conducting deliveries in central city areas. The courier hub facility in Sydney has a set of lockers that can be used to exchange goods between carriers and vehicle modes (Stokoe, 2017).

4   Networks

4.1   Courier networks

Existing courier networks typically involve each courier acting independently and performing routes to pick up parcels from all the origins of their customers tasks in the outer area and then undertaking a tour to drop off parcels to all the destinations of their customers in the inner area (See Figure 1).
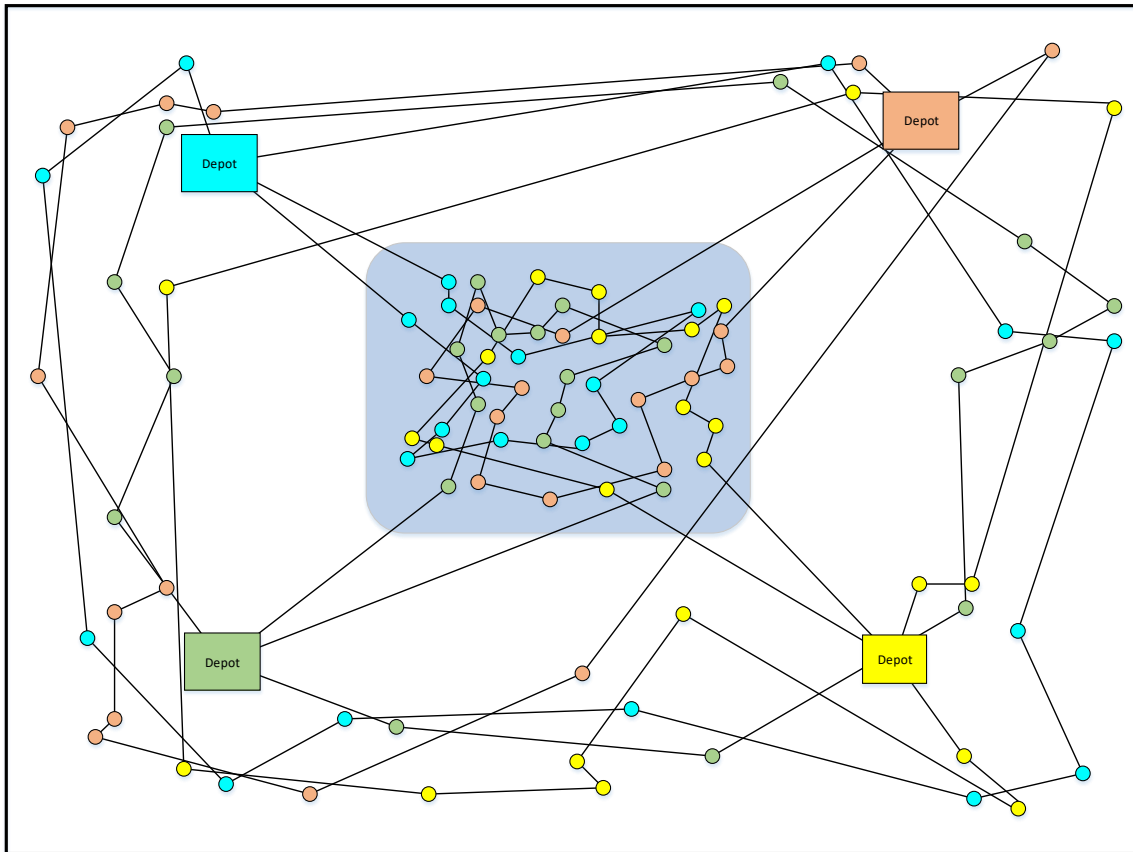
Figure 1: Existing CBD courier network

4.2 Hyperconnected city logistics (HCL) based networks

Within an HCL network each courier can participate in a joint service. This can involve performing a route to pick up parcels from all origins of customers tasks near their depot as well as delivering them to a locker bank located near or within the CBD, and then undertaking a route from this locker bank to deliver to nearby receivers in the inner area (See Figure 2).
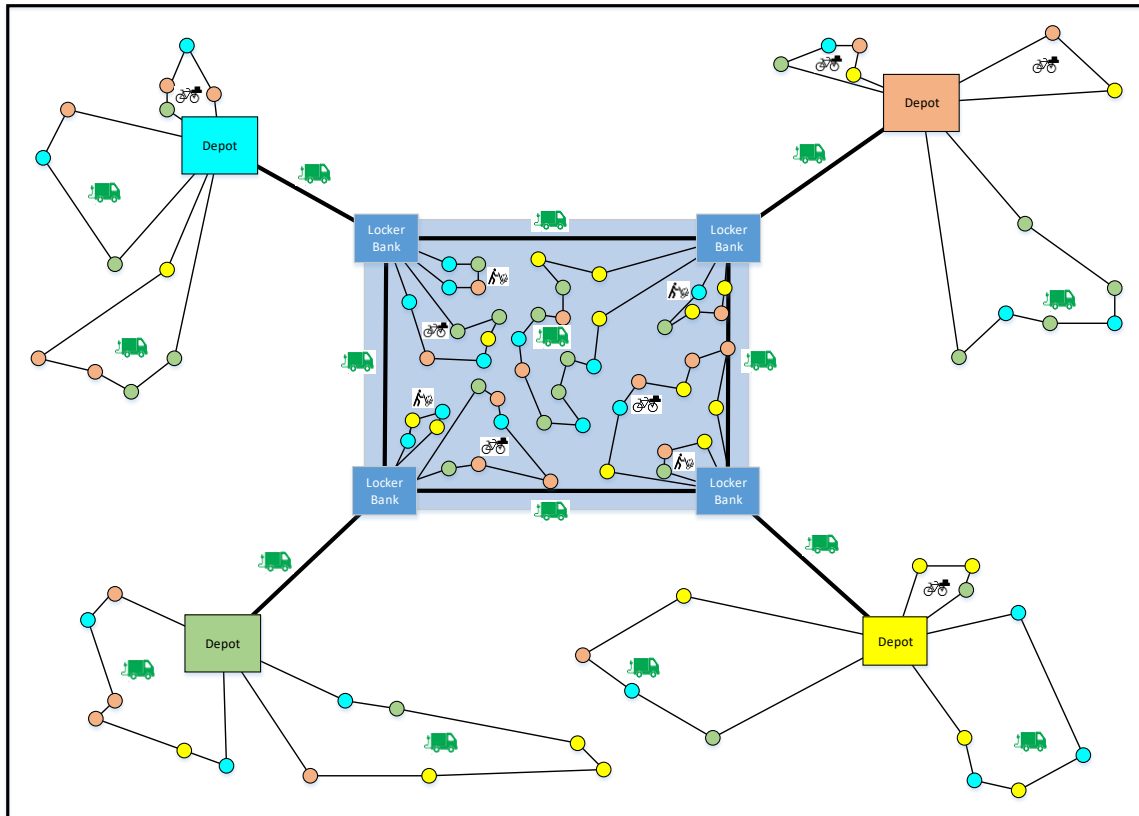
Figure 2: Potential HCL CBD courier network with parcel lockers

5   Model development

A model was developed to estimate the savings in distance travelled using a shared parcel locker system. A hypothetical urban area of 20km x 20km consisting of 25 zones (each 4km x 4km) and a centrally located CBD (1km x 1km) consisting of 25 zones (each 200m x 200m) was used (Figure 3). Each of the four courier companies has one depot located in one corner of the urban region (triangles in Figure 3). Parcel pickups are from within the urban area and drop-offs within the CBD (Green square in centre of Figure 3).

Distances to and from zones were calculated using the Manhattan distance between the location of depots and centroids of zones. A continuous approximation model was used to estimate the distances travelled while performing the pick-up and drop-off routes within zones (Daganzo, 1984).

The daily demand for each courier was 400 customers with an average of 1.5 parcels per customer. The capacity of courier vans was set at 30 parcels.
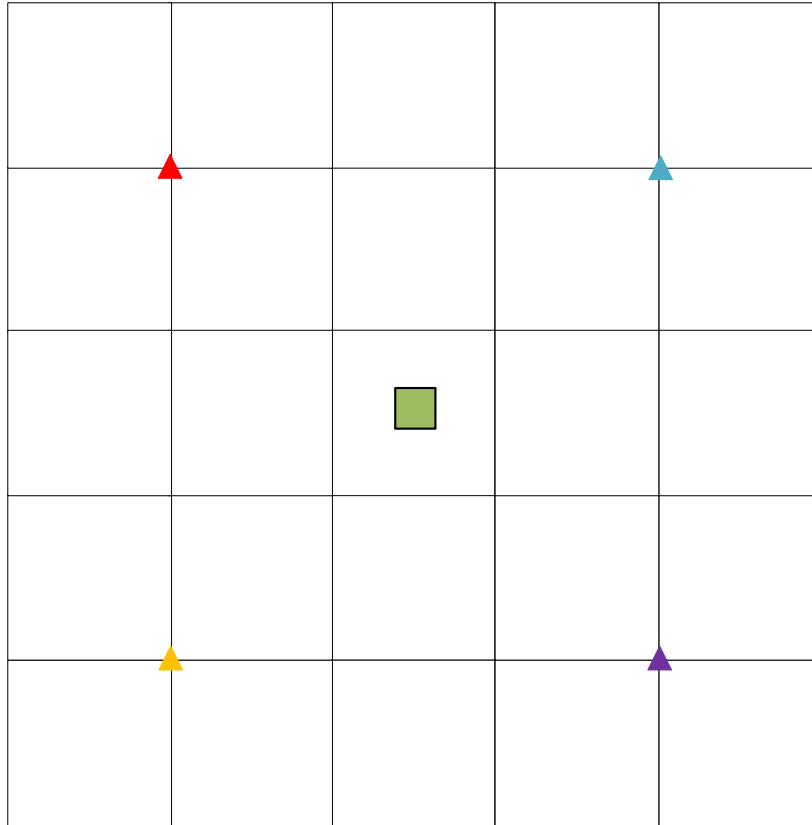
Figure 3: Metropolitan area and CBD

5.1 Estimation process

The model for estimating the distances travelled by vehicles requires data relating to the demand and capacity of vehicles as input. The number and size of zones for courier routes were then determined based on vehicle capacity. The number of vehicle routes within a specified time period is then determined.

The time taken to complete routes consists of loading/unloading times at the depot, service times at each customer, travel times between the depot and customers as well travel times between customers. Parameters used are shown in Table 1.

Table 1: Route parameters

Average vehicle speed: Urban area (km/h)	40
Average vehicle speed: CBD area (km/h)	30
service time at each customer (min.)	2
Walking between vehicle & customers (min.)	2
Loading/Unloading of vehicle at depot (min.)	30

5.2 Independent networks

As a base case, each courier company was assumed to operate separate routes for picking up and delivering parcels throughout the urban area. Pickup routes involve courier vans travelling from their depot to shippers within the urban area and then returning to their depot with parcels. Drop-off routes involve courier vans delivering parcels from their depot to receivers in the CBD.

Demand was presumed to be uniformly distributed within the urban area, allowing each van to perform one pickup route within each urban zone. Based on the distances travelled for each route, some drivers could undertake multiple routes within a four-hour shift. The total distance travelled for pickup routes for each driver shift for each delivery company was estimated to be 928km with a combined total of 3,712km for all the four courier companies (Table 2). Based on average speed of 40km/h for courier vans and a maximum route time (including driving and servicing times) of 4 hours it was estimated that a total of 13 driver shifts would be required to undertake the pickup routes within the urban area to each depot.

Vans were also assigned drop off routes within the CBD zone. Demand was assumed to be uniformly distributed within the 25 CBD zones, with each van having sufficient capacity to complete all the parcel drop-offs within a CBD zone in one route. However, due to the long steam distance of the drop-off routes between the depots and the CBD zones, only 2 routes for each van could be completed within a four-hour period. Thus 13 driver shifts are required for each courier company to perform the parcel drop-offs from their depot to the CBD zones.

5.3 Shared parcel locker networks

The shared system involves each courier company picking up parcels from urban zones near their depot (Figure 4), transferring the parcels from their depot to locker banks in the CBD and then conducting drop-off routes from the parcel lockers to customers in the CBD zones.
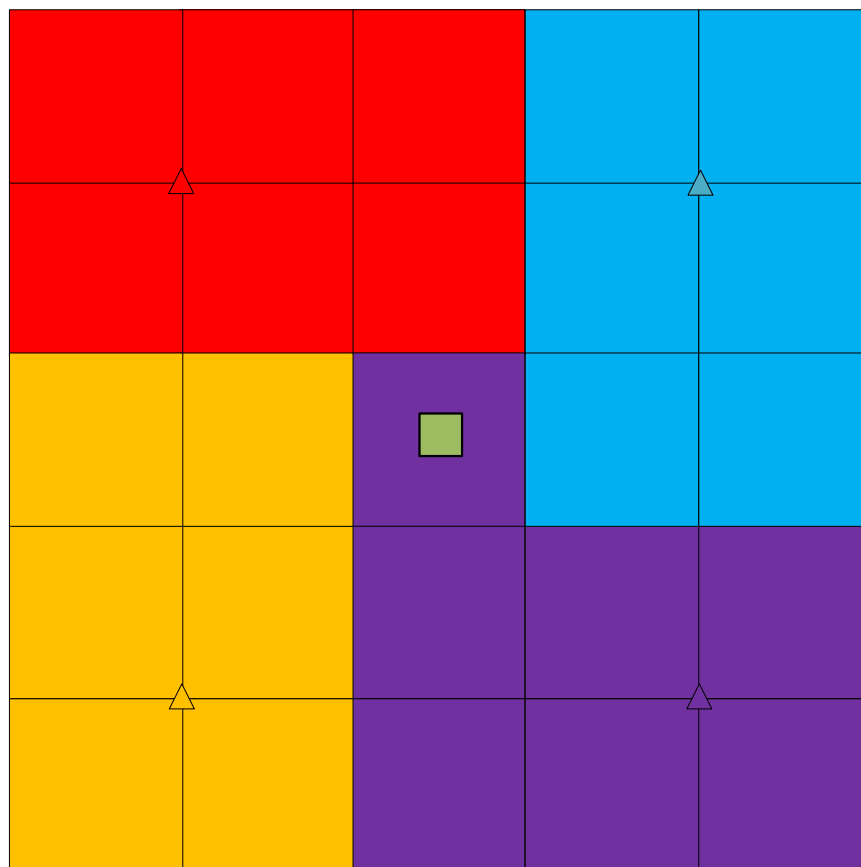
Figure 4: Local Pick-up zones for shared system

Vehicles from each depot perform a shuttle between depots and the 4 parcel locker banks within the CBD area. Parcels are transported to the parcel locker that in close proximity to each drop-off customer. Parcels are then distributed to customers in the CBD zones from the parcel locker

banks. The shared system involves each courier company conducting drop-off routes from one of the parcel locker banks to 6 or 7 CBD zones near each locker bank. The capacity of the vans allows 1 route to be undertaken for each CBD zone.

A summary of the distances travelled by vans for both the independent and shared networks are shown in Table 2. Considerable savings in total distances travelled by van are achieved using a shared system.

Table 2: Distances for courier routes

	Independent (km)	Shared (km)	Saving (km)	Saving (%)
Pickup → Depot Metro Area	3712.0	528.0	3184.0	85.8
Dropoff → CBD Area	2447.2	505.8	1941.4	79.3
TOTAL	6159.2	1033.8	5125.4	83.2

For the independent system, 13 vehicles are required for driver shifts with multiple routes for metropolitan pick-up routes as well as deliveries to the CBD zones based on maximum route duration of 4 hours.

For the shared system, 13 vehicles are also required for driver shifts with multiple metropolitan pick-up routes, however 5 vehicles are required to perform the shuttle service between each depot and each parcel locker within a three-hour period, therefore a total of 20 vehicles from each courier company is required. Only 4 vehicles are required for driver shifts for routes from each parcel locker.

Considering the number of parcel lockers at each locker bank, since there is only 1 route from each parcel locker to each CBD zone to drop-off parcels, all parcels must be at the locker bank before the CBD drop-off routes can be commenced. Thus, each locker bank needs to be able to accommodate 600 parcels (1/4 of the total demand) and requires an area of 60m^3 if parcels are on average 0.1m^3. This is equivalent to a moderate sized room (e.g. 5m x 4m x 3m).

6   Conclusions and future work

A shared courier distribution system for delivering small parcels from a metropolitan area to a CBD utilising locker banks has been evaluated. A model was used to estimate the savings in distances travelled by vehicles. Overall the shared system was predicted to substantially reduce vehicle operating costs as well as improve sustainability.

The shared courier system introduced in this paper could be varied to consider utilising non-motorised transport modes, especially within the CBD area. This would change the times required to undertake deliveries. The model could also be used to investigate how much less travel distance would be achieved if larger vans or trucks were used for the shuttle between depots and parcel lockers.

It would be useful to incorporate financial modelling to consider the potential revenue and costs associated with setting up and operating the locker banks.

The model could also be extended to minimise the total costs for both carriers as well as locker bank owners and managers considering synchronisation of vehicle arrivals and departures from locker banks to reduce the number of lockers required. This would involve the shuttle runs feeding locker banks from depots. Further studies could also investigate the potential savings in joint delivery of parcels between couriers within urban and CBD areas. The implementation

of such practices by couriers could potentially unlock significant benefits in terms of distribution costs and lower number of vehicles used for performing the same task.

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Integrating passenger and freight transport via public transport-based crowdshipping for sustainable last-mile deliveries

Edoardo Marcucci[1,2], Valerio Gatta[2], Marialisa Nigro[2], Michela Le Pira[3], and Michele Simoni[4]

1. Molde University College, Molde, Norway
2. Università degli Studi Roma Tre, Roma, Italy
3. Università degli Studi di Catania, Catania, Italy
4. University of Texas at Austin, Austin, USA

Corresponding author: valerio.gatta@uniroma3.it

Abstract: This paper discusses a shared mobility service that combines passenger and freight transport. Crowdshipping, in fact, implies delivering goods (freight) via the crowd (passengers). Any trip people perform to fulfil individual objectives can, in principle, be transformed shipping freight service too by using the free load capacity passengers have when moving from A to B. If widely developed this could provide a substantial contribution to reduce transport externalities by avoiding dedicated freight trips. This paper discusses both feasibility and behavioural issues with the intent of diffusing its deployment in urban areas. It does so by presenting some recent research advances related to the study of both demand (i.e. buyers) and supply (providers, i.e. crowdshippers) and discussing the main impacts this solution might have from an environmental and an economic point of view. In particular, it focuses on a particularly environmental-friendly crowdshipping service. The service considered assumes using a city mass transit network where customers/crowdshippers pick-up/drop-off goods via automated parcel lockers located either inside the transit stations or in their surroundings. Crowdshipping can play a crucial role in relieving cities from transport-related negative externalities by promoting the sharing economy and Physical Internet paradigm aiming for a shared, hyper connected, sustainable and efficient last-mile logistics.

Keywords: urban freight transport, sharing economy, sustainable mobility, behavioural analysis, city logistics innovation, Physical Internet, stated preference, scenario analysis.

1 Introduction

Demand for mobility is continuously rising in cities due to concurring urban and logistics sprawl. The coinciding peaking of passenger and freight transport demand aggravates negative externalities affecting urban dwellers' health and welfare (Krzyzanowski et al., 2005). Moreover, emerging trends, among which e-commerce plays a key role, are generating a substantial demand for fast, efficient, low-cost and environmentally friendly delivery services. This is not easy to achieve. In fact, additional freight demand is causing an increase of the social and environmental costs urban freight distribution generates (Taniguchi et al., 2016). Researchers have proposed different innovative urban freight transport solutions to increase both efficiency and sustainability (Quak, 2008; Marcucci and Gatta, 2017). Among these, solutions adopting the emergent socio-economic "sharing economy" paradigm are of particular

interest. In fact, they have the potential to revolutionize the current economic system based on individualism and consumerism (Rifkin, 2014).

Information and communication technologies (ICT) will support the affirmation of sharing both economy by making new opportunities available for citizens and businesses. Transport-related initiatives in this realm go under the name of shared mobility among which one can recall, among others, car sharing, carpooling, and ridesharing. While recognizing its innovative stance to promote its actual deployment and acceptance one has to investigate under which conditions would people accept the new emerging business model (Ravenelle, 2016).

This paper illustrates and discusses an innovative shared-mobility service that pools passenger and freight transport together. The peculiar focus is on the necessary pre-requisites that one needs to satisfy to make crowdshipping, i.e. delivering goods via the crowd (McKinnon, 2016), successfully implemented. In fact, one can transform any trip people perform to satisfy personal objectives in a freight transport service by using the available spare load capacity each individual typically has. The idea rests on the consideration that one could stimulate a better use of currently unused transport capacity to reduce transport externalities while performing the same amount of deliveries (Bubner et al., 2014).

This approach is fully compliant with the Physical Internet (PI) paradigm and objectives. In fact, the innovative service this paper discusses aims at supporting the creation of a collaborative and robust physical "network of logistics networks". This, in turn, will contribute to standardized parcels shipment optimization while satisfying customer requirements, optimizing operator and customer economic models while minimizing environmental footprint. The service proposed is compatible with existing routing protocols, interoperability and traceability standards, remuneration rules, compensation mechanisms and new trade configurations (Ballot et al., 2014).

E-commerce market growth fosters crowdshipping up-scaling potential (McKinnon, 2016). The last leg of delivery is also the most appropriate section of the e-commerce supply chain where crowdshipping might prove both applicable and useful. In fact, most of the goods are small in size and light in weight, allowing the "crowd" of commuters to act as a last-mile vector (Gatta et al., 2019a). The last decade has witnessed a noticeable increase of crowdshipping services and its diffusion around the world has been substantial. Some platforms use algorithms to match delivery requests with crowdshippers' trip availability. Others let crowdshippers post their offers on a virtual billboard (supply) allowing a possible sender to buy their service (demand) (Marcucci et al., 2017b).

Despite crowdshipping intrinsic potential, initiatives are still struggling in gaining a wider market share when it comes to urban freight transport (McKinnon, 2016). A critical review of urban crowdshipping initiatives offers a set of interesting suggestions with respect to possible success/failure elements. For example, Marcucci et al. (2017b) discovered a strong link between crowdshipping success and people's awareness/perception of sustainability issues implying a willingness to make an effort to solve them.

Furthermore, for crowdshipping to prove socially beneficial one should develop it as an "environmental-friendly" service. The best option to do so is to transform dedicated into non-dedicated trips based on the consideration that the least polluting trip is the one not performed. It is thus necessary to investigate delivery models that can make use of commuters' trips that would be performed anyhow so to avoid generating additional ones (Serafini et al., 2018). It is appropriate to focus on commuters' trips since they are typically frequent and predictable.

The paper critically discusses feasibility and behavioural levers that might foster crowdshipping diffusion in urban areas. This is performed by presenting recent research advances related to the study of both demand (i.e. receivers buying this service) and supply (those who actually perform the service, i.e. crowdshippers) with a focus on the main impacts the solution proposed would have from and an environmental and an economic point of view. In particular, it delves on an environmental-friendly crowdshipping based on the use of a city mass transit network where customers/crowdshippers pick-up/drop-off goods by use of automated parcel lockers (APL) located either inside the transit stations or in their surroundings. Crowdshippers are passengers that would use the transit network anyhow for other activities (e.g., home-to-work), and their delivery activities would not induce additional trips. The idea is to involve people using public transport which, on average, impose lower environmental and congestion costs on society while also allowing for freight deliver within the city in a timely and efficient fashion. In other words, each APL is the final location where parcels are dropped off by the crowdshipper and picked up by the receiver. Therefore, the APL network represents a PI for which appropriate strategic and operational decisions must be taken (Raviv and Tenzer, 2018).

The paper illustrates results related to three main crowdshipping issues:

(1) *supply* - under which circumstances passengers would consider acting as crowdshippers (Marcucci et al., 2017b; Serafini et al., 2018; Gatta et al., 2019b);

(2) *demand* - under which conditions people might consider receiving goods via a crowdshipping service (Marcucci et al., 2017b; Gatta et al., 2019b);

(3) *potential impacts* - what would be the likely implications the solution proposed might have from an economic and environmental perspective (Gatta et al., 2019a).

The potential adoption of the innovative solutions considered made use of stated preference (SP) and discrete choice modelling (DCM). This allows for robust analyses of different crowdshipping future scenarios and the associated main impacts. A hybrid dynamic traffic simulation model constitutes the base for teasing out the macroscopic traffic features (triggering of congestion, queue spillbacks and interactions with traffic signals) in combination with the microscopic features of delivery operations (delivery vehicles are tracked along their routes) so to realistically account for last-mile delivery operations.

The case study is the city of Rome (Italy) characterized by a population of 3 million people performing around 700,000 thousand trips during the morning peak, and where approximately 32,700 vehicles are daily used to perform more than 35,000 loading/unloading operations in the city centre (Gatta et al., 2019b).

This paragraph describes the structure of the paper. Section 2 reports a state of the art literature review on crowdshipping initiatives. Section 3 focuses on the case study, by first illustrating results from a preliminary investigation, focusing on University students, to acquire the necessary knowledge base for developing the full-fledged SP research endeavour (3.1). Subsequently the paper discusses the SP results for both supply (3.2) and demand (3.3). Section 4 concentrates on an evaluation of the potential impacts of this solution from an economic and environmental point of view (4.1) while also presenting the next research step based on a hybrid dynamic traffic simulation approach capable of reproducing the macroscopic features of traffic in combination with the microscopic features of delivery operations (4.2). Section 5 concludes.

2   Crowdshipping analysis

The last decade has witnessed a substantial increase and diffusion of crowdshipping around the world (Figure 24). E-commerce market growth strengthens crowdshipping up-scaling potential. Crowdshippers, entrusted to move goods from senders to recipients, are the key actor. They deliver freight and typically operate on a freelance basis. A citizen, travelling from point A to B, becomes a crowdshipper when agreeing to carry some items for others along her trip. Sender, recipient and crowdshipper typically connect and interact through an online platform. Some platforms use algorithms to match delivery requests with crowdshippers' trip availability. Alternatively, crowdshippers post their offers on a virtual billboard (supply) and wait for a possible sender to buy the service they offer (demand). In principle, crowdshipping is a win-win solution. In fact, sender and recipient both save money thanks to lower transport costs while the crowdshipper obtains a reimbursement. Despite crowdshipping potential, some initiatives are still struggling to gain a wider market share in urban freight transportation while a non-negligible number of initiatives failed soon after inception. A critical review of urban crowdshipping initiatives stimulates some interesting reflections with respect to possible success/failure elements to investigate in further detail. For example, crowdshipping strongly depends on people's awareness/perception of sustainability issues and their willingness to make an effort to solve them.
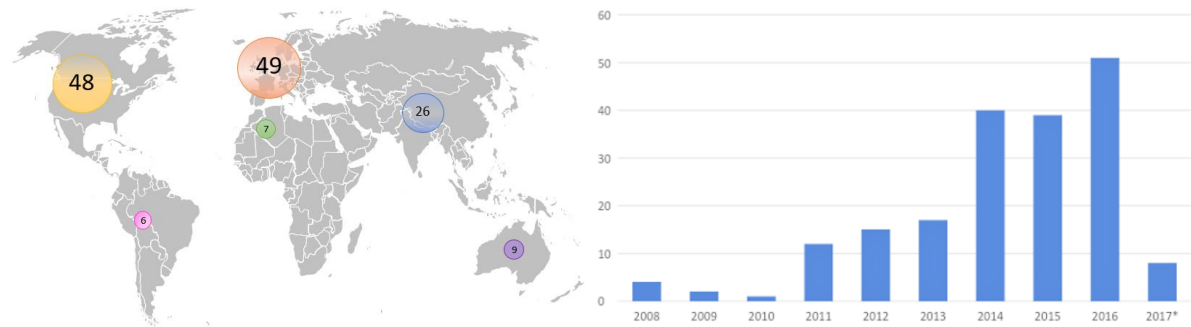
Figure 24: Geographical and temporal distribution of crowdshipping initiatives (Marcucci et al., 2017a,b)

McKinnon (2016) identifies six crowdshipping characteristics, namely:

1) Customer base: crowdshipping can cater for all delivery types: customer to customer (C2C), business to customer (B2C), customer to business (C2B), business to business (B2B). C2C and B2C are the most frequent crowdshipping business models. Both sender and recipient are private actors in C2C while recipient's counterpart is typically a shop in B2C.

2) Pricing: the most common pricing model allows couriers the freedom to bid for deliveries. Customers enter parcel delivery details (e.g. origin, destination, maximum amount they are prepared to pay for delivery). Couriers bid for the work by competing on delivery time and cost. Rates can be predetermined and stable within cities.

3) Distance range: crowdshipping is predominantly an urban phenomenon.

4) Travel type: crowdshipping inception relied on people carrying packages for others on trips they were already making, however, nowadays it this might also imply performing trips just to deliver a given package. Especially in the first case described above, maximum travel deviation from the original path is critical.

5) Commodity: platforms accept shipping almost any non-hazardous freight, while individual couriers decide how big/heavy a consignment can be. Typically, the weight limits are 23kg

(50lb) by car and 14kg (30lb) by bicycle. *Postmates*, for example, has so far concentrated on food deliveries by building a crowdshipping platform capable of handling a broad range of products.

6) <u>Transport mode</u>: some platforms heavily rely on motorized deliveries, while others have perform deliveries by bicycle.

Table 9 reports a numerical analysis of 90 crowdshipping initiatives using the six characteristics previously discussed on the base of the work of Marcucci et al. (2017a).

Table 9: Crowdshipping initiative analysis (based on Marcucci et al., 2017a)

Classification of 90 initiatives based on Mc Kinnon's six characteristics											
Customer base		*Pricing*		*Distance range*		*Travel type*		*Transport mode*		*Commodity*	
C2C	34	Freedom to quote	63	Internat.	33	Non-dedicated	61	All	33	Freight	66
B2C	32	Fixed rates	27	National/ Internat.	5	Dedicated	22	Air transport	30	Food	8
C2C+ B2C	22			Urban/ Internat.	4	Both	7	Motorized transport	13	Freight and animals	6
B2B	1			National	10			Public and Private	7	Freight with weight and value restrict.	4
C2C+ B2C+ B2B	1			National/ Urban	4			Private	6	Freight and Passenger	4
				Urban	26			Non-motorized transport	1	Waste	2
				All	6						
				Unknown	2						

The recent increase in crowdshipping initiatives worldwide has attracted academic researchers' attention who started investigating this subject looking both at service characteristics and at the underlying optimization problems. Most studies focus on alternative business models (Rougès and Montreuil, 2014), while little is known about crowdshipping users' and buyers' behaviour and perception. With only few exceptions (e.g. Paloheimo et al., 2016), limited are the works investigating crowdshipping externalities implications. Table 10 reports a selection of the recent literature on crowdshipping based on Gatta et al. (2019b).

Table 10: Literature review (based on Gatta et al., 2019b)

Author(s)	Topic	Methods	Main Findings
Archetti et al. (2016)	Problem of Walkmart using a fleet of capacitated vehicles and drivers to perform deliveries and occasional drivers seeking to minimize the costs of satisfying demand	Multi-start heuristic to solve the Vehicle Routing Problem with Occasional Drivers	Employing occasional drivers may produce significant benefits especially if coupled with an appropriate compensation scheme
Behrend and Meisel (2018)	Analysis of a platform combining shipping requests with community members' planned trips	Three optimization models, two heuristics, a decomposition scheme and a graph-theory based method	Benefit of integrating item-sharing and crowdshipping as a function of crowdshippers' detour flexibility and compensations
Yildiz and Savelsbergh (2019)	crowd-sourced transportation for on-demand meal delivery	stylized equilibrium model for analysing service coverage and delivery capacity design	Quantification of the impact of courier non-compliance and assessment of the benefit of supplementing crowd-sourced delivery capacity
Punel and Stathopoulos (2017)	Investigation of delivery scenarios performed by non-professional shippers compared to traditional shipping options	stated choice experiments and discrete choice models (Multinomial Logit and Mixed Logit models)	Insights into the attributes affecting preferences for goods delivery performed via occasional drivers
Punel et al. (2018)	Analysis of how and to what extent attitudes, preferences, and characteristics of crowdshipping users differ from non-users	Web-based survey - proportional t-test analysis and binary logit model	Crowdshipping is more prevalent among young people, men, and full-time employed individuals and urban areas are preferential
Buldeo Rai et al. (2017)	State of practice of crowdshipping	Systematic literature analysis + interviews with logistics practitioners	Three characteristics affect crowdshipping sustainability: third party involvement, crowd motivation, and its modal choice

Below we present some results from recent research papers. The innovation in research relates to the joint investigation of both crowdshipping demand and supply. The focus is on preferences and on the environmental sustainability of the service, which is supposed to rely on public transportation. Finally, we present a comparative evaluation among different scenarios.

3 Investigating the potential of crowdshipping in Rome

The analysis focuses on Rome. The city has a population of 3 million people performing around 700,000 thousand trips during the morning peak. Approximately 32,700 vehicles perform more than 35,000 loading/unloading operations in the city centre (Gatta et al., 2019b). Crowdshipping initiatives in Rome are still few and mainly linked to the food sector. The all imply performing dedicated trips. Foodora, for instance, delivers food from restaurants to homes, and Take my things/LoPortoPerTe that recently joined forces plan start operating soon in Rome.

Marcucci et al. (2017b) perform a preliminary investigation with respect to the underlying motivations that can facilitate and/or hinder the deployment/diffusion of a crowdshipping initiative in Rome. A more robust evaluation made use of SP and DCM. A SP experiment implies defining several choice sets, each involving two or more alternatives, described by several attributes with two or more levels. Each respondent chooses one of the options presented in the choice set according to her preferences. The core component is the statistical design used to construct the choice sets. The underlying idea is to investigate the relative influence the independent variables (attributes) have on a given observed phenomenon (choice). DCM adopts random utility theory to model SP respondents' choices. Microeconomics assumes rational agents maximise utility. The latter comprises both a deterministic and a stochastic component. Different assumptions about the distribution of the stochastic term imply different DCM models. The simplest model is the multinomial logit (MNL) (Ben-Akiva and Lerman, 1985).

3.1 Preliminary investigation

Marcucci et al. (2017b) investigate the main characteristics of an innovative crowdshipping initiative in Rome. Pursuing this aim, they administer a questionnaire to approximately 200 students enrolled at Roma Tre University. Students can be considered, in general, "early adopters/providers". The questionnaire has two parts. The first investigate under which conditions would students agree to carry freight according to crowdshipping principles. In particular, a typical crowdshipper profile is elaborated along with the necessary conditions that would induce a student to become a crowdshipper. Moreover, the questionnaire delves on which are the preferred locations where to exchange freight between actors and the preferred transport modes. The second part enquires students' preferences for receiving deliveries from a crowdshipper so to study and classify their main concerns.

The sample includes 90 females and 100 males with an average age of 24 years. The majority was not familiar with crowdshipping, and no one had ever operated as a crowdshipper before.

The most important result is the overall positive attitude towards crowdshipping. In fact, 87% of the students stated their willingness to act as crowdshippers. However, depending on the following conditions, the percentage decreases to: (i) 55% if package is not of small dimension (i.e. shoebox); (ii) 40% if remuneration is between 1€ and 5€ (3% up to 3€); (iii) 25% if both of the above. In general, the inclination is slightly higher for men and for people who most frequently buy online.

On the other hand, 93% would accept to receive goods via a crowdshipping service. Also in this case, the percentage drastically decreases to: (i) 18% if customers cannot contact the crowdshipping company; (ii) 16% if there is no direct contact with the crowdshipper; (iii) 14% if no package tracking is possible/available. No one judges crowdshipping an outright "bad idea". Women are more likely to receive goods via crowdshipping.

As it is for the supply side, the most important condition for participating relates to remuneration. On average, the students interviewed would like to earn 5-10€ per delivery. Existing working initiatives usually provide an average remuneration of 2-4€ with a substantial differences depending on the geographical area. The reason why many students overestimate the possible economic gain per delivery is most likely due to the weak understanding of the real aim of crowdshipping. Moreover, students do not often consider that they must perform a given trip anyway and consequently overestimate the true effort the delivery implies. Apart from remuneration, interviewees are willing to act as crowdshippers as long as, on average: no deviation requires more than 15 minutes from a regular trip, or implies more than 2.5 km, or more than 2 additional stops on a regular trip. Additionally, crowdshippers prefer to preserve their privacy and, in general, are unwilling to be traced (57%). Finally, they generally require a proof of crowdshipping sustainability to support it and this relates to its social sustainability.

The results obtained represent a good starting point for a deeper and wider behavioural analysis, aimed at investigating the social and economic acceptability of alternative crowdshipping solutions and the elements/policies needed to produce the required behavioural shift.

3.2 SP survey to investigate supply

Serafini et al. (2018) use SP to identify the most important features associated with the choice of acting as a crowdshipper and DCM to study the underlying behaviour. The SP scenarios refer to the city of Rome and its metro network assuming B2C deliveries. The paper assumes packages can be picked-up/dropped-off in APL located either inside metro stations or in their surroundings. Initially, parcels are delivered in the terminal stations of the metro lines. These represent the origin points in order to start the parcel movements by crowd shippers. In that sense, terminal stations work as transit points where freight is deconsolidated in order to be moved from standard vehicles to "green solutions", i.e. the crowd. Considering such distribution approach, the restocking type model to be followed is a one to one model (from station to station) where the metro user can substitute the usual courier. It has to be noted as the first destination of the parcel would not be also the final destination, while the parcel can be moved between different APLs by different crowd shippers until it reaches the final destination, i.e. the metro station where the user would like to pick up the good.

Data were collected by administering 240 interviews to metro users in the city of Rome. Using hypothetical crowdshipping service's features, the survey investigates the role location of delivery/pickup points (inside metro stations or outside metro stations/adjacent buildings), remuneration (1 or 3 €/delivery), delivery booking (real-time or off-line) and alternative bank crediting modes (single delivery or every 5 deliveries) have in stimulating people to act as crowdshippers. Remuneration was set considering current shipping costs in the B2C market and the rates applied by existing national crowdshipping companies; the "delivery booking" feature mimics the high/low flexibility the crowdshipper might have in reacting to an on-line delivery request.

One notes with respect to the maximum deviation from the usual path that about half of the potential crowdshippers (43.1%) is not willing to modify the path if the APL is outside the metro stations while 39.2% would walk a maximum of 300 m. Only 15.3% is willing to travel an additional distance of 600 m, while the percentage of those willing to travel more than 600m

is negligible (Gatta et al., 2019b). Further investigations on this feature will require inserting a value of time in the modelling approach, depending on socio-economic parameters and characteristics of the trip (length, time, purpose) to refine the willingness to be a crowdshipper.

An MNL was estimated using three independent choices: option A, option B, and "no choice" (as in the SP scenarios). The estimation process adopted a maximum likelihood two-stage approach[19].

APL location is the attribute with the greatest impact while delivery booking the smallest. Having APL inside the metro stations instead of outside is more important than the remuneration (considering the range used in the survey: 1–3€/delivery). Real-time booking is preferred with respect to the off-line option. However, this characteristic is less important than others suggesting that people need to get organized to produce the crowdshipping service using public transport.

Explorative estimation exercises have considered the "not interested" option in the model. Preliminary results suggest that introducing the "not interested" option provokes other attributes (e.g. green attitude) to become statistically significant. Specifically, a stronger green attitude contributes to the choice of one of the two alternatives of being a crowdshipper. Moreover, the survey includes a question to test whether respondents focus more carefully on a specific feature with respect to others. It was possible to identify four types of respondents: the "basic" interested in the bank credit mode in order to obtain an immediate gain, the "static" concerned in the location of APL inside the metro stations, the "dynamic" attentive in higher remuneration, the "flexible" focused on real time booking.

MNL results allowed estimating the probability of choosing each alternative assuming different service specifications and potential crowdshipper characteristics (Figure 25). As far as the characteristics of the service are concerned, the paper considers all possible combinations of the investigated features, while for the "no choice" scenarios, the age attribute is fixed. Specifically, the paper considers three possible profiles assuming different crowdshippers' age:

• Profile 1: considers a crowdshipper aged 50 representing the average age of the population in Rome ("Pop. Roma");

• Profile 2: assumes a young population with an average age of 25 ("Young people");

• Profile 3: focuses on an elderly population with an average age of 65 ("Old people").

Impacts largely depend on the proposed service conditions (level of service). It is interesting to observe also a variability of the probability of acting as a crowdshipper as a function of individual characteristics. This variability is small between the profiles representing the population of Rome and the young people, while it is evident with respect to the elderly.

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[19] Please refer to Serafini et al., 2018 for more details about the process and results.
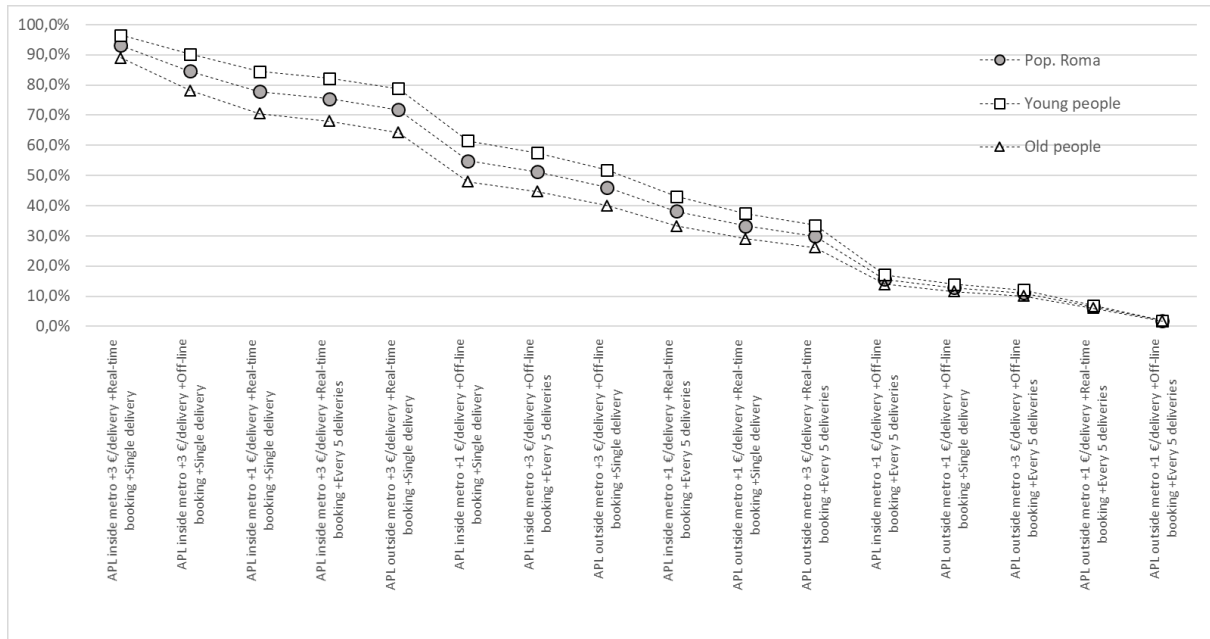
Figure 25: Probability of acting as a crowdshipper with respect to the characteristics of the service (level of service) and the characteristics of the potential crowdshipper (Age) (Serafini et al., 2018)

3.3   SP survey to investigate demand

Gatta et al. (2019b) report the SP survey investigating crowdshipping demand. Data originate from the administration of 240 interviews to inhabitants of the city of Rome. The survey exploring the demand-side investigates the role service time, service cost, parcel tracking availability (available/not available), delivery schedule date/time flexibility (available/non-available) play in stimulating potential e-commerce users to choose a crowdshipping service for receiving goods. Shipping fees and time refer to current national shipping companies operating in Italy (the levels for both attributes are lower/typical). Also in this case, the "no choice" alternative represents the *status quo* implying not using the crowdshipping service.

Most crowdshipping service potential users declared to prefer to pick-up the parcel during the afternoon (38%) or evening (33%) and to have the pick-up option available at least for 24 h (44%). Only 9% of the respondents declared to prefer having a short pick-up time (less than 3 h), mainly for safety reasons.

The Authors, also in this case, estimate a MNL model. All the coefficients have the expected signs and are statistically significant (for more details about the attribute weight results, please see Gatta et al., 2019b).
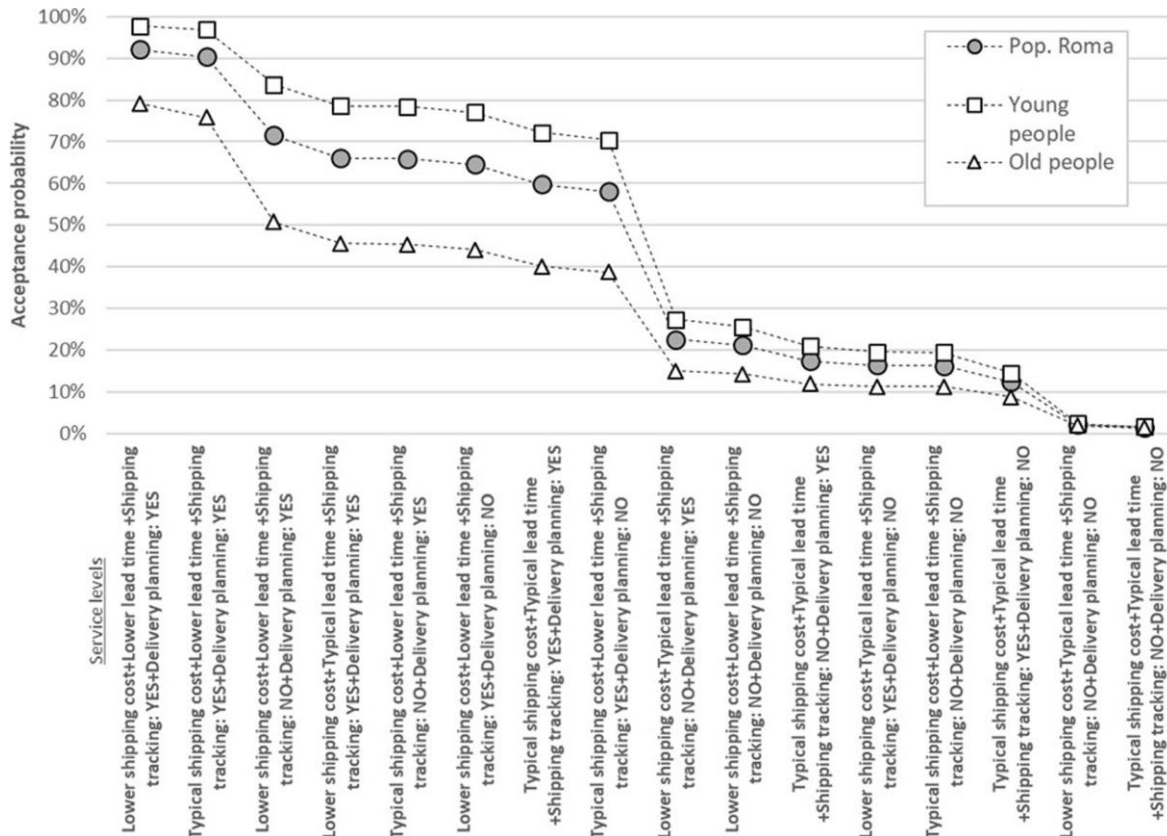
Figure 26: Probability of adopting the crowdshipping with respect to the characteristics of the service (level of service) and the characteristics of the potential user (Age) (Gatta et al., 2019b)

The possibility to plan the delivery date and schedule its timing is the most relevant feature, while having a shorter shipping time with respect to present has the lowest impact on utility. This reflects the fact that the actual delivery system is, in general, efficient in terms of shipping time (e.g. same-day delivery) while time windows are usually wide, and people have to wait at home their goods, inducing either dissatisfaction or missed deliveries.

Starting from the MNL results on can simulate the probability of choosing each alternative assuming different service specifications given the above defined user categories. Most important changes are attributable to the proposed service conditions (level of service). It is also interesting to note a substantial variability linked to age.

4 Evaluating the potential impacts of crowdshipping

Starting from the results obtained, Gatta et al. (2019a) try to understand and evaluate the environmental and economic impacts a crowdshipping platform might have in urban areas.

4.1 Economic and environmental scenario evaluation

Figure 27 reports the methodological architecture. This can be summarised as follows:

1) Define possible crowdshipping demand levels as a function of the main service features;

2) Convert demand into orders, and compute the vehicle-kilometres saved by developing a public transport-based crowdshipping service;

3) Evaluate the benefits and costs of the service in terms of externalities reductions, revenues, investment, and management costs;

4) Compute the net present value of the service.
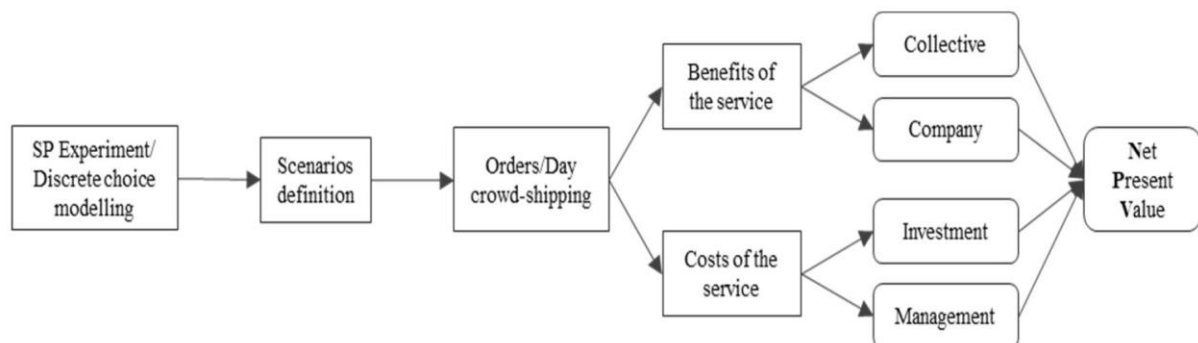
Figure 27: Gatta et al. (2019a) - Methodological structure

The paper reports some scenario simulations assuming different service configurations and using the econometric results obtained. Depending on the acceptability level of the service (base, favourable, and unfavourable) we test three demand scenarios. Transforming individual orders into vehicle equivalent units (i.e., the number of commercial vehicles needed to transport a certain quantity of orders) allows computing vehicle-kilometres savings when implementing a public transport-based crowdshipping service.

Authors use COPERT 5.1.1. (COmputer Programme to calculate Emission from Road Traffic, EMISIA SA, Thessaloniki, Greece) calculation model to estimate the environmental benefit due to lower air pollutants emissions. These include the reduction in emissions for particulate, nitric oxide, carbon monoxide and carbon dioxide, thus covering both local (urban scale) and global impacts (greenhouse gases emissions). Gatta et al. (2019a) reports all the details regarding emission evaluation, traffic conditions data, vehicle fleet composition, kilometres travelled for each year and the cumulative value of the overall amount of kilometres travelled.

The transformation of environmental measures into monetary ones made use of Ricardo-AEA (2014) and Litman (2012). This allowed performing a Cost-Benefit Analysis (CBA) calculation for the crowdshipping service in Rome. The financial sustainability evaluation of the service, assumes a time frame up to 2025 and the following factors: (i) e-commerce demand growth, (ii) socio-demographic evolution, and (iii) metro network expansion. The calculation of the externalities saved assumes, for each demand scenario and each reference year, that a certain share of orders, and therefore equivalent vehicles, are transferred to couriers (crowdshippers) that use the metro network to commute to work. The reductions in environmental externalities were subsequently transformed, using unit costs, in monetary values so to calculate the ensuing economic benefits.

We assume 10% margin on the fee paid to the crowdshippers for the service produced that is the typical private company profits in line with other crowdshipping services already operating in the market. The service costs, split in investment and management costs, are assessed on the base of each scenario. Investment costs refer to the purchase and installation of APLs and the creation of an IT platform to manage the service. Purchasing and management costs have been derived from different sources, including articles and manufacturers' brochures and websites. Gatta et al., (2019a) report and discuss the specific values.

Three demand scenarios have been considered, i.e.: (1) the "base scenario" assuming the most likely configuration of the possible crowdshipping service; (2) a "favourable" scenario with lower shipping fees; (3) an "unfavourable" scenario with no flexibility in delivery date and time schedule. The probability of choosing such a service ranges from 16% to 66%.

The potential crowdshipping demand is mainly generated by the same users of the metro network, as well as by the inhabitants located in the surrounding areas of the metro stations. We use an e-shopping rate of 0.0262, for the whole period considered, to transform demand in potential daily orders. We also account for orders/day per inhabitant, percentage of the population making at least one online purchase, percentage of orders requiring a physical shipment and annual average purchase rate.

The environmental-related benefits for the 2017–2025 period of a crowdshipping service in Rome are summarized as follows:

- 239 kg of particulates per year will, on average, be saved, with oscillation between 66 kg and 265 kg
- 3.76 tons of nitrogen oxide per year will, on average, be saved, with a variation between 1.04 and 4.17 tons
- 2.24 tons of carbon monoxide per year will, on average, be saved, with a minimum of 0.58 and a maximum of 2.49 tons
- finally, for carbon dioxide, the emission avoidance is 1098 tons per year with extreme values reaching 304 and 1215 tons.

If one does not consider public benefits, the NPV obtained is negative, suggesting that discounted costs are greater than revenues for the platform operator. However, considering that environmental benefits and accident reduction impact on society as a whole, it is reasonable to convert their economic value into public incentives and, therefore, deduct them from the total platform cost. This assumption makes the NPV positive (Figure 28).

	UNFAVORABLE SCENARIO	BASE SCENARIO	FAVORABLE SCENARIO
NPV with environmental benefits	208,779 €	1,682,241 €	1,898,610 €
NPV without environmental benefits	-978,622 €	-2,627,591 €	-2,871,319 €
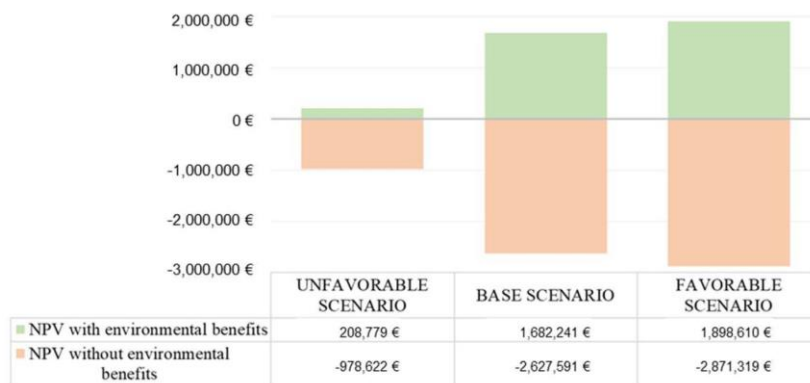
Figure 28: Net present value (Gatta et al., 2019a)

4.2 Next steps: simulation-based evaluation

In the following, we sketch the latest results related to the presented project we have illustrated. In order to analyse externalities of crowdshipping services, a network-wide perspective is

adopted, including public transit as a delivery mode (in addition to car), and explicitly considering operational issues like kerbside parking.

The aim of this investigation stream is twofold:

(1) Provide a systematic investigation of the scale-effects of crowdshipping from a "supply perspective," by analysing the impacts of different operational features (e.g., mode, length of detours, availability of parking, and levels of traffic) on congestion and emissions;

(2) Investigate the effects of crowdshipping in a realistic large-scale scenario, by accounting for real traffic conditions, availability of commercial bays, and freight demand.

The dynamic simulation framework adopted (Simoni and Claudel, 2018) is consistent with the dynamics of congestion and reproduces delivery operations as temporary fixed-bottlenecks in case of double-parking. Its hybrid nature allows for large-scale analyses and, at the same time, detailed investigations of individual delivery tours and crowdshippers' deliveries. This approach allows calculating freight related emissions and traffic congestion effects (including those related to kerbside delivery). In addition, its hybrid nature permits analysing several different scenarios at very low computational costs (few seconds per simulation) thus making it possible to perform robust evaluations accounting for uncertain freight demand and traffic conditions.

Simulations of the crowdshipping in the city centre of Rome can benefit much from this approach using three different alternatives when simulating the last mile delivery process: (i) a "traditional" (i.e., existing) delivery service, (ii) a standard "car-oriented" crowdshipping framework and (iii) a "public transit-oriented" one. One can integrate both of the last two delivery services into the "traditional" one. In both crowdshipping frameworks, the crowdshipper is not the final recipient of the parcel.

In order to reproduce the crowdsourced delivery process we embedded into the original simulation framework thanks to the development of a new algorithm that derives crowdshippers' original and new delivery trips while integrating them in the original delivery framework (by replacing and consolidating existing trucks' tours) based on different input parameters.

We use as a main reference for the implementation of crowdshipping in Rome the investigation of the conditions for public transit passengers to act as crowdshippers and for people to receive goods with crowdshipping performed in the abovementioned studies.

Thanks to simulations, it is possible to study the influence of mode and matched demand, the effects of operational aspects such as the length of detour made by and the parking behaviour of crowdsourced drivers, and the influence of daily traffic fluctuations. By doing so, it is possible to assess the impacts of different crowdshipping implementation features on the overall levels of pollution and congestion.

To synthetize, traffic simulations can be adopted to properly model the effects on traffic and pollution of delivery operations dynamic. This modelling approach is uncommon in city logistics related studies and, to the best of our knowledge, no systematic simulation-based study of crowdshipping has yet been performed.

5 Conclusion

This paper presents an innovative crowdshipping service relying on public transport. Following PI paradigm, one can imagine a collaborative network of "crowdshippers", i.e. those

performing the delivery service, customers, and a platform that matches demand with supply, aiming at optimizing the shipment of standardized parcels, focusing on routing protocols, interoperability and traceability standards, remuneration rules, compensation mechanisms and new trade configurations (Ballot et al., 2014). This can prove particularly valuable in managing peak situations (Christmas, Black Friday, San Valentine day, etc.).

The paper discusses the feasibility and behavioural levers that might facilitate the diffusion of crowdshipping in urban areas. It reports some recent research advances related to the study of both demand (i.e. receivers of this service) and supply (those who perform the service, i.e. crowdshippers) and of the main related impacts this solution would have from and an environmental and an economic point of view. It specifically focuses on an environmental-friendly crowdshipping service. This innovative service uses the mass transit network of a city, where customers/crowdshippers pick-up/drop-off goods in APL located either inside the transit stations or in their surroundings. The case study we consider is the city of Rome. With respect to this city, we administer surveys and perform simulations. The study of the potential adoption of this innovative solution rests on SP and DCM techniques that allow performing sound analyses of different crowdshipping future scenarios and estimate the main associated impacts. A hybrid dynamic traffic simulation methodology is presented capable of accounting for realistic last-mile delivery operations.

This research paves the way for further investigation of crowdshipping, given its potential to relieve the city from transport-related negative externalities and to fully affirm the sharing economy and Physical Internet paradigm aiming at a shared, hyper-connected, sustainable and efficient last-mile logistics. Potential research lines are: 1) making the user aware of the environmental benefits of a public transport based crowdshipping, thus inserting an ecolabel as an explicit variable in the choice process; 2) quantifying the economic benefits for a crowdshipping company due to the adoption of such a green delivery solution; 3) evaluating the freight type and parcel dimension that can be handled by a public transport based crowdshipping; 4) inserting the public transport based crowdshipping into a network design problem combining both transit and logistic network design, thorough the simulation approach. Finally, from a policy perspective, when moving private services inside public areas, safety and security issues need to be taken into account. Thus, ad hoc regulations are expected to be developed to assure the feasibility and real operation of the service.

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Physical Internet Enabled Hyperconnected Fulfillment of Delivery Time Sensitive E-Commerce Orders

Nayeon Kim[1,4], Benoit Montreuil[1,2,3,4] and Walid Klibi[1,5]

1. Physical Internet Center
2. Supply Chain and Logistics Institute
3. Coca-Cola Chair in Material Handling and Distribution
4. H. Milton Stewart School of Industrial & Systems Engineering
Georgia Institute of Technology, Atlanta, United States
5. The Centre of Excellence for Supply Chain Innovation & Transportation (CESIT),
Kedge Business School, Bordeaux, France
Corresponding author: nkim97@gatech.edu

Abstract: In the era of e-commerce and home delivery, it is critical to satisfy growing customer expectations on service levels. Delivery lead time is one of the most important service level differentiators. Being incapable of offering timely delivery not only means customer dissatisfaction but can result in demand loss under high market competition. This paper investigates the potential of Physical Internet enabled hyperconnected fulfillment systems relative to both meeting customer delivery lead time expectations and reducing customer delivery burden. With a broader network of open fulfillment centers and a flexible sourcing policy, simulation-based experiments based on a e-manufacturer case show result in up to 6% reduction of lost demand rate and up to 73% reduction in customer delivery miles, as compared to a current dedicated fulfillment system when significant portions of customers expect timely same-day or next-day delivery.

Keywords: Physical Internet; Hyperconnected Fulfillment; Hyperconnected Distribution; E-commerce; Last-Mile Delivery; Service Level; Delivery Lead Time

1   Introduction

The growth of e-commerce has been rapidly changing customer behaviors and logistic environments for e-retailers and e-manufacturers (Lett & Whang, 2001; Agatz et al., 2008). Customers tend to order smaller amounts more frequently while expecting shorter delivery lead time (Lang & Bressolles, 2013; Jie et al., 2015). As e-commerce culture is getting settled and competition among e-retailers as well as among e-manufacturers, customers become more likely to be lost, rather than simply dissatisfied, when they are not delivered within expected lead times. In this context, delivery service levels, associated with the capability to deliver within expected times, are critical to design e-fulfillment systems and measure their performance. Achieving delivery service levels indeed induces costs, but also has potential to affect revenues and market shares.

The paper aims to investigate the relative performance of dedicated versus hyperconnected fulfillment systems in terms of delivery service level performance and delivery burden in the context of time-sensitive e-commerce order fulfillment. Hyperconnected distribution and fulfillment systems are based on Physical Internet principles (Montreuil, 2009-2012, 2011, 2015).

The potential of hyperconnected system has first been investigated by Sohrabi et al. (2012) who provided a comprehensive design of hyperconnected distribution systems from manufacturing to delivery, and contrasted dedicated, collaborative and hyperconnected distribution systems. Sohrabi et al. (2016) reported 38% gain on the total induced cost by utilizing hyperconnected distribution and transportation instead of dedicated distribution and transportation for ten companies serving USA markets. They solved comprehensive optimization models for distribution network design for each scenario, each under three service level constraint sets. The tightest constraint set requires 1, 2, and 3 day delivery from zones A, B, and C which are determined by demand sizes. They assume deterministic demand in each zone, and the service level is treated as a hard constraint. In this paper, as will be detailed later, we do not assume delivery service expectations to be uniform across a zone, but rather at the individual customer level, with a zone-based probabilistic distribution of customer service level requirements. In other words, some customers may require next-day delivery while other customers may be fine with 5-day delivery although they are living in the same city, while it is true that customer living in metropolitan cities are likely to expect faster delivery than those living in rural area. Also, we do not treat service level as a hard constraint, but instead we treat it as an incentive as the demand can only be captured when service level can be met. Lastly, Sohrabi et al. (2016) focused on network design while we focus on the service capability of fulfilling delivery time sensitive customer orders of alternative networks. Yang et al. (2017a, 2017b) and Pan et al. (2015) showed the potential of hyperconnected distribution system with a focus on inventory management. However, the fulfillment capability with respect to delivery service level was not considered. Montreuil (2016) provided a primer on exploiting the Physical Internet to enable hyperconnected e-commerce and omnichannel fulfillment logistics and supply chains.

The motivation and goal of the paper can be described with the schematic diagram shown in Figure 29. Four fulfillment schemes are shown in Figure 29, differentiated by resource and operation. Fulfillment center (FC) locations and inventory levels are depicted on a grid of demand zones, each shaded by its demand rate. The darker the shade is, the higher the corresponding demand rate. Potential customers are represented as a dot with requested delivery lead time. When there is no FC with available inventory located within the distance to meet the delivery lead time, the customers are lost. In real operation, this customer demand may not be even observed by a retailer or a manufacturer. Lost customers are marked in red. When demand zones to be served by each FC is determined in advance (demand zone allocation), the allocated zones to each FC are grouped in a dashed area.

The upper left diagram of Figure 29 represents a most traditional fulfillment system where each company relies on its dedicated fulfillment centers (FCs), optimizes their number and locations, uses single-sourcing strategy by pre-allocating demand zones to one of the FCs. The customer in the middle is shown as lost since the allocated FC on the right is too far to serve the customer in a timely manner given the requested delivery time, although the left (not assigned) FC is capable to serve it within requested delivery lead time. Four other customers cannot be served from any of the two FCs within requested delivery lead time.

The lower right diagram represents a hyperconnected fulfillment system with respect to resources and operations. In a hyperconnected system, multiple players are concurrently exploiting the open logistics resources. In the paper, we focus on the fulfillment operation of a single company among these to examine the potential capability a hyperconnected system is bringing to such a company. Here, a network of open FCs can be exploited, providing the company access to a broader FC network, as compared to a dedicated FC network. This increases the proximity to customers when inventories are smartly spread dynamically over a

larger number of FCs. By utilizing a higher number of FCs, the inventory level of each product at each open FC can be smaller. Also, customers can be served by any FC as long as the requested delivery lead time is respected and there is available inventory, minimizing the need for isolated safety stock computations at each FC and thus minimizing the overall network-wide inventory requirements.
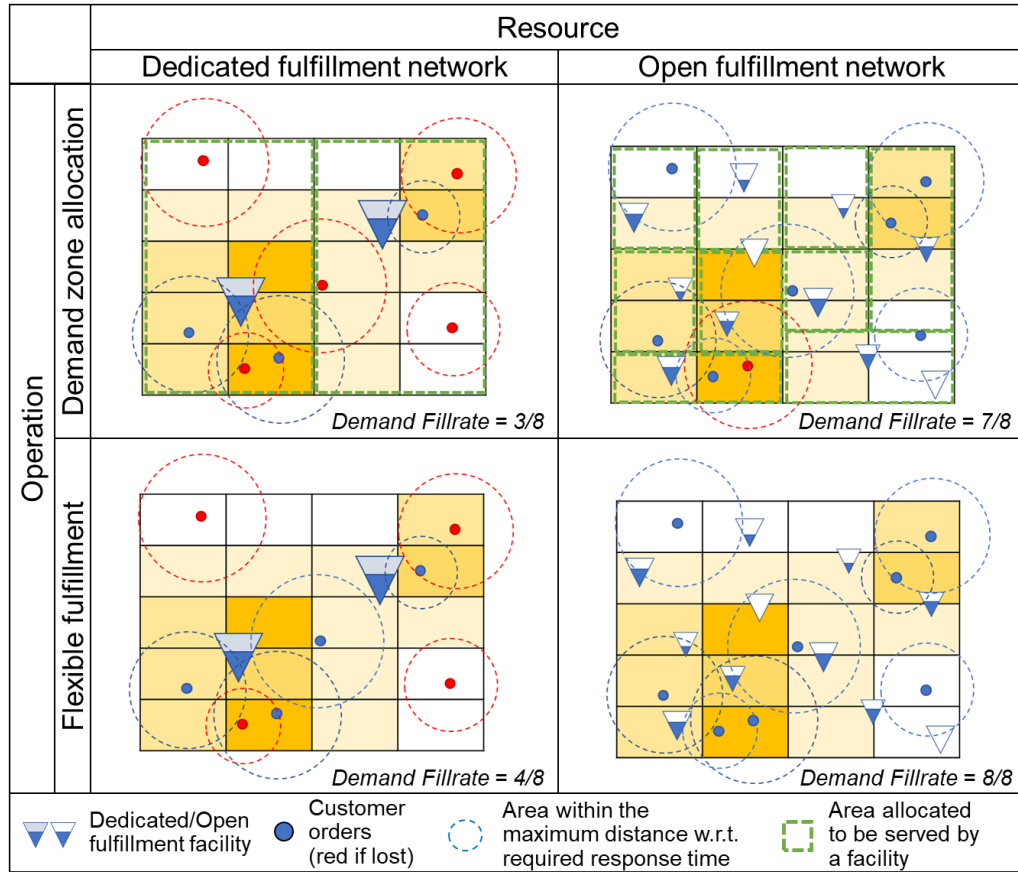
Figure 29: Four fulfillment schemes with the service requirement as a customer specific delivery lead time

The other two diagrams show the partial combination of dedicated and hyperconnected fulfillment systems. When flexible sourcing operations are used, the customers in the middle between zones that were lost due to single sourcing in the dedicated upper left diagram can be now served. When single sourcing is imposed with open FCs, by allocating demand zones to each open FC, a customer may be lost although it is able to be served from another FC.

Figure 1 contrasts the fill rate achieved by each illustrative system, measured as the fraction of customer order requests met by the system given their zone assignment policy and inventory level. Achieved fill rates ranged from 3/8 for the dedicated system to 8/8 for the hyperconnected system.

This paper is structured as follows. Section 2 defines hyperconnected fulfillment systems and compare them to dedicated systems. Section 3 introduces the case of an e-manufacturer used for the simulation-based experiment, whose results are exposed and analyzed in Section 4. Finally, conclusive remarks are provided in Section 5.

2   Hyperconnected fulfillment

As the goal of the paper is to explore the potential customer delivery service and cost containment capabilities of dedicated vs. hyperconnected fulfillment, it is important to properly define hyperconnected fulfillment systems, and to distinguish them from dedicated or collaborative distribution systems. In this section, this is achieved through focalizing on three major aspects distinguishing hyperconnected fulfillment systems from the others: resources, operations, and players.

2.1   Resources

In dedicated and collaborative systems, resources are only shared respectively within a single organization and among the organizations that are members of the collaborative partnership. Hyperconnected systems rely on open resources provided by resource service providers and available to be shared by any user organization according to standardized protocols, transactions and platforms. In hyperconnected distribution, fulfillment and transportation/delivery, the key resources are respectively distribution centers (DCs), fulfillment centers (FCs) and transportation/delivery fleets.

In collaborative fulfillment, the services of FCs can be shared only within the collaborative group. The shared resources must still be managed as group-dedicated resources. This often imposes limits on achievable scalability. Moreover, most of the time, building such collaboration is difficult due to competition, conflicts of interests, distrust and digital/physical system incompatibility (Dominquez et al. 2012, Lindawati et al. 2014). In hyperconnected fulfillment, the services of open fulfillment centers are meant to be used on demand by any company, and these open logistics resources are managed by the service providers, who may be third party service providers or one of the players in the market, for example e-retailers, omnichannel retailers and e-manufacturers having fulfillment centers with extra capacity, transforming them into business-generating centers.

The business cases of ES3 (Hambleton & Scherer, 2016), Flexe.com (www.flexe.com) and Fulfillment by Amazon (FBA, https://services.amazon.com/fulfillment-by-amazon/benefits.htm) exemplify business and service models in line with Physical Internet enabled hyperconnected distribution and fulfillment, with ES3 and Flexe.com focused on hyperconnected distribution, and FBA on hyperconnected fulfillment. FBA is notably an example of omnichannel retailer opening its network of fulfillment centers.

Without being limited by an exclusive group of collaboration members, hyperconnected fulfillment can achieve greater scale by being open to any users in need of the service. For users, this provides an access to broader set of resources compared to dedicated or collaborative resource management. The implication on the access to the broader network can be found in Sohrabi et al. (2012, 2016) and Yang et al. (2017b) as well. Also, with the service provider as a trusted intermediary, it can bypass competition and distrust issues.

2.2   Operations

Several operational policies can affect fulfillment efficiency. One key example is the fulfillment sourcing policy, notably selecting between single sourcing and flexible sourcing. Traditionally, single sourcing is used, with each demand zone allocated to a single FC which is to be responsible to fulfill all demand from that zone. This is decided at a strategic level, often during the network design phase. Such single sourcing policy can help optimizing the opening and

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locating decision of FCs as well as reducing the complexity of fulfillment operations and inventory decisions. However, it excludes any pooling potential among FCs and therefore tends to increase total inventory level required in the network. This is not the most appropriate policy in hyperconnected fulfillment systems exploiting an open FC network. Single sourcing and its induced demand zone allocation to a single FC can substantially hurt the potential of hyperconnected systems. Flexible sourcing allows demand pooling between FCs and potentially improves demand fill rate. The degree of sourcing flexibility can vary. In fully flexible sourcing, any FC located near enough and having inventory enough to deliver within the customer required lead time can be chosen as the source for a customer order, either completely or partially. Among candidate FCs, the sourcing FC can be chosen based on one or more criteria such as minimizing transportation costs and maximizing demand fill rate over multiple time periods. In context of Physical Internet, Pan et al. (2015) showed the best source selection rule from a single-product inventory perspective was to choose nearest source with available inventory. Multi-product contexts may create situations where relying exclusively on this rule is suboptimal.

Another critical operational policy is inventory policy. This policy is affected by the sourcing policy discussed above. On one hand, the more restricted the sourcing flexibility is, the more inventory is needed in the network due to loss of pooling impact (Eppen, 1979). On the other hand, the target days of inventory in the network and inventory deployment policy have a significant impact as well. Target days of inventory decisions are closely linked to production as well distribution and fulfillment. A large production batch size and/or long production lead time increase required inventory levels in the fulfillment network. Company strategy also plays a critical role to determine target inventory level in the network. Inventory deployment through lateral transshipment between FCs can improve fulfillment capability and demand fill rate over multiple periods, especially when the lateral transshipment cost is managed efficiently (Axsäter, 2003, Firoozi et al., 2016). It can have more impact when lean inventory levels are maintained.

Transportation operations focused routing and consolidation policies are also critical. Routing scheme and transportation efficiency can affect FC assignment decision. For example, it can be cheaper to fulfill some customers from FCs that are not the nearest available FC due to better consolidation and routing efficiency as long as delivery lead time is met. It is also possible to postpone shipping when the requested delivery lead time is not tight to get better consolidation in transportation with future orders.

2.3 Players

Players are one of the most distinguishing characteristics of hyperconnected fulfillment systems as the open resources, notably the open fulfillment centers, can be utilized by any player on demand, subject to a service fee. The fact that it can be utilized by any player means that there can be numerous players, potentially all players in the market. Also, since the service can be bought by players on demand, it is not true that a logistics resource would always be used by a certain player and vice versa. From a resource utilization point of view, this can potentially improve utilization by pooling variability and seasonality of different players' operations. In fact, the number of players has a critical role in determining how the resources are utilized and in inducing the total incurred cost. For example, in the context of inventory operation in Physical Internet, Pan et al. (2015) showed inventory cost can be reduced as the number of player increases.

3 Case description

In this paper, we use for simulation purposes, a case based on an existing dropship furniture e-manufacturer selling its furniture in North America through online retailers, shipping to end customers from its fulfillment centers (FCs). Slightly modified from reality while keeping its essence, the case is here focused on the continental US market, excluding Alaska. Since this paper is hyperconnected fulfillment focused, from FCs to end customers, the case starts with a given inventory status in the network from which upcoming customer orders should be fulfilled. The upstream operations, such as manufacturing across the factory network, distribution from factories to FCs, and fulfillment inventory management are excluded to emphasize the last step that is the order fulfillment capability.

In this section, firstly we describe the demand the e-manufacturer is serving, so as to make clear the business context. Then we describe its fulfillment network and operation policies follows, as they are essential fulfillment components to be differentiated in the hyperconnected system. Lastly, we describe the scenarios designed for computational experiment.

3.1 Demand

Offering a portfolio of 1000 distinct products through the e-commerce sites of the majors in the industry, following a typical Pareto distribution of product demand within the portfolio, the e-manufacturer daily ships around 3000 product units to online customers in 1000+ cities across the continental USA. Figure 30 shows the sample of demand distribution in US at a city level of the dropship manufacturer. The circles are sized by relative volume of demands from each city. Figure 30 clearly shows how spread the demand is over the US territory.
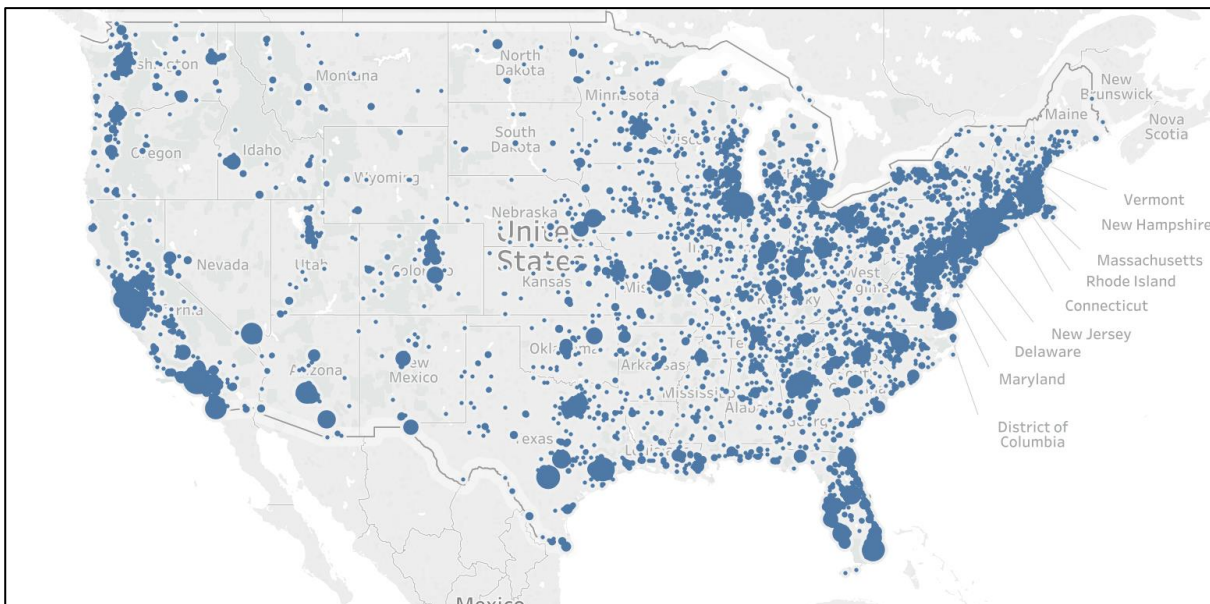
Figure 30. Sample of demand to be fulfilled in the USA, with nodes corresponding to cities, sized according to demand volume

In the paper, we investigate delivery service requirements that are customer specific, yet influenced by whether they live or not in a metropolitan area. Indeed, the demand density in metro areas has lead e-commerce and omnichannel players to propose fast delivery to customers, and these customers have become highly demanding in terms of delivery speed,

precision and reliability. Figure 31 depicts the set of metropolitan areas in the USA. In terms of delivery lead time, in online furniture expectations have gradually shifted from 5-7 days to 3 days, and are expected to slide toward 2 days, next day and same day, with the metro customers having the toughest expectations.
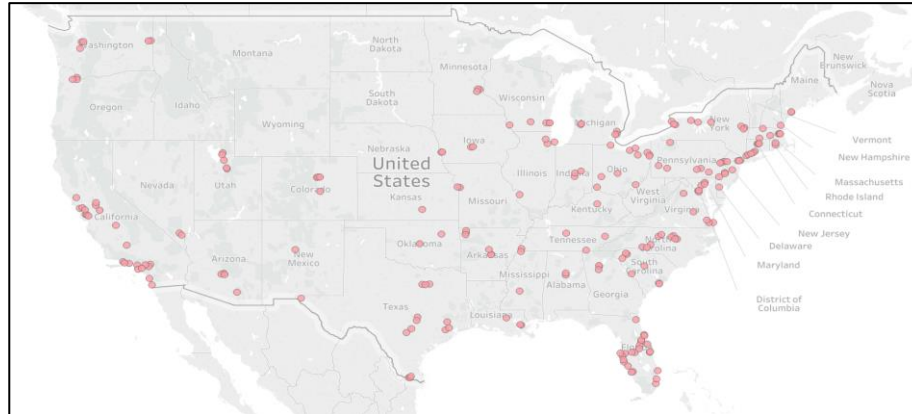
Figure 31: Metropolitan areas in USA

3.2   Fulfillment network

One of the major characteristics of hyperconnected fulfillment system is access to a large network of open FCs. For most of the companies, it is impossible to justify more than a few FCs dedicated to them. On the other hand, a network of open FCs can afford a large number of facilities and cover broader areas more deeply, thanks to the economies of scale from its users which can be any company who needs the services of FCs.

In this case, we compare two fulfillment networks: current and open network. The current FC network includes three FCs in the US and the potential open FC network is comprised of ten FCs spread evenly over the US as shown in Figure 32. This limit to ten FCs is to control the size computational workload of this paper, as hyperconnected fulfillment could allow to exploit an open FC near every major metropolitan area. Further research should examine deeper the impact of such decisions. Note that exploiting ten dedicated FCs is beyond the financial capability of the e-manufacturer, so relying on open fulfillment centers becomes critical.
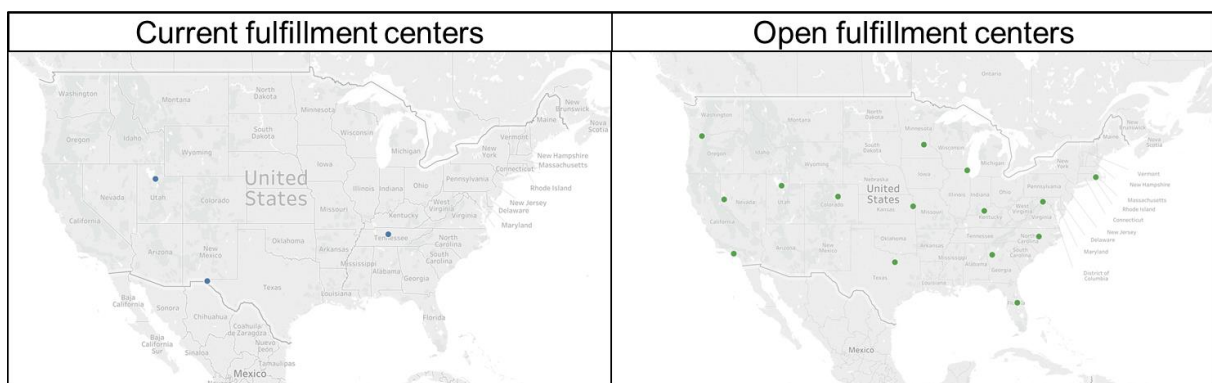
Figure 32. Current dedicated and open fulfillment network

3.3   Operation policy

As discussed in the previous section, sourcing, inventory, and transportation operation policies are among the relevant operational policies.

Regarding sourcing policy, two policies are examined: single sourcing with demand zone pre-allocation and fully flexible sourcing. In case of single sourcing, demand zones are allocated to the closest FCs at state level as shown in Figure 33. When flexile sourcing is chosen, each customer is fulfilled in a first come, first served (FCFS) basis from the nearest FC having the demanded products. In both cases, if there is no inventory in FCs from which the delivery is allowed to be completed within requested delivery lead time, the customers are lost.
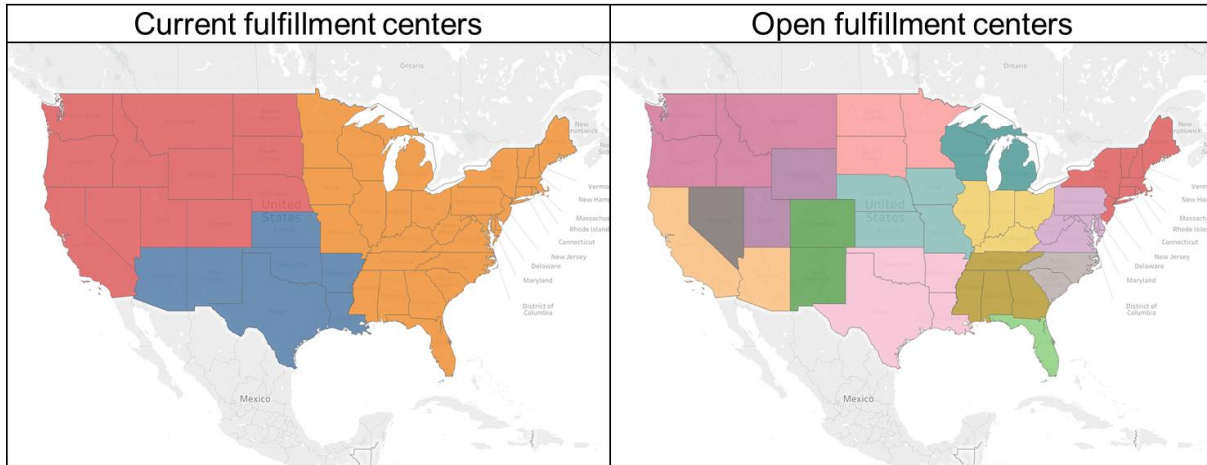
Figure 33: Zone allocation to FCs to current and open FCs

As the case is built for investigating a short-term fulfillment horizon without a link to upper stream operations, inventory policy or management scheme cannot be adequately modeled. Therefore, the inventory policy is reflected through the setting of the total inventory level in the network at the beginning of the first day. It can reflect different inventory policies, lean or fat, and/or timing with respect to inventory replenishment point for each product.

Transportation related operations such as routing, consolidation, and delivery postponement are a factor of efficiency but not a factor of fulfillment capability. To highlight the focus on fulfillment capability, simple transportation operations are assumed: each delivery is to be provided by a delivery service provider, with promise to deliver on time as per requirement as long as distance requirements are met, and price charged by the deliverer for each order to be proportional to the distance from FC to the customer. No delivery postponement is accounted for in this experiment. That is, when a customer order is received, a FC to serve the customer is chosen based on current inventory status and the product is shipped from the FC as soon as possible. For this study, delivery time is assumed to be solely dependent on travel distance, where k-day delivery is possible when the distance is less than equal to $300 + 600*k$ miles.

3.4   Scenario design

Scenarios are constructed reflecting customer expectations on delivery lead time, fulfillment network topology, fulfillment sourcing policy, and inventory levels, as described in this section.

The first scenario building element deals with customer expectations relative to delivery lead time. As synthesized in Figure 34, we constructed two delivery service expectations scenarios, respectively termed slow delivery and fast delivery. In the slow delivery scenarios, customers are expected to require delivery time between three and seven days, according to a probability distribution having the metropolitan customers slightly more demanding than other customers. In the fast-delivery scenario, metro customers would require same-day and next-day delivery with a respective probability of 40% and 25% while other clients would require next-day and two-day delivery with these respective probabilities.

The second scenario building element is fulfillment network topology. Two fulfillment network topologies are considered, one with current dedicated FCs and the other with ten open FCs, as shown in Figure 32.

Order-To-Delivery Expected Time (up to day-s)	Average % of Customers			
	Scenario a: Slow Delivery		Scenario b: Fast Delivery	
	Metropolitan Areas	Other Areas	Metropolitan Areas	Other Areas
0	0%	0%	40%	0%
+1	0%	0%	25%	45%
+2	0%	0%	5%	25%
+3	25%	20%	5%	5%
+4	25%	25%	5%	5%
+5	20%	25%	5%	5%
+6	15%	15%	5%	5%
+7	10%	10%	5%	5%
Longer	5%	5%	5%	5%
Total	100%	100%	100%	100%

Figure 34. Customer service level expectation scenarios as a delivery lead time

The third element is the fulfillment sourcing policy. For fulfillment sourcing policy, single sourcing via demand zone pre-allocation and complete flexible sourcing policies are selected for comparison. Scenario construction with these second and third elements can be visualized in Figure 29.

Lastly, inventory level is the fourth scenario building element. Three inventory level scenarios are considered, respectively named as low, lean, and high, based on the overall inventory level in the network. Since one-week time period is chosen for the computational experiment, low, lean and high inventory levels are respectively set as 7, 15, and 30 expected days of inventory. Let I_s be the overall inventory level in the network, I_f be the inventory level at each FC f and k_s be inventory days for each scenario $s = low, lean, high$.

$$I_f = \lceil k_s E[D_f] \rceil \ \forall s \ \forall f$$

Where $E[D_f]$ is average daily demand from the zones allocated to FC f, $k_{low} = 7, k_{lean} = 15, k_{high} = 30$. The same inventory level is applied for both single sourcing and flexible sourcing cases. When open FCs are used the sum of inventories at each FC tends to be higher due to the round up. To have identical inventory level in the total network regardless of the number of FCs, inventories at open FCs is reduced by unit by an ascending order of $I_f - k_s E[D_f]$ until the total inventory level becomes same to the total inventory level of dedicated network.

The overall scenarios defined for the computational study are listed in Table 11.

Table 11. Scenarios

Fulfillment network	Current dedicated FCs												Open FCs											
Sourcing (zone allocation)	Single sourcing (zone allocation)						Flexible sourcing						Single sourcing (zone allocation)						Flexible sourcing					
Service requirement	Slow delivery			Fast delivery			Slow delivery			Fast delivery			Slow delivery			Fast delivery			Slow delivery			Fast delivery		
Inventory level	Low	Lean	High	Low	Lean	High	Low	Lean	High	Low	Lean	High	Low	Lean	High	Low	Lean	High	Low	Lean	High	Low	Lean	High
Scenario ID	1	2	3	4	5	6	7	8	9	10	11	12	101	102	103	104	105	106	107	108	109	110	111	112

4   Computational study

All scenarios are evaluated through a simulation with common input demand. Ten experimental replications are performed where each run, all scenarios are run with a specific set of seven-day demand log of customer requested orders, sampled from historical logs. Note that with the simple third-party delivery service provider focused operations defined in section 3, the operation becomes essentially independent by product. Therefore, one high-demand product has been selected for computational simulation in this paper. For the selected product, there are about 26 orders received per day on average. For the ten experiments with 7 days, there are total 180 orders over the 7 day period on average, varying from 157 to 193. The comprehensive results are reported in Table 2 in Appendix. Lost demand rate, which is (1- fill rate), is reported as a main performance measure.

Figure 35. Average lost demand by scenario by reason shows the average lost demand rate by scenario. The left half of the scenarios shows the results for the dedicated FC network, the right half of the scenarios shows the results for open FC network. For each network scenario, the results for single sourcing via zone allocation scenarios are presented first on the left and the results for flexible sourcing scenarios are presented on the right. A customer is lost due to inventory shortage and/or service capability. Here, when there is no inventory in the network when customer order arrives, the lost customer is classified as lost due to inventory shortage. When there was no inventory in the area from which the customer can be reached within the requested delivery lead time although there is available inventory in the fulfillment network, it is classified as lost due to service capability.
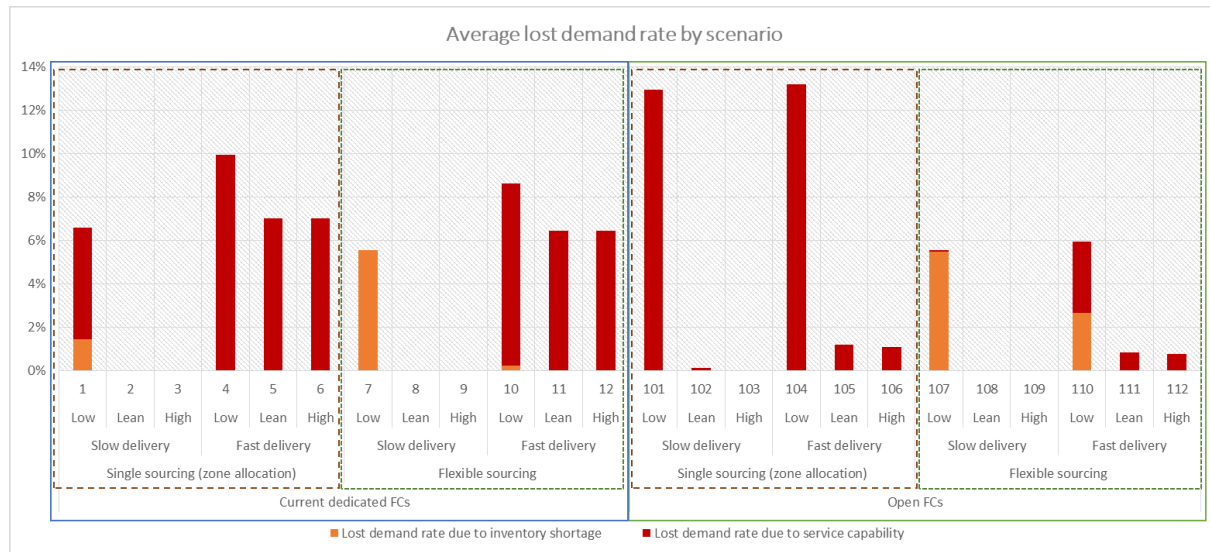
Figure 35. Average lost demand by scenario by reason

In Figure 35, it can be seen that when inventory is low as in scenarios 1, 7, 107, and 110, customers tend to be lost due to inventory shortage. However, even the inventory is equally low, when customers require faster delivery as in scenarios 4 and 10 or fulfillment is inflexible due to zone allocation as in scenarios 101 and 104, service capability becomes a tighter constraint. Another noticeable result is that pre-allocating demand zones to specific FCs hurts the service capability of open FC networks more when inventory is low – as we compare scenarios 1 and 4 to 101 and 104. However, when inventory level is more than lean, open FCs is likely to outperform dedicated FCs especially as customers expect faster delivery. Results from scenarios with high inventory provide insights on ultimate service capability. The lost demand due to service capability even with enough inventory in all FCs can only be fulfilled

by expanding the FC network. Results from scenarios 3, 9, 103 and 109 show that both dedicated and open FC networks have potential capability to meet all customer service requirements when relatively long delivery lead time are overall accepted. However, when customers expect fast delivery, the potential service capability of current FC network drops significantly by about 7%, whereas that of open FCs only drops by about 1%.

Figure 36 shows the demand loss rate with dedicated and open FC networks where the demand loss rate difference (dedicated – open) is colored depends on the sign. Open FC network is likely to outperform dedicated FC network when fast deliveries are expected. When slow delivery is accepted by customers, the dedicated and open FC networks have about the same demand lost rate in most cases. However, when demand zones are pre-allocated, the capability of open FCs is greatly hurt even to the degree that its performance becomes worse than that of dedicated FCs when combined with low inventory as shown in single sourcing & low inventory scenarios.
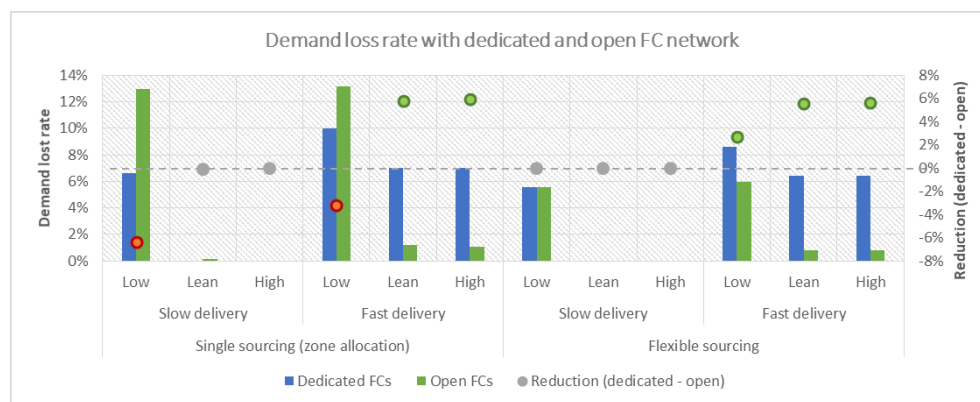
Figure 36. Comparison of demand loss rate with dedicated and open FC network by scneario

Demand loss rate is also compared by sourcing policy as shown in Figure 9. It can be seen that in all cases flexible sourcing outperforms single sourcing. The reason can be found easily as flexible sourcing gives flexibility to fulfillment operations and enables pooling between FCs.
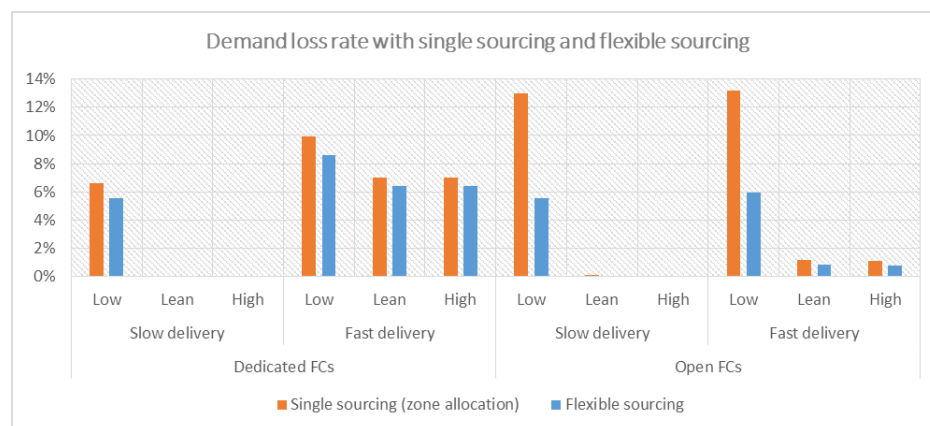
Figure 37. Comparison of demand lost rate under two sourcing policy by scneario

Along with the demand loss rate, the average travel miles per order are assessed, providing the results exposed in Figure 38. In all scenarios, travel miles are reduced significantly by more than a half. The reduction in miles not only implies saving transportation costs, but also implies average delivery time is reduced. Since most of online customers' satisfaction level for delivery service increases, or do not decrease at least, with faster delivery regardless of requested delivery lead time, this implies concurrent service improvement and fulfillment cost reduction.
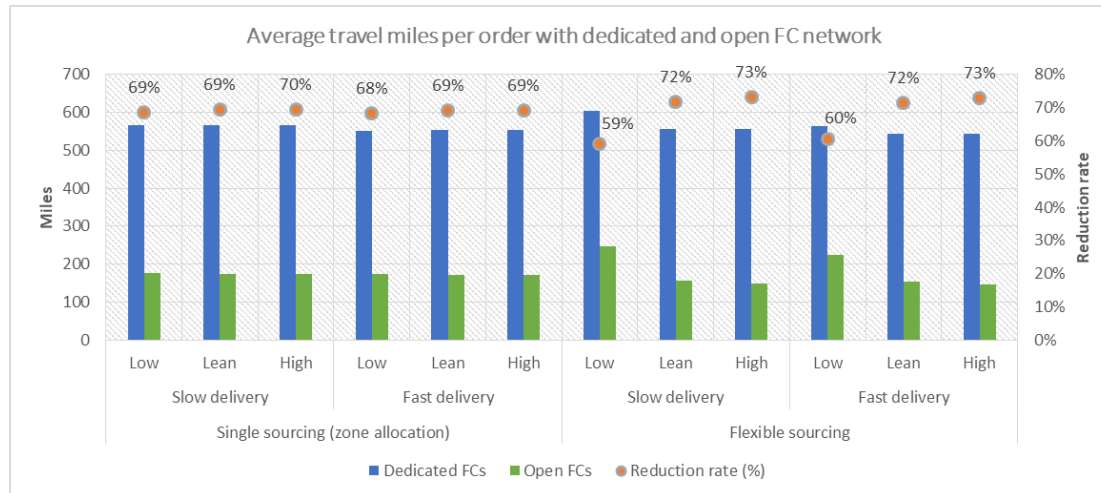
Figure 38. Average travel miles per order by scenario

5 Conclusion

This paper has presented the main characteristics and explored through an empirical simulation the potential of hyperconnected fulfillment systems to support delivery time-sensitive fulfillment in the era of e-commerce and home delivery.

Based on the business case of a dropship e-manufacturer, the numerical results of the empirical simulation experiment demonstrate that exploiting an open FC network, which provides an access to a broader set of FCs to the manufacturer, and operating smartly with flexible sourcing, can improve significantly the service capability, especially when customers expect timely delivery. The scenarios on various combinations of FC networks, operation policies, customer expectations and inventory levels, demonstrates that smart and flexible fulfillment operations such as sourcing policy is critical to get the full potential of hyperconnected fulfillment systems. Overall, results show up to 6% reduction of lost demand rate and up to 73% reduction in customer delivery miles, as compared to the current dedicated fulfillment system when significant portions of customers expect timely same-day or next-day delivery.

The encouraging results show the way forward, while also leaving potential of future research avenues. One extension potential is the scale of open fulfillment network. The fulfillment network of ten FCs assumed in this paper is far from the full scale of open fulfillment network. A network of hundreds of open FCs can further improve service capability but the operations must be more carefully designed as it becomes more likely not to use all FCs but to use a subset of FCs at a time where the subset changes over time on demand. The paper only focuses on the last-leg fulfillment to customers, excluding other logistics components such as multi-period inventory management and production, and the transport of products to and between the FCs. Also, there is clear potential in investigating the multi-product context, with appropriate transportation and delivery hypotheses. The work can be also extended to upper echelons as in Sohrabi et al. (2012, 2016) and tackle longer time horizons to obtain more comprehensive results and to measure the impact on the full logistics system encompassing full product portfolio, across the multiple supply chain and logistic players.

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Appendix

Table 2. Computational results: average demand loss rate and travel miles per hour by scenario

Fulfillment network	Sourcing (zone allocation)	Service requirement	Inventory level	Scenario ID	Demand loss rate	Demand loss rate due to inventory shortage	Demand loss rate due to service capability	Demand loss rate in metropolitan area	Average travel miles per order
Current dedicated FCs	Single sourcing (zone allocation)	Slow delivery	Low	1	6.6%	1.4%	5.2%	0.5%	565.5
			Lean	2	0.0%	0.0%	0.0%	0.0%	567.3
			High	3	0.0%	0.0%	0.0%	0.0%	567.3
		Fast delivery	Low	4	10.0%	0.0%	10.0%	4.3%	551.9
			Lean	5	7.0%	0.0%	7.0%	4.2%	553.1
			High	6	7.0%	0.0%	7.0%	4.2%	553.1
	Flexible sourcing	Slow delivery	Low	7	5.5%	5.5%	0.0%	0.6%	604.4
			Lean	8	0.0%	0.0%	0.0%	0.0%	555.7
			High	9	0.0%	0.0%	0.0%	0.0%	555.7
		Fast delivery	Low	10	8.6%	0.2%	8.4%	4.3%	564.1
			Lean	11	6.4%	0.0%	6.4%	4.2%	544.7
			High	12	6.4%	0.0%	6.4%	4.2%	544.7
Open FCs	Single sourcing (zone allocation)	Slow delivery	Low	101	13.0%	0.0%	13.0%	1.0%	177.0
			Lean	102	0.1%	0.0%	0.1%	0.0%	173.1
			High	103	0.0%	0.0%	0.0%	0.0%	172.9
		Fast delivery	Low	104	13.2%	0.0%	13.2%	2.0%	174.3
			Lean	105	1.2%	0.0%	1.2%	1.1%	170.6
			High	106	1.1%	0.0%	1.1%	1.1%	170.4
	Flexible sourcing	Slow delivery	Low	107	5.5%	5.5%	0.1%	0.7%	246.7
			Lean	108	0.0%	0.0%	0.0%	0.0%	156.7
			High	109	0.0%	0.0%	0.0%	0.0%	148.8
		Fast delivery	Low	110	6.0%	2.7%	3.3%	1.9%	223.3
			Lean	111	0.8%	0.0%	0.8%	0.8%	154.8
			High	112	0.8%	0.0%	0.8%	0.8%	146.8

Self-organization in parcel distribution – SOLiD's first results

Hans Quak[1], Elisah van Kempen[1], Bernd van Dijk[2], Frank Phillipson[1]

1. TNO, The Hague, the Netherlands
2. PrimeVision, Delft, the Netherlands

Corresponding author: hans.quak@tno.nl

Abstract: *To bridge the gap between the long(er) term Physical Internet vision and the short term daily logistics operations, the Dutch Topsector Logistics (TKI Dinalog and NWO) requested a research project that would provide an impulse for self-organizing logistics. This contribution discusses the development of the research project SOLiD, Self-Organizing Logistics in Distribution, that answers to that request. First of all, we describe the design and developments of SOLiD by discussing the challenges in the parcel industry and how these could benefit from implementing solutions that relate to a more self-organizing logistics system. Next, the first results of SOLiD's experiments are presented. The experiments under consideration focus on dynamic planning and adding local intelligence to reduce handling activities. Lastly, we describe how autonomous sorting robots can be a means to achieve a more self-organizing logistics system. This paper provides new insights with respect to the considerations of designing, and the execution of practical experiments for implementing SOL as a step towards realizing the Physical Internet and make it more concrete for logistics industry.*

Keywords: *Physical Internet, Self-Organizing Logistics (SOL), Practical experiments, Parcel distribution, City Logistics*

1 Introduction

1.1 Towards a transition in the logistics system

Following Montreuil (2011) "the way physical objects are currently transported, handled, stored, realized, supplied, and used throughout the world is not sustainable economically, environmentally, and socially" and "Addressing this global unsustainability is a worldwide grand challenge, hereafter termed the global logistics sustainability grand challenge", we recognize the necessity for the logistics system to change in the (near) future. The grand challenge to make the transport and logistics system more sustainable is the major external driver for the required transition, as the Paris climate agreement requires a serious decrease in the GHG emissions of transport. Besides, transport turns out to be one of the most difficult and complex sectors to decarbonize.

Such a required transition could be seen as a major threat for the transport- and logistics industry in the coming years. However, the developed PI vision as well as other (external) developments, can also provide opportunities for transport- and logistics companies to, not only to improve the system's sustainability, but also to better serve the customers. The main contributing external developments we distinguish are:

- automation and robotization; and as a result a higher productivity level, which can make customer-oriented solutions affordable, that are currently (far) too expensive. The reduction in handling costs at different parts in logistics system (e.g. warehousing, last-mile deliveries) and the ability to run operations 24 hours a day could result in completely new logistics services satisfying customer demands better than the current services offered and at a reasonable price.
- full connectivity in the physical world; as the Internet of Things comes closer to reality, the digital and physical world integrate. This connected world allows physical objects, transport means and (logistics) infrastructure to be connected (constantly or intermittently). As a result new logistics services can be offered that are currently not feasible yet.

Although, these three developments, i.e. the requirement for more sustainability, automation and robotization, as well as the IoT-applications, are widely recognized to be or become very important to the logistics system in the future, for many logistics practitioners these developments sound more like the far future, than as concrete opportunities for their daily logistics operations. To bridge the gap between the long(er) term vision and the short term daily logistics operations, the Dutch Topsector Logistics (TKI Dinalog and NWO) therefore requested a research project that would provide an impulse for self-organizing logistics as well as a more concrete perspective / way of thinking for logistics practitioners with respect to opportunities for new logistics services or activities that on the short term can be expected by taking the mentioned developments in account. This contribution discusses the development of the research project SOLiD (Self-Organizing Logistics in Distribution) that answers to that request, as well as the first results of some of the experiments that followed that development.

1.2 Contribution's position and objective

This paper builds further on Quak et al. (2018) by discussing SOLiD's first experiments and how these can contribute to realizing some practical steps in the PI vision. SOLiD, (partly) financed by the Dutch Topsector Logistics (TKI Dinalog and NWO), started February 2018 as a response to the call 'Impulse for Self-organizing Logistics'. The nature of the call and the composition of our consortium[20] required us to satisfy several conditions for building up the project (for a more detailed account we refer to Quak et al., 2018):

- Enable research in an experimental environment,
- Proof-of concept project,
- The outcomes provide practitioners a perspective with respect to opportunities and barriers of a more self-organizing logistics system, and
- Experiments should be feasible on the short term and should fit in existing operations.

As a result SOLiD is composed around four different experiments in the parcel delivery industry. The experiments in SOLiD are a way to learn more on what self-organization could mean in daily logistics operations, rather than that the experiments are designed to develop innovations in itself. These experiments can provide an outlook with respect to the feasibility of a more self-organizing logistics system and the extent to which it possibly adds value for the parcel delivery- and logistics industry.

As this contribution continues on Quak et al. (2018), we also examined how SOLiD can be positioned in research published last year; when looking at the 2018 IPIC proceedings a few observations can be made:

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[20] The SOLiD project consortium consists of the following project members: TNO (project leader), DPD Netherlands, PrimeVision, TWTG, Thuiswinkel.org, the cities of Utrecht and Amersfoort and the Dutch universities: Delft University of Technology, Eindhoven University of Technology, Erasmus University Rotterdam and University of Groningen.

- The papers take varying angles with respect the Physical Internet and the logistic system of the future. Some adopt a data-driven and technology perspective, amongst others: deep learning (Gijsbrechts & Boute, 2018; Hillerström et al., 2018), and blockchain (Hofman et al., 2018; Dalmolen et al., 2018).
- Relatively a lot of papers are conceptual in nature, but at the same time provide results of (small-scale) simulation studies. Though there is a wide array of topics among these, such as: inventory control models (Ektren et al., 2018; Nouiri et al., 2018), capacity of parcel lockers (Thompson et al., 2018) and order bundling (Ambra et al., 2018).
- Also papers can be categorized based on their primary focus on either hubs or networks in the PI.
  - Arjona et al. (2018) provide a framework for PI hubs based on hubs in the digital internet, Faugère et al. (2018) consider smart locker based access hubs, Wang et al. (2018) focus on smart design of the PI hub (or warehouse) itself, Buckley and Montreuil (2018) simulate the impact of modular containerization on a parcel logistics hub.
  - The more network focused papers amongst others discuss: a case-study on the possible outlook of the PI network in Hungary (Ehrentraut et al. 2018), a case study on bulky goods delivery (Luo et al., 2018), a case study of a PI test region in Austria (Brandtner et al., 2018; Haider et al., 2018), hyperconnected last-mile delivery of large items in urban areas (Kim et al., 2018) and intermodal route planning in the PI (Prandstetter (2018). More vision-like papers are amongst others on PI networks in general (Dong & Franklin, 2018), or more specific with the concept of LogiPipe as a logistics pipeline for last-mile distribution in the Physical Internet (Schönangerer & Tinello, 2018).

Based on the above analysis (in a nutshell) we can relate our work both to the more vision-like papers, as we provide an outlook for realizing PI through SOL (self-organizing logistics), and to the research that conducts simulations with respect to hubs, as we show the results of dynamic sorting at a parcel delivery hub (see this contribution's section 3). On top of that, we add by providing first insights in real-life experiments (see section 4) and examples of already piloted concepts, such as the connected and modular automated sorting solution (see section 5). By doing so, we aim to bridge the gap between theory and conceptualizations of the PI and real-life implementation and implications for logistics practitioners.

First, this contribution discusses the joint efforts of practitioners and researchers in the choices and development of SOLiD's experiments to examine what value SOL can have in practice in the parcel delivery industry. Subsequently it discusses the (intermediate) results of the practical experiments the authors are involved with:
- Experiment 1: Dynamic planning
- Experiment 2: Adding local intelligence
- Implementing autonomous robots in sorting process

Finally, in the concluding discussion it provides a direction towards a more self-organizing logistics system.

2 Experimenting with self-organizing logistics as step to realize PI

The necessity as well as the opportunities leading to a changing logistics system, as discussed in this paper's introduction are not new. A growing number of papers examines the possibilities and limitations of a more self-organizing logistics system, in which more autonomy at a decentralized level in the logistics system and more local intelligence can contribute to either performance improvements or a better way to satisfy increasing receivers' demands efficiency.

Pan et al. (2017) describe the Physical Internet as an application of a Self-organizing Logistics System, in which physical assets, information systems and organization models are modularized and standardized to enable the connectivity, the following main functionalities are of importance in a future Self-organizing Logistics System:

- Openness (meaning that actors and assets can easily enter or leave the system).
- Intelligence (meaning the object-based capability of local real-time communication and activeness).
- Decentralised control (focusing on collaborative rules and communication protocols, that aim at preventing unexpected or undesirable system outcomes, rather than optimal planning).

Although, we mentioned developments in the introduction, that can lead towards the direction of a more self-organizing logistics system, such as the increase in connectivity, the further automation and the demand for a more sustainable logistics system, the transition of existing logistics systems is not evident for logistics practitioners, as was also recognized in literature by for example Sternberg and Norrman (2017) in a number of cautions for logistics practitioners in their PI review. Sternberg and Andersson (2014) do so with regard to decentralized intelligence in freight transport. They indicate in a critical review that - despite the growing number of studies and articles relating to decentralized intelligence in freight transport - there is little scientific support for the success of decentralized intelligence in logistics and that most research was mainly conceptual and rarely empirical. They conclude their review (of more than 40 articles) with the question if the transport efficiency can improve through more local intelligence. Next, Sternberg and Norrman (2017) discuss in their PI review (of 46 publications) that the majority of the PI literature contributions is conceptual. They conclude "What is crucial to understand from a shipper's or policy maker's perspective is that currently there are no well-developed models that illustrate how the move from the entrenched logistics models to the PI could ensue" (Sternberg and Norrman, 2017, page 750). Therefore, our aim is to experiment with logistics practitioners with only some of the functionalities Pan et al. (2017) mention for a self-organizing logistics system, as a full transition of the existing system is not within the abilities of (applied) researchers nor logistics participants in the short term. Our aim with these limited experimentations is to further develop both the thoughts in logistics industry on the (short-term) possibilities of more self-organization in logistics as an answer to existing and future challenges, as well as to enrich the scientific knowledge-base with more empirical evidence on applications where decentralized intelligence can be of value.

To reach this aim, we developed a research project together with logistics-practitioners (i.e. among others DPD Netherlands and Prime Vision[21]) and took their existing challenges as well as the expected future developments as a starting point to examine where some of the functionalities of a self-organizing logistics system could be applied and add value at the short-term. This has resulted in the research project called 'SOLiD'. In the remaining of section we shortly discuss the choices we made in the development of this research project, related to relevant literature. In the development of SOLiD we discussed several potential experiments that fit in the PI vision and in particular in applications of a more self-organizing logistics system for the parcel delivery industry. We choose the parcel delivery industry because of the following drivers that could allow for opportunities to develop new or other logistics systems:

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[21] Prime Vision (PV) is a Delft based software company with a long history in Computer Vision – particularly Optical Character Recognition-, System Integration and Sorting Decision management. Today, the company focuses on broader AI (apart from Computer Vision, also Robotics, Machine Learning and Natural Language Programming), general decision management and data connectivity.

- This industry faces – especially in the B2C home deliveries - an increasing development in customer-driven logistics, which can be a driver for a more self-organizing (decentral) logistic system, where web shops and carriers try to distinguish themselves by increased customer intimacy, and
- The volumes in this industry are increasing seriously.

Next, SOLiD's aim is not to develop a self-organizing logistics system for the parcel delivery industry, nor for one logistics operator, but to experiment with ideas that are in line with the PI-vision and can result in or show potential impacts of changes that could be undertaken to make the system more self-organizing. So the developed experiments in the project are not an objective in themselves, but a mean to further develop ideas and practical knowledge on the possibilities for a more self-organizing logistics system. Following Pan et al. (2017)'s functionalities of a future Self-organizing Logistics System, i.e. openness, intelligence, and decentralised control we developed several ideas based on the existing operations of our partner DPD Netherlands. In developing actual experiments we faced a couple of practical limitations. First of all, the functionality of openness is quite difficult to realize if you want to do experiments within running operations in a competitive market. We try to deal with this limitation by considering this functionality and its opportunities in the experiments, but do not actually combine or mix the existing operations of several (competing) parcel delivery companies. Next, practical limitations at the work floor or in the used systems can also be a limitation, as some functionalities are simply not yet available in most premises in the parcel distribution industry, e.g. parcels are not (yet) able to actively communicate. Based on such practical limitations, we developed a couple of ideas to gain (practical) knowledge in the possibilities and limitations for a more self-organizing logistics system in the parcel delivery industry.

2.1 Answering existing and future challenges in parcel distribution operations

First of all, there should be a logical reason to assume that a more self-organizing logistics system is an interesting direction for the parcel delivery industry. Therefore, we first examined the existing operations as well as the literature on what we defined most relevant and feasible as parts of a more self-organizing logistics system: more autonomy at a decentralized level in the logistics system and more local intelligence. We examined two areas where more self-organizing logistics elements could answer existing or future challenges in the parcel distribution system based on DPD Netherlands; i.e. i) challenges in the existing operations (also related to the increase in parcels over the last years and the expected growth) and ii) developments in the e-commerce and home-deliveries from the receivers and the e-tailers (i.e. customers of a parcel delivery company).

We started with examining the challenges in the current parcel delivery system of DPD Netherlands, and looked for solution-directions that would include more local autonomy or local intelligence. We also discussed challenges with two Dutch cities and the Dutch e-tailers interest organization Thuiswinkel.org. Based on the sessions with these organizations we found six challenges in the current parcel delivery practices, that (also on the short-term) could benefit from solutions that are (partly) in line with ideas to transform the system to a more self-organizing logistics system.

2.1.1 Relative static planning process

The existing process to determine the initial delivery areas in which the parcels are sorted at the depots are relatively static. The delivery areas are determined every four months and all parcels are already designed to a delivery area at the moment a label is printed by the sender of the

parcel. After the sorting of the parcels in these fixed areas, the parcels have to be reshuffled to the right areas, depending on for example the exact number of parcels per delivery area, which takes extra time (and man-hours) in the sorting process. Making this static process more dynamically, would reduce the time and man-hours needed for sorting, and – in line with the SOL system – would also allow for openness in the future of such a hub. However, in order to do so, several issues should be dealt with. Practically, as humans do the last part of the sorting (in some depots), it should be clear in which delivery area they have to put the parcel. Currently, that information is printed on the label, but in case these delivery areas are dynamically assigned this would no longer be sufficient. This issue could be dealt with using local scanners that show the new delivery area. Next, there should also be ways to plan the areas more dynamically, including elements such as (expected or actual) volume and with that the total number of delivery areas per day, and requirements per delivery address or area (which can be considerably different for B2C and B2B deliveries – that are combined in the delivery areas). Although, this practice cannot be generalized to all parcel delivery companies, it shows that in practice openness of hubs is not straightforward. Not only are new dynamic planning processes and algorithms necessary, but the actual hardware in the existing system probably needs to be updated to actually execute these dynamic planning and sorting processes. The experiments and studies for this idea are examined in SOLiD's experiment 1 (see also section 3 for the first results).

2.1.2 Increasing receiver demands

One major future challenge, that could also be a driver for change in the home delivery industry, is the change in receiver demands. More and more flexibility is required at a late stage of the process. However, if all receivers get the opportunity to require last minute changes in e.g. time slots or even locations, it won't be possible to plan efficient delivery routes. Following among others McFarlane et al. (2016), adding local intelligence and / or more decentralized decision-making power at a system level will not necessarily lead to kilometer-efficient logistics, but it enables for better customer intimacy. McFarlane et al. (2016) indicate that especially intelligent logistics systems allow for a higher degree of receiver (customer) orientation, in which decentralized intelligence is required. In this way the logistics system is able to answer to developments as:

• individualization of customer demand (including further diversification in delivery options);
• more transparent planning and execution, and as a result the ability to communicate about deviations, whether or not due to external factors, such as varying from traffic jams, recipients not being at home for the package delivery, etc., and;
• further automation of more components within the logistics process, in which local intelligence of people will be replaced by more automated processes, which also raises the question, at which level which decisions should be taken autonomously and how to arrange the systems accordingly.

It is precisely in these cases that more decentralized intelligence (or decision-making powers) could lead to solutions, which may initially not be optimal (compared to centralized planning), but which can lead to a quick and reasonable solution within the reality that has arisen. And for these cases it might be interesting for logistics industry parties to make the first steps that are in line with a more self-organizing logistics system. We examine the possibilities and the effects of suchlike systems in SOLiD's case 3 (both in simulation, as well as in – still to be defined – experiments in some neighborhoods). However, at the moment case 3 is still under development and therefore no results can be discussed in the remainder of this paper.

2.1.3 Relative low hit-rate at certain times in B2C deliveries

Another existing challenge is that, especially in the B2C deliveries, the number of non-successful first time deliveries can be relatively high. In the case of DPD Netherlands, B2C and B2B deliveries are combined in one round trip, and most roundtrips are between about 9.00am and 6.00pm. Very often the parcel delivery company cannot communicate with the receiver (i.e. the customer of the shipper), as the shipper (i.e. the customer of the parcel delivery company) does not provide the receiver's communication details; usually for the second attempt, the receivers can contact the parcel delivery company and provide their delivery options, such as neighbor-delivery, put down at front door allowance, parcel shop delivery or specified delivery day (and time), which results in a high success rate for the second time deliveries. However, the hit-rate in the beginning of the afternoon is currently relatively low, as many receivers are not at home then and most B2B deliveries are made in the morning. Probably the simplest answer to this challenge is to start delivering B2C parcels in the evening, as more receivers are at home then. However, this is not really in line with the SOL system, nor is it desirable from DPD Netherlands perspective at the moment. Therefore, we aim at increasing the 'local intelligence', which means (as we cannot directly communicate with receivers, which would be the preferred option, see also 2.1.2) that we could plan to build address intelligence on neighborhoods where the first time right is relatively high and plan these parcels early in the roundtrips and the areas that have usually a low hit-rate later in the trips. These changes might influence the kilometer efficiency of the roundtrips, but that should be weigh up against the improved successful deliveries. SOLiD's experiment 3 deals partly with this challenge (see also section 2.1.2), however, we are – at the time of writing – still defining the exact experiment, so we cannot present results in this paper.

2.1.4 Expected increase in volume

A major challenge for parcel delivery companies is the yearly increase in parcels to be delivered, and in particular the increase in peaks; both in length (amount of days) and in height (the number of parcels on peak days). The main challenge lays in the capacity to sort all parcels for which more and more (expansive) sorting centers are necessary. Next, also the availability of delivery men and vehicles is a challenge for the peak periods. In section 5 we discuss an illustration of autonomous sorting robots (that can be self-organizing), as a way to deal with the sorting capacity in peak periods (which is developed by Prime Vision, separate from the SOLiD project).

2.1.5 Perceived van nuisance in neighborhoods

A complete different challenge comes from the participating cities. In many (Dutch) neighborhoods, residents (as well as other traffic participants) perceive nuisance from the many vans and small trucks making home deliveries. Although, ideas could be generated, such as neighborhood hubs (as part of the PI) to bundle all home deliveries for a neighborhood to reduce the number of vans from (competing) companies making home deliveries, experimenting with it in practice turned out to be quite difficult, as this would require the support and collaboration of more than one company making home deliveries.

Although cross-docking activities and activities at a parcel distribution center are not necessarily the same (as at cross-docking facilities some temporary less than 24h inventory might be held, whereas at a distribution hub parcels are immediately assigned to delivery areas), the study of Chargui et al. (2018) provides interesting results which might give us some insights with respect to Experiment 1 (see section 3) and the role of autonomous sorting robots (section 5). In the PI-hub the authors assume automated loading and unloading PI-docks and conveyors and an automated storage and retrieval system. Chargui et al. (2018) show that a PI-hub with automated loading and storage and retrieval have a positive impact on the performance of cross-

docking facilities. Especially by reducing the waiting time of inbound and outbound trucks, the total time spent by products in the cross-dock and the number of inbound and outbound trucks waiting for a service. Similarly, our further work that will build on experiment 1 will look into KPIs such as waiting time and resource usage.

Another idea that was examined was the 'self-organization' of parcels in different vans, without the need for a local hub. The idea was relatively simple, two vans can park next to each other and based on parcel information exchange parcels so that the deliveries are smaller, and the number of vans necessary per area is halved. Unfortunately, the same barriers applied to this experiment as for the neighborhood hub, so this was not further developed. There are opportunities, though, for a reduction in vans by suchlike solutions, however this seems mainly interesting for neighborhoods and local policy makers, and business-wise not too interesting for the delivery companies at this moment.

2.1.6 *Separation of tasks: efficiency gains for van driver / delivery person*

Finally, we found another operational challenge; at the current operations at DPD the van driver loads its own van. The advantage is that the driver knows where the parcels are located in its van and the driver should be able to find the parcels relatively easy when delivering. The disadvantage is that it takes time from the driver, in which the driver cannot make deliveries. Considering the lack of drivers, as well as the (future) possibilities to partly automate this process (which would belong in section 2.2), we look at ways to add intelligence in the process, so that the driver can find the parcels in the van during the delivery route, also in case someone else loads the vans. SOLiD's experiment 2 goes into this issue (which is described in more detail in section 4). From the direction of adding SOL elements in the process, this would contribute to adding more intelligence at a parcel level. In experiment 2 we focus on reducing the handling activities of the parcel before loading the vehicles in the parcel distribution hub. The throughput time of a parcel in a hub is critical to overall network performance. Similarly, Buckly and Montreuil (2018) also suggest to minimize a parcel's required touches. However, their solution lies in introducing PI containers such as packs and boxes. These can ensure consolidation of parcels that head for the same destination. Simulated results show promising efficiency gains of 8% if parcels are pre-consolidated using these boxes. So there are different ways to reduce the number of handling of parcels and to improve efficiency. We were not able to include PI containers in SOLiD's experiment.

2.2 Technology push: opportunities due to new technology

In our definition of directions towards more self-organizing logistics systems we considered more autonomy at a decentralized level in the logistics system and more local intelligence as most important elements. After examining the 'pull-developments' in the previous section that can pull the parcel distribution system towards a more self-organizing system, we also looked at 'push-developments'. These push developments come more in the form of opportunities following from technologic developments that mainly allow for more automation in the parcel delivery system (see for example Maslarić et al. 2016).

Although some of the technology push developments can contribute to or closely relate to answering the challenges mentioned in section 2.1, the difference is that for the push category the main challenge is not so much in adding more autonomy at a decentralized level in the logistics system or more local intelligence. The challenge is mainly how to make sure that the existing local autonomy and intelligence that is available in the humans who are currently quite self-organized parts of the existing logistics system can be sufficiently made available in a more automated process. We recognize here that the automating of parts in the parcel distribution system in itself does not imply that the system becomes more self-organizing, but that for a

more automated system the degree of local autonomy and intelligence are very relevant in the possibilities for the design. As a matter of fact, in the current system the humans turn out to be quite 'self-organizing' in solving issues and performing best practices based on experience. Therefore, we see quite a challenge in automating different processes, as that kind of behavior should be captured in order to make the parcel distribution system more autonomous (and the several elements self-organizing). We distinguished two ideas during the development of SOLiD that fall in the technology push category, i.e. autonomous sorting robots and the use of an autonomous moving locker box for make the last mile deliveries. The next sections shortly discuss these ideas. We are not able to realize these experiments in SOLiD.

2.2.1 Autonomous sorting robots

Montreuil et al. (2018) examine how hyper-connectivity and modularity concepts underpinning the Physical Internet enable the parcel logistics industry to efficiently and sustainably offer faster and more precise urban deliveries. In section 5 we provide an illustration that is precisely exploiting these two characteristics through implementing (modular) autonomous sorting robots in the parcel industry. This illustration is based on the developments by Prime Vision, and is not part of the SOLiD research project.

2.2.2 Autonomous parcel locker boxes for last mile deliveries

Finally, one technology push driver for more self-organization in the parcel distribution process that was often mentioned in the SOLiD's development stage had to do with automating the execution of the last mile, as this is both a relative expensive part of the parcel delivery system, as well as that it is expected to change in order to even deliver more receiver-oriented (see section 2.1.2). A possible technical solution would be to use autonomous vehicles for making the final deliveries. Some studies are showing the potential benefits (see for example McKinsey, 2018) and experiments are running (see for example the experiments with Starship's Self-Driving Delivery Robots), eventually we decided not the experiment in this direction in SOLiD. Although, we developed plans in which we could experiment with delivering via a driving parcel box, that would not have been autonomous in the neighborhoods but still use a driver, to examine the receivers' experiences, the expected time to real implementation of suchlike solutions (due to the too low TRL level of the autonomous driving vehicle) was the reason to focus on other elements that relate to a more self-organizing logistics system in the parcel distribution system.

2.3   Experiments and developments

Finally, we developed the plan for four experiments in SOLiD, that are often combinations of simulation studies, followed by experimentation in practice. SOLiD's four experiments are shortly mentioned in the previous sections and in Quak et al. (2018). The remainder of this contribution discusses the first simulation results of experiment 1 (more dynamically planning of the delivery areas) and the set-up of experiment 2 (adding local intelligence in order to reduce handling activities; i.e. separation of the van loading from the driver, but still provide the sufficient information to find the right parcels during the last mile delivery roundtrip). Experiments 3 (replanning of delivery routes based in receiver feedback – even during the trip) and experiment 4 (making local intelligence of a good-performing drivers available) are at the moment in the planning phase, and won't be discussed in the remainder of this contribution. This contribution discusses a side-development of PrimeVision that relates to the SOLiD experiments, i.e. autonomous sorting robots in section 5.

3 Experiment 1: Dynamic planning

3.1 Background and objective

In the current situation, the delivery areas at DPD Netherlands are already determined before the sorting process in the sorting center or hub location starts. The delivery areas are defined using historical data and are replanned every few months and are already printed on the labels at the moment of sending. As a result of this, fluctuations in the number of parcels in specific delivery areas can only be adjusted after the sorting has taken place. Reassignment of parcels to delivery areas is done manually after sorting in case some areas have too much or too little capacity left.

Objective: We aim to plan the delivery areas more dynamically. The question is how many parcel data is required to determine these areas better than is done in the current situation. By more dynamically planning delivery areas, this case provides a view on possibilities for decentralized sorting. These insights can be used in the parcel industry to handle peaks more easily by for example using small sorting robots. More flexibility in the planning is also a necessity in a SOL system for hubs to function, as the existing static planning way contradicts to Pan's et al. (2017) openness-functionality (as well to the other SOL system functionalities).

3.2 Method

In this experiment a simulation environment is set up where various dynamic planning options can be tested and examined in more detail. In essence we consider the issue of assigning the incoming parcels at a hub (with limited or no storage capacity) to a number of delivery areas. After the assignment to the delivery areas parcels will be distributed to the final receivers. An important challenge lies in the fact that the destination is not known on beforehand and is revealed only when it arrives at the hub. We distinguish two steps in our approach (Phillipson & De Koff, Working paper):

1. Initial assignment of the delivery areas: this gives a potential direction and scope of the delivery area.
2. Dynamic assignment of the arriving parcels: this involves the direct assignment of parcels that arrive at the hub. This occurs dynamically or 'on the go'.

For each of these steps we distinguish several methods. By combining these methods we can generate various possible scenarios, which we simulate in the simulation environment.

3.2.1 Initial assignment

The methods used for initial assignment are presented in Figure 39. In the first method (No load), the delivery areas (in Figure 1 represented as a van) stay empty until the first dynamic assignment in step 2 of the assignment process (see 3.2.2). The basic load method assumes that a certain percentage (x%) of the parcel's destination is known on beforehand. Subsequently these are assigned to the delivery areas using a VRP method solution. In case of method 3, separation by dummy location, a k-means clustering over all potential customers (based on postal code) is executed. Subsequently a dummy parcel with one of the customer cluster

Figure 39 - Initial assignment method

means is assigned to each of the delivery area. The fourth and final method also executes a (k-

means) clustering over all potential customers. Then, a zip code cluster is assigned to a delivery area.

3.2.2 Dynamic assignment

The methods used for dynamic assignment are presented in Figure 40. The first method is based on smallest distance to cluster mean. The arriving parcel is assigned to that delivery area for which the distance from the parcel destination to the geographical mean is minimal. In case of dynamic assignment based on minimal insertion costs we calculate a minimal cost of inserting the arriving parcel destination to the route of a specific delivery area. The insertion that is cheapest will be selected. The third method uses fixed clusters; the parcel is assigned to the cluster it belongs to using the postal code of the receiver. The fourth strategy is proposed to account for situations in which parcels arrive at the hub that should have been assigned to a vehicle, but cannot, due to capacity restrictions. The price of insertion increases when the vehicle has more load.

1. Smallest distance

2. Minimal insertion costs

3. Fixed clusters

4. Minimal insertion costs with penalty
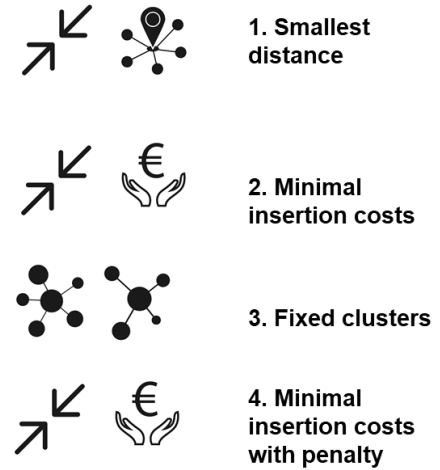
Figure 40 - Dynamic assignment methods

3.2.3 Assumptions

The assumptions made in this simulation are listed below:

- Demand = parcels have to be delivered to receivers in a certain region
- There is a homogeneous demand over all potential receivers. Receivers are characterized by a postal code area.
- In the base case the parcel is simultaneously with revealing its destination assigned to a delivery area (and an outgoing vehicle).
- The delivery areas (and vehicles) have a fixed capacity, implying that: in case of dynamic assignment method 1 and 2, the vehicle cannot be selected anymore for assignment if the vehicle is full.

3.3 Result

Various scenarios (a combination of an initial assignment method and a dynamic assignment method) were tested and compared a 'full information solution' in which all information (amount of parcels and related destination) is known on beforehand. Phillipson and De Koff (Working paper) show that the best performing methods are: A). The combination of No load (1) and dynamic assignment by minimal insertion costs with penalty (4) and B). The combination of separation by dummy location (3) and dynamic assignment by minimal insertion costs with penalty (4). These two methods would result in a 14-17% higher cost than the full information VRP solution.

Further analysis reveals that forecasting can be very powerful. In this scenario there is a known basic load for all delivery areas and dynamic assignment using 'minimal insertion costs with penalty' is used. Furthermore, 50% of the destinations of parcels is known/ forecasted on beforehand. Consequently, a decrease in costs can be realized and this solution results in a 6% higher cost than the full information VRP solution. To conclude, a dynamic assignment method that minimizes insertion costs whereby insertion prices increase when a vehicle has more load, leads to most favorable results in terms of costs minimization. The outcome can even be improved if the destination of half of the parcels is forecasted.

3.4 Experiment 1 in relation to SOL

The situation continues coming period, where we also examine if adding of more information (e.g. parts of the incoming parcels is pre-registered) can help in making forecasts in both the expected volume for a day and the expected distribution – including also historical data on volumes. At the same moment, the necessary hardware changes are also made by DPD Netherlands, which make it possible to actually execute a more dynamic planning of delivery areas; i.e. the information on the final delivery area should be made available to the final sorter (also there where this is done manually, and where people now rely on the printed area on the label). This continuing study and experiment shows, that it now already has advantages to move more in the direction of what would be necessary in hubs in a self-organizing logistics system. This enables current operations to become more efficient, and at the same time provides the first (small) step to become aware and a bit ready for the logistics operator for the transition towards a more SOL system in the parcel industry (in the future).

4   Experiment 2: Adding local intelligence to reduce handling activities

4.1   Background and objective

In the current situation after parcel sorting several manual actions are required by the van driver. Such as reassigning parcels to delivery areas in case capacity requirements are not met. This is a highly unfavorable situation as drivers bring more value to the parcel distribution system when they are actually driving around and distributing parcels, instead of manual actions inside the distribution hub to cope with and solve inefficiencies that result from the sorting process. One of the tasks that could be separated from driving and delivering is the loading of the vans. Currently the driver is loading the vans, which has the advantage that the driver already saw all parcels and knows where the parcels are in the van when starting the roundtrip. Note that the amount of parcels is high, and that the vans are relatively fully loaded (which makes the use racks, as is common-practice at some express distributors, in the van impossible, as this would reduce capacity too much).

Objective: We aim to reduce handling activities. It is hypothesized that once handling becomes more efficient, self-organizing logistics can be realized sooner; parcels 'flowing' through the system will become a closer reality. In order to reduce handling activities it is chosen to add local intelligence in the process.

4.2   Method

In this experiment we compare a more central form versus a more decentral from of intelligence. We do so by developing two elements. We include local intelligence by adding a location of the package in the van in the hand-held of the driver: by means of a virtual grid in the van, the parcels are indicated where in the van the specific parcel must be placed during the loading This location is made available to the driver during the execution of the trips. This decentralized intelligence is further increased as photographs (made during the sorting process, i.e. on the sorting belt of each package, are also made available to the van driver. The barcode of each package is linked to the relevant photo and location in the van. Next, the van driver is enabled through an interface (e.g. a smartphone) to view the picture of the package and the location (where it was placed during the loading of the van) on the mobile phone. The duration (and thus performance indicator "costs") to find the right package in the delivery van is measured (and compared to the first situation). At this moment, the technical developments are finished, so that both the locations in the van are assigned (and if necessary overruled by the person loading the van) and the pictures are taken during the sorting. This information is now linked to the information the driver normally has, such as bar code and address.

The first measurement for the experiment are also done; which basically only includes measuring the time it takes to load a van by an experienced van driver. Next, the experiment continues, at this moment it is planned both in a controlled environment (loading and unloading of a fixed set of parcels by a test person) and in the practice (with experience drivers doing the unloading during the roundtrip).

4.3 Experiment 2 in relation to SOL

Both ways to add local information in the parcel delivery process provides ways to disconnect the loading of the van from the unloading of it during the execution of the actual roundtrip. This shows how parts of the process could be further automated (i.e. technology push, in which case it is necessary to increase the amount of local information, as some of the self-organizing elements of the human being who is responsible for the process at the moment, is nreplaced due to automation). Besides, it also illustrates how, in a more self-organized (like PI application) situation, van drivers can easily distinguish the right parcel – even if it comes from other networks and is not loaded by the driver.

5 Autonomous sorting robots as a means towards SOL.

As described by Quak et al. (2018) external developments such as the progress and increasing pace of automation and digitization enable the connection between the physical and the digital world. These create ample of possibilities for a transition of the logistics system into a more self-organizing system. We do not argue that automation and digitization automatically would lead to a self-organizing logistics system, nor that all logistics systems should become more self-organizing. Rather, we see some direct examples in how automation can contribute to self-organizing logistics. As such, we explore the possibilities of the Autonomous Sorting System that PrimeVision, a SOLiD project partner, is experimenting with.

5.1 Autonomous sorting system – the concept

PrimeVision introduced the Rover, an autonomous robot, controlled via algorithms, that can identify, assess, sort and physically transport items to dispatch location (see Figure 3). Currently pilot implementations at logistics companies are running that combine the Rovers with human operators. The operators scan the parcels and put these one-by-one on the Rover (Figure 42). The Rover automatically determines to which destination conveyor belt the parcel should be transported and makes sure it arrives there. The Rover drops the parcel at the destination conveyor belt and finally the operator takes the parcel off. Rovers are safe to operate alongside human co-workers.

Figure 41 - Rover: An Autonomous Sorting Robot by PrimeVision

| 1. The operator scans the parcel and puts it on the Rover | 2. The Rover finds its way | 3. The Rover drops the parcel at the destination conveyor belt | 4. The operator takes the parcel from the roller belt. |

Figure 42 - Autonomous sorting system as example of a self-organizing logistics solution (source: PrimeVision)

5.2 Developing autonomous sorting

Postal and logistics companies are keen to learn how intelligent combination of advanced robotics and Internet of Things (IoT) could bring cost and efficiency savings to the parcel sorting processes. To meet this demand in the logistics market, the Autonomous Sorting Robots were invented and developed. The Rovers are not a stand-alone technical innovation, but are part of a broader vision that impacts the whole (parcel distribution) logistics system (see figure 5).

Autonomous robots: To date the robots autonomously sort parcels and are able to roll containers. Currently, the system is organized in a hybrid fleet management system.
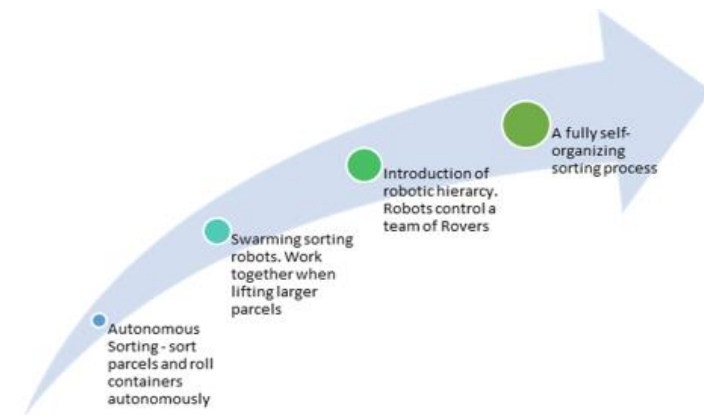
Figure 5 - From autonomous sorting robots to a fully self-organizing sorting process

The robots operate in a decentral path, while decisions are formed with information from a central database. The configuration of the current robots was created in close cooperation with technical partners and also insights gained through market consultation were incorporated. The design is adapted to meet Working Conditions regulations. Computing power has been increased to allow for higher quality algorithms and sensors. Also, further autonomy has been achieved by decentralising collision avoidance, path planning and navigation.

Swarming robots and robotic hierarchy: The next step in the development of the Rovers is to create the ability for the robots to swarm. The robots work individually, but can work together as a single unit to move larger items when needed. The Rovers will be designed to behavior similar to worker bees, collision evasion is inbuilt, allowing them to work together when lifting larger parcels. Furthermore it is planned to introduce a robotic hierarchy, with a master-slave relationship that employs increased intelligent robots that able to make real-time, data-led decisions to control teams of Rovers.

A Self-Organizing Sorting Process: Eventually the swarming autonomous sorting robots can be part of a more broadly self-organizing sorting process, whereby also robotic loading arms, autonomous vehicles and maybe even drones can be deployed. It is important to note that the ultimate goal is *not* to automate the current system. Rather, the cornerstones of the envisioned self-organizing sorting process are agility and scalability. PrimeVision closely monitors the responses in the logistics practice towards their autonomous sorting system. It is observed that practitioners in the logistics industry value the flexibility and the modularity of the system. It is exactly these characteristics that make it fit in the Physical Internet vision. As figure 5 also illustrates, suchlike – at this moment – small new innovations in the system can be a starting point for a larger transition of the system towards a more self-organizing parcel delivery system.

6 Concluding discussion

This contribution deals with the first results of the SOLiD project; Self-Organizing Logistics in Distribution. Already described by Quak et al. (2018) how serious gaming and practical experiments can contribute to raise awareness for realizing the PI vision, we build further on this by providing the latest findings in SOLiD on dynamic planning approaches and adding local intelligence for reducing handling activities. Also we describe – though not in the scope of SOLiD, but executed by one of our project partners – how autonomous sorting robots can be a means for achieving a more self-organizing logistics system. As this paper presents SOLiD's

(preliminary) results of experiment 1 and 2, future contributions will further deepen these and look into whether and how to implement these in daily operational business. Also next year, results of SOLiD's other experiments on continuous replanning of delivery routes based on receiver feedback and local intelligence of good-performing drivers can be expected. By that we will give a more practical contribution to the field of Physical Internet and Self-Organizing Logistics in the parcel distribution industry.

By showing the process of designing and developing real-life experiments towards a more self-organizing logistics system as a step to the Physical Internet, we hope to inspire other researchers in the field of PI as well. By analyzing the current logistics system (which is in our case limited to the parcel distribution industry), identifying challenges together with logistics industry and related stakeholders, coming up with self-organizing logistics solutions that might help overcoming or bringing benefit to these, and translating these into concrete experiments, we have shown a way of bridging the gap between the more long(er) term PI vision and short(er) term implications for logistics practitioners. Here we would like to emphasize the importance of this process as we believe that the field of PI could move forward by more practical-based research with a clear perspective for action for the logistics industry.

Acknowledgements

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"protoPI" - Development of a prototypical Gateway to the Physical Internet

Dr. Bartosz Piekarz[1],
FH-Prof. DI Hans-Christian Graf[2], DI Florian Ehrentraut[3]

1. Johannes Kepler University Linz - Institute of Production and Logistics Management, Austria
2. University of Applied Sciences Upper Austria – Logistikum, Steyr, Austria
3. Graz University of Technology – Institute of Logistics Engineering, Graz, Austria
    Corresponding author: Hans-Christian.Graf@fh-steyr.at

Abstract: Within existing supply chains there is still a significant potential for the combination of part and single unit loads, but in many cases competing suppliers as well as fix contracted service providers hinder optimized truck fill rates and transport consolidation. To overcome these drawbacks, within the FFG-funded project "protoPI", a team of Austrian research and business partners developed a) an integrated conceptual framework and b) a web-based transportation management platform in order to show and evaluate the potential of the PI approach to real life applications. By digitalizing the transport management process as far as possible, pooling systems for further developed returnable transportation items (RTIs) are made possible and significant potential cost savings in the delivery process can be identified, resulting from the use of specialized transport service providers (TSP). This could be of particular relevance for small and medium-sized enterprises, which in many cases are dependent on global forwarding companies.

Keywords: *Transportation Management, Digital Business Platform, Coopetition Business Model*

1   Introduction

The conceptual approach of the Physical Internet can undoubtedly be granted a tremendous charm in scientific terms, but the great leap from the digital concept world to the lowlands of physical logistics (still) does not succeed. Industrial and commercial companies cannot really approve of PI approaches because they often prefer their own (non-open) transport systems. Transport and logistics service providers often see the PI approach as a threat to their own core business.

The complexity of the project is reflected not least in the assessment of the European technology platform ALICE, which makes recommendations to the EU under Horizon2020 to propose the Physical Internet as a target for the year 2050 (ALICE 2015). Previous pilot projects clearly show the difficulties of such a project, which does not only have to solve technical problems but also organizational and legal difficulties. On the other hand, there are industrial pilot projects in which parts of the PI (such as the exchange of information and physical resources) are successfully deployed (Bohne/Ruesch 2013). A selection of practical applications from the areas of warehousing and transport are described in DHL/Cisco Trend Report, for example. Applications in incoming goods (acceptance of goods with RFID tags), better application possibilities in Track & Trace through higher visibility of the objects as well as information on the content of load carriers on the Last Mile and tools for monitoring the resilience of the supply chain (DHL/Cisco 2015) should be highlighted.

Project Goal

The aim of the protoPI project was to demonstrate the potential of a new PI business model to be conceived via Internet-based order platforms using a demonstration model corresponding to the visions of the physical Internet for the inter-company consolidation of transport orders. The chances, tasks and duties of the future PI system partners were assessed or mapped in a prototypical application model. In addition, the functional and technical requirements had to be developed based on the philosophy of the physical Internet and on state-of-the-art IT systems available on the market. Ultimately, these elements lead to a reference model, which serves as a basis for further work packages and developments.

Case study simulation and prototype design were chosen as the main methods, which, in the context of comparable PI publications (Sternberg/Norrman 2017), are among the most frequently applied research methods.

Survey on Transportation Management Systems

In the course of the project, transport-relevant software products were first examined, which are increasingly being used in German-speaking countries. Tour planning programs, freight exchanges and classic freight forwarding software packages were identified as the most frequently used ICT systems. Over the past two years, however, it has also been observed that more and more start-ups are entering the transport market internationally who want to change it disruptively. These therefore represent a further system group, as they enable new functionalities and cannot be assigned to an existing group. The start-ups push the direct contact between shipper and freighter or truck driver as a digital forwarding agency. From an operational point of view, this means that the system actively displays additional loads to the truck driver (alternatively also to freight forwarders or dispatchers) when free capacities are available, which he can also take with him and which are anyway on the route or represent a minor detour. This enables the hauliers to generate additional turnover, the transport operators to transport goods quickly and the overall transport distances to be shortened.

Modern transport management systems (TMS) are increasingly relying on the complete outsourcing of transports (to the detriment of the company's own fleet) and thus represent quasi-digital purchasing platforms. The main customer benefit resulting from the use of such systems is the management of the transport partners together with their freight offers and the IT-supported commissioning of individual transports according to certain criteria (e.g. the cheapest freight rate for a particular transport relation). A selection of well-known TMS in German-speaking countries can be seen in the fig.1 below: In addition to the market leader Transporeon and the "digital forwarding platform" Cargonexx, two Austrian solutions are also represented with Elogate (of the project partner SATIAMO) and Spot.

	Key Features:
SATIAMO ELOGATE	▪ web-based transportation order allocation ▪ administration of service provider tariffs ▪ mobile feedback via app
SPOT Supply Chain Visibility & Collaboration Platform	▪ digital platform for automating the procurement and delivery process ▪ transportation and freight price module
TRANSPOREON	▪ contracting platform for shippers ▪ connection to a large number of TSPs ▪ individual services available
CARGONEXX	▪ digital trading platform for FTL transports ▪ truck loads are priced and sold based on algorithms

1.1.1 Figure 1. Overview of Selected Transportation Management Systems

Integration of Transport Service Providers

A look at the structure of the Austrian transport industry (see fig.2) reveals the great benefits that transport management systems bring to loading industrial and trading companies: The freight transport sector with its more than 11,000 players and more than 1,600 freight forwarders reflects the highly fragmented market.

☐ 44.1 billion **turnover**
☐ 213,224 annual average number of **employees**
☐ 11,082 **Enterprises** in the freight transport sector
☐ 1,645 **freight forwarders**
☐ 109 **railway operators**

1.1.2 Figure 2. Structural data of the Austrian transport industry with a focus on freight transport (WKO 2017)

The companies surveyed or examined in the course of the project use a different number of transport service providers depending on the size of the company. While small companies often only commission a single groupage freight forwarder and, depending on the consignment structure, also use parcel services and, in some cases, carriers for full loads, medium-sized and large companies use a significantly higher number of transport service providers (see fig.3). A distinction is made here not only according to the structure of the consignments (parcels, general cargo, partial loads, full loads, containers, etc.) but also according to the respective destination (usually as countries or regions).

	Small Enterprise	Medium-size Enterprise	Large Enterprise
parcel service	0-1	1-3	1-5
groupage freight forwarder	1-2	1-5	3-7
FTL carrier	0-3	1-10	5-25

1.1.3 Figure 3. Typical Structure of Used TSP depending on Company Size

In summary, it can therefore be said that the larger and more differentiated the shipment volume and the more standardized (digital, uniform) the process handling, the higher the number of transport service providers used. This means that the corresponding profiles, tariffs and performance and cost values must also be managed by an appropriate transport management platform.

As "post and search" coupled with "negotiation" is still the prevailing method of freight purchasing in practice (Lafkihi et al. 2019), a digital supplier management of transport service providers must be in the focus of a PI transportation management platform.

Effect Evaluation

In order to be able to quantitatively evaluate the concrete benefits of a PI-based transport management platform, the flows of goods between two strong economic regions in Austria, namely Upper Austria in the north and Styria in the south, were used as the background for the analysis and evaluation.
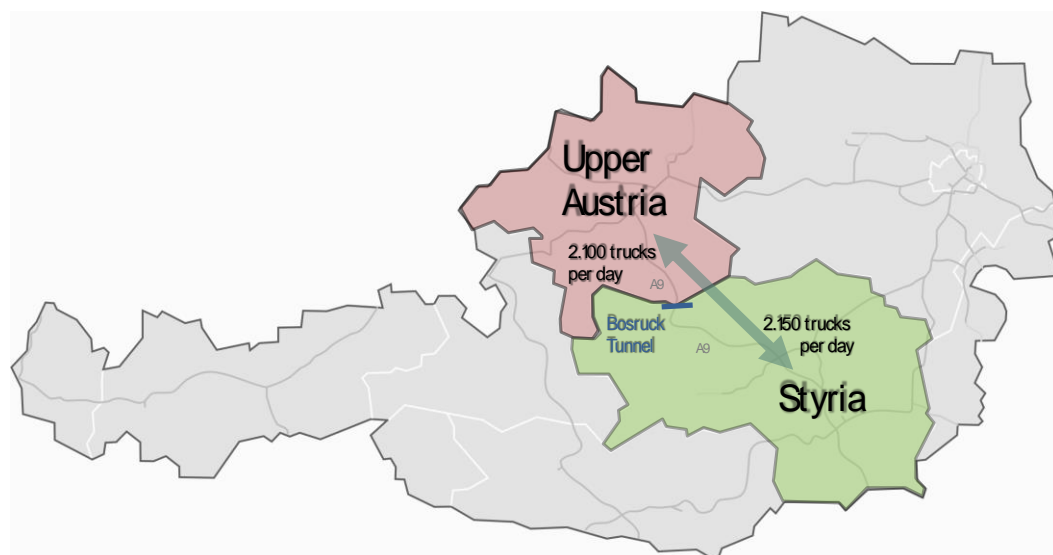
1.1.4 Figure 4. Considered Transport Relation on the Austrian A9 Motorway

Since the main connection between the two regions runs through a toll tunnel - the Bosruck Tunnel - on the A9 motorway, the corresponding counting point could serve as a quantitative starting point for the benefit assessment. The Austrian motorway operator ASFINAG records the traffic at the Bosrucktunnel toll station (see fig.4). The relevant data were therefore easily

available online. On average, 2,150 trucks per day were travelling towards Styria and 2,100 towards Upper Austria at the Bosrucktunnel toll station on Mondays to Fridays. This results in a volume of about 300-400 trucks per working day and per direction on this route. Every year this is between 90,000 and 120,000 trucks.

In addition, relevant practical partners (freight forwarders, forwarding agents, industrial partners and software partners) were interviewed for an in-depth analysis of market conditions in order to draw conclusions about volume flows, consignment structure, order processing process and filling levels. In some cases, the project consortium was also provided with a shipment structure data set.

Conceptual Framework

What do a medicine, an X-ray machine, a frozen chicken and a doctor's coat, all of which are to be delivered to a hospital, have in common from a logistical point of view except for the same delivery address? From the point of view of the physical Internet metaphor, it would be efficient to pack these goods in standardized PI containers and deliver them together. In practice, however, this is difficult to impossible since

- There are bans on loading between certain goods (medicine/food);

- Different temperatures are required for transport (frozen goods);

- Larger appliances are usually supplied with a crew of 2 (appliances);

- Certain goods require a higher delivery service or shorter delivery times.

This simple example illustrates the current gap between an overall theoretical concept and actual logistics practice. Isolated PI prototypes cannot hide the fact that a general roll-out of the PI approach is problematic. Even the best documented case studies refer to one class of goods (see Hakimi et. 2012 and the example of the French Fast Moving Consumer Goods flows described there). Therefore, the application-oriented implementation of the concept should be based on the following premises:

(1) A larger number of different transport service providers must be integrated into an envisaged transport management platform;

(2) Their service offerings must be sensibly segmented according to certain criteria so that they also contribute to higher profitability through more adequate logistics structures;

(3) The role of the platform operator must be defined in such a way that it does not have a negative impact on the actors involved.

(4) Standardized returnable load carriers should be integrated into the concept.

System Architecture

The transport management systems used in practice (see fig.5) are all geared to individual shippers. The underlying service provider pool as well as the corresponding tariff structure are mostly static (determined by periodic tenders), the exchange of documents in the transport chain is limited (since usually only a one-step view is taken).

Shipper

Transportation Management System

- restricted proprietary **service provider pool**
- static integration of new service providers through **tenders**
- service provider **tariffs** apply only to the individual shipper
- **new service providers** are de facto unknown
- mainly **carriers** are listed
- **transport documents** are not shared

Carrier   Carrier   Carrier   Carrier
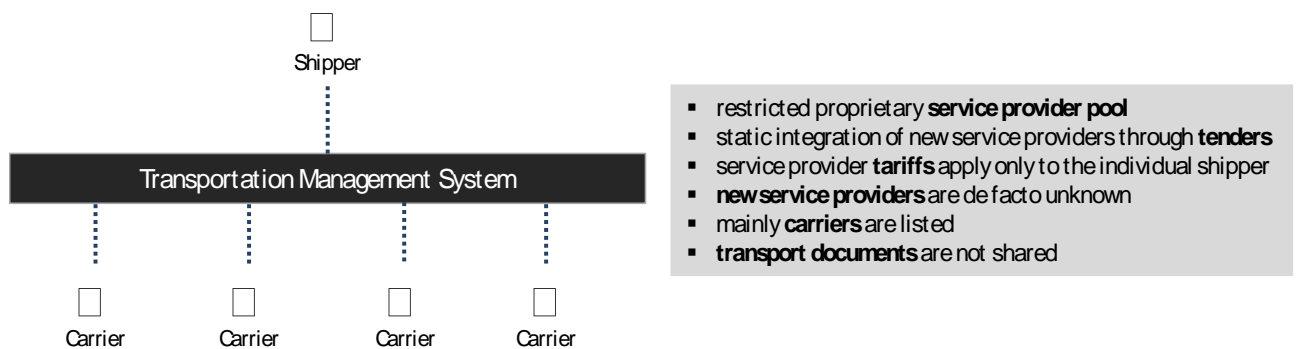
Figure 5. Traditional TMS Architecture

In opposite to that, the PI concept is based on the approach of an open transport platform, where the transport service providers (TSPs) used are shared between the shippers, thus creating a higher degree of bundling. In addition, logistics infrastructure and pool providers for returnable systems must also be integrated in order to be able to map new and multimodal transport routes (see fig.6).

Shipper   Shipper   Shipper   Consignee   Consignee

PI Transportation Management Platform

- joint, open pool of **service providers**
- dynamic integration of **new service providers**
- service provider **tariffs** might apply to all shippers
- a **history** is available for each service provider
- neutral **HUB operators** and **pooling services** will be listed
- transport documents are shared

Carrier   Carrier   Carrier   Carrier   HUB   Pooling Service

Figure 6. Open PI Transportation Management Platform Architecture

PI Channels

Starting from the almost universal idea of a physical Internet for all kinds of goods, the following realistic limitations were imposed due to the practical observation and evaluation of the logistic systems represented in the project:

- Due to product technical, legal and other aspects of the transported goods (e.g. temperature requirements, hazardous goods, bans on additional loading, choice of means of transport, ...), not all goods can be transported via a single, overall optimized system. Rather, it makes sense to define individual transport channels that are independent of each other but can also be used alternatively.

- This leads to the applied definition of PI channels with a bundling of mutually compatible goods via an adequate system configuration.

According to our understanding, the Physical Internet thus consists of a multitude of PI channels existing side by side, which have the following practical characteristics:

- **Industry-specific channels**, e.g. for temperature logistics, hazardous goods logistics.

- ▪ **Channels related to means of transport**, e.g. parcel service, sea and air freight.
- ▪ **Receiver-related channels**, e.g. cross docking systems for branch distribution (see Pan et. al 2013, where geographical and products' flows pooling was proposed, namely geographical consolidation among suppliers or retailers with similar flows).

On the one hand, each channel thus contains a concrete service description (e.g. temperature-controlled transport of standardized parcels and individual pallets within a country in the next-day logistics network with delivery van with lifting platform). Thus the parameters type of goods to be transported, relation, recipient segment, service definition, equipment used and freight price have to be defined. On the other hand, a PI Channel bundles comparable service offers of different transport service providers, so that corresponding selection decisions regarding price, service and/or quality can be made by the users of the PI transport management platform.

The logistical advantage of more specialized transport channels lies above all in a higher receiver-related bundling, which is ideally achieved via an appropriate hub, "open to any PI-certified users" (Pach et al. 2014) - without the need for intermediate outbound and inbound depots (see fig.7).
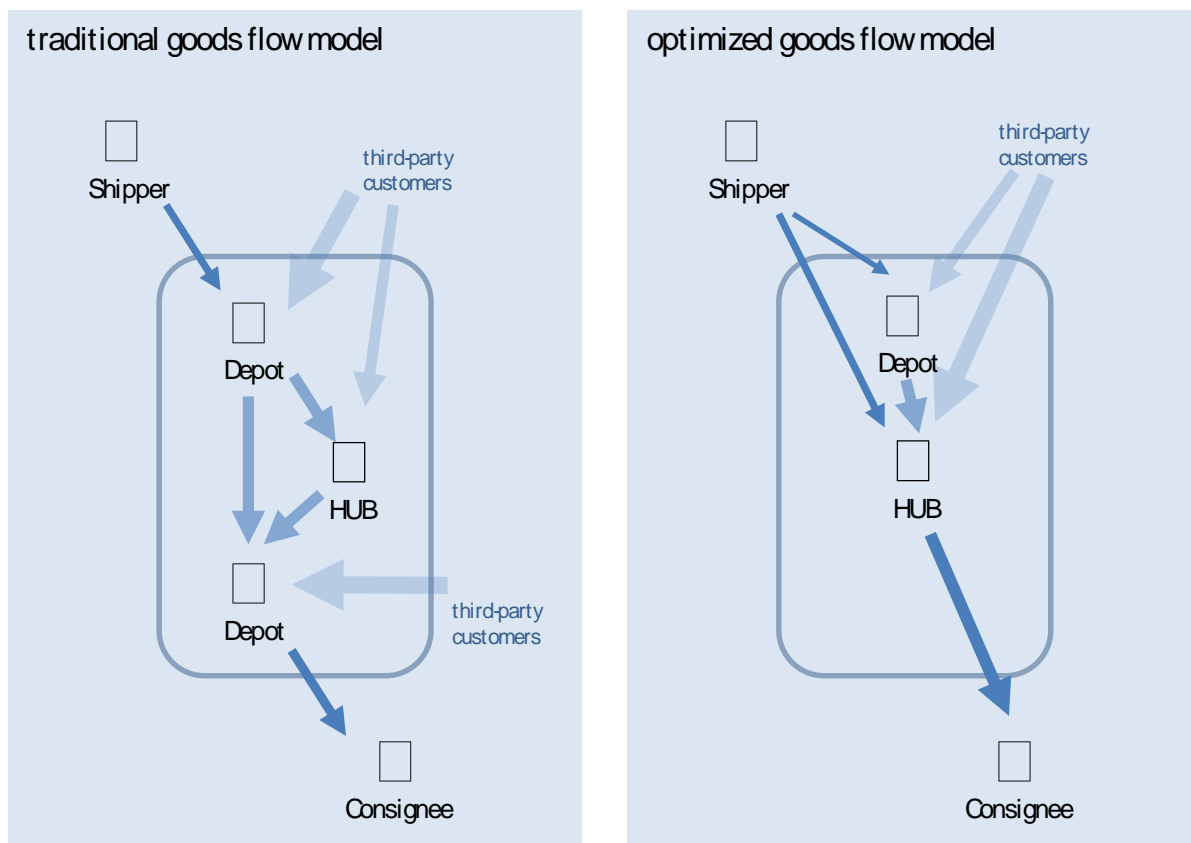
Figure 7. Traditional vs. Optimized Goods Flow through Groupage Cargo Systems

This also corresponds to the findings from the expert interviews carried out within the framework of the project, according to which the profitability of groupage systems depends to a very high degree on receiver-related consolidation - when several customers send their consignments to the same receiver independently of each other -, whereas trade logistics systems use precisely this effect to establish their own logistics systems.

Another new feature of the concept is that both users and transport service providers can introduce new PI channels to the transport management platform in order to map specialized service offerings accordingly. This also corresponds to the business orientation of highly specialized service providers who only focus on limited market segments (e.g. a freight forwarder that specializes in partial loads from Austria to Spain and Portugal and performs this as a subcontractor for many leading groupage freight forwarders). It is the responsibility of the platform operator to manage, set up, activate and combine the corresponding channels.

Business Model

The conceptual framework comprises the organizational, technical and legal framework for the operation of a corresponding business model. The role of the platform operator is of central importance here. In order to make the platform as attractive as possible for a large number of TSPs - and at the same time to offer the loading partners a broad spectrum of potential carriers - the actual task of the platform operator is limited to providing adequate transport channels in the form of so-called PI channels and arranging transport orders. In addition, the integration of RTIs as a practicable form of PI containers is made possible. PI channels map different service bundles for different goods with different requirements as higher-level clusters, for which specialized TSPs are listed by the platform operator. The listing process as such runs along the milestones identification - qualification - validation: The TSP interested in the cooperation is qualified for the channels relevant to him and all the transport services he provides flow into an integrated supplier evaluation system, which is made available to other interested clients in aggregated form. This is intended to make it easier to find new and efficient TSPs. The actual conclusion of the contract ultimately takes place between the shipper and the selected transport service provider, ideally on the basis of a tariff stored in the associated PI Channel - specifically for the shipper or in general. The platform operator's business model as a neutral freight broker is therefore primarily based on corresponding freight brokerage commissions.

From individual expert interviews with the transport and logistics service providers involved in the project, it became clear that a commission in the lower single-digit range would just be acceptable. As a way out with regard to the rigid determination of the amount of commission, targeted experimentation in a pilot phase of a real operation is a good option. In addition to the transaction volume - which as a rule will correlate strongly with the transport distance - the following factors are of particular relevance:

Relation: Journeys to areas with weak cargo technology are usually more expensive and less in demand than vice versa; attractive "return cargoes" therefore tolerate higher commissions.

Season: Especially in spring and autumn, prices rise significantly due to a greater shortage of truck capacity, while the price level from January to February or summer is usually lower (holiday season).

Equipment: Expensive special equipment is generally reflected in the transport price. Since this is often not easy to get, higher commissions would be possible.

Seen in this light, the commission model is related to the traditional business model of freight forwarders. The economic benefit of the platform is based on the reduction of freight forwarding margins through a largely digital process handling and targeted channel and transport service provider selection, which overall leads to more efficient process handling. This circumstance is supported by practical findings from the analysis phase of the project, according to which part loads of the shippers are predominantly assigned to large forwarding companies, which in turn - after deduction of their margin - use specialized carriers. The latter would have been the more economical alternative from the outset if a) these are known to the

shipper and b) are digitally linked to the process flow. It is precisely these two points where the PI transport management platform comes into play.

PI Container

The most common standard load carrier in (European) practice is the Euro pallet. The protoPI project therefore discussed the further development of a collapsible box pallet based on a Euro pallet into a variant of a **PI container**. This would not only be Euro-compatible, but also stackable, foldable, lockable, upgradeable with RFID tags and other sensor technology and ultimately suitable for use in an open transport pool (see table 1; for a generic set of requirements for PI containers see Landschuetzer et al. 2015). The platform operator thus also has the task of mapping the exchange processes of the PI containers between the individual players.

Standard steel box pallet	PI-Container
standard height (2.5m) of a truck fully usable	flexible size due to modular design
stackable	stackable
non foldable	foldable for space-saving storage and transportation of empty containers
box with grids on the sides	lockable
compatible with euro pallets	compatibility with truck load space
space for RFID tags in the stand blocks	integrated RFID tag for identification
space for further sensors in the stand blocks	integrated sensor technology for measuring environmental influences
space for tracking system in the stand blocks	integrated tracking system
easy assembly/disassembly by one person	easy assembly/disassembly by one person
cost-effective production	cost-effective production
boxes are stacked and secured against lateral slippage	integration of several containers to a single shipping unit
handling with conventional equipment (forklift, etc.) possible	handling with conventional equipment (forklift, etc.) possible

Table 1. Comparison of the requirements for a further developed PI container based on steel box

Based on the properties of the PI container specified in this way, a simulation model for the analysis of the loading and distribution processes was created on the basis of the transport and shipment data of a practical partner, with which the utilization of the transport capacity could be evaluated against the actual state. In addition, requirements were placed on a cross-loader load carrier pool in order to ensure the provision of returnable load carriers without the need for a closed distribution system.

Prototypical Realization

The vision underlying the prototypical implementation can be described as follows: Imagine an open portal called "YouFreight" (name invented!), which offers different service bundles in the form of so-called "channels" for different goods with different requirements. Shippers can allocate their transport volumes to the different channels, while transport service providers can easily sign up for existing channels ("reinstall their content"). Through the channel system, services are sensibly segmented; the trust aspects ("which provider is behind it") are covered by evaluable performance histories. Finally, additional services can be added to the platform.

Development

Based on the reference model developed in the analysis phase, the requirements for the PI transport management platform for bundling transports were developed. Based on this, a demonstration prototype was created, with which the basic processes of the PI platform - from the point of view of the respective actors - could be simulated. Step by step, it became apparent at which points a corresponding interaction on the part of the shipper / the TSP / the platform operator became necessary and accordingly, the demonstration prototype was conceptually extended or interactively rebuilt step by step. At the end of this process, a conclusive process could be defined with which the required functionalities could be integrated in a target-oriented way.

The project addresses not only the technological implementation of a PI transportation management platform as an experimental prototype at TRL-5 level, but also takes into account the associated services around the data platform, which are supposed to solve meaningful tasks from the existing data base (see fig.8).
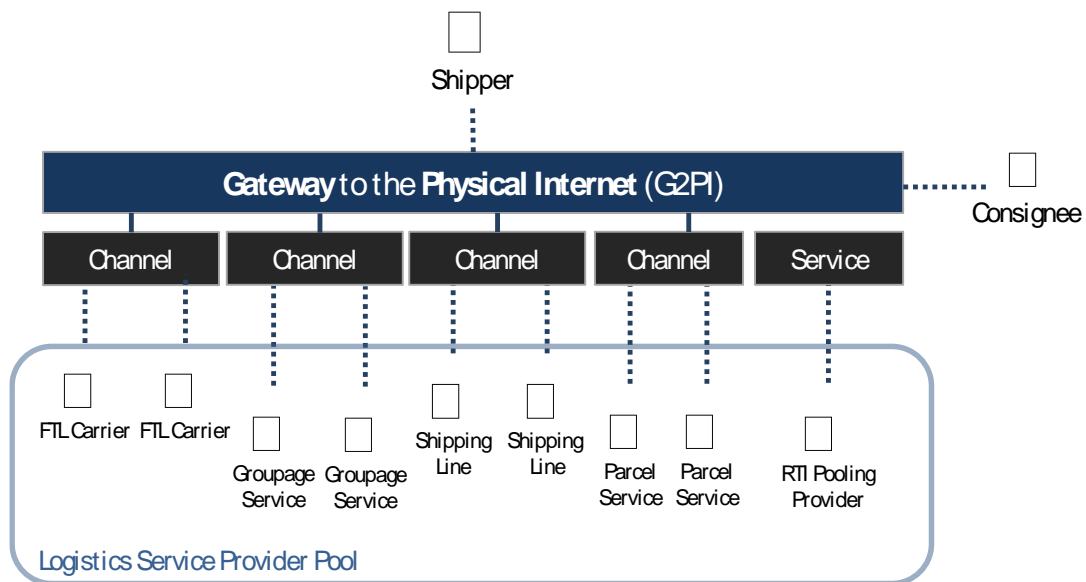
Figure 8. G2PI-System Architecture

The demonstration prototype was realized iteratively in several loops with an adequate prototyping tool within the scope of an explorative prototyping. Thus, the "product" went through several life cycles, as the requirements changed in part over the course of the project. In addition, several parallel views - those of the client, the transport service provider and the platform operator - had to be arranged in a logical sequence in order to be able to run through

the entire process. Decisive for the final design of the demonstration prototype was the introduction of the channel term in order to be able to group similar transport offers in a clear and structured way. In addition, novel processes had to be completely redesigned, namely the channel setup, the inclusion of a transport service provider in a channel as well as the channel selection. The prototype, which was completed at the end of each development cycle, was logistically tested both within the project and with selected practical partners and thus validated for consistency and functional fulfillment. At this point, the use of prototyping as a project tool proved to be particularly effective, as the cycle times (also in view of the given project duration) were relatively short.

The PI transport management platform as a **digital gateway to the physical internet** (G2PI) has three main tasks: To connect the participating shippers to the PI system, to enable cross-company consolidation of freight and to measure the performance of the TSPs involved.

Connecting to the PI: A shipper docks to the PI system via a digital business platform, which we call the Gateway to the Physical Internet - G2PI. After an appropriate registration process, the shipper gains access to the available PI channels and can request the TSPs listed there with regard to transport offers. In this respect, quotations are always prepared only by the TSP itself for a specific customer. Building on this, the TSP can then be commissioned accordingly via the PI platform.

Enabling Consolidation: The actual added value of the transport platform results from a primarily receiver-oriented channel definition of the platform operator. For example, channels such as "partial consignments in the deep-freeze segment to southern Spain" or "delivery to C&C-markets in Austria" are possible. The assignment of a shipment to a channel therefore depends not only on the dimensions of its load carriers (parcel, pallet, etc.) and the framework parameters (temperature, equipment,..), but also on the specific recipient address. A corresponding assignment algorithm proceeds in such a way that a specialized channel is always displayed before a general channel as a default decision for the shipment assignment. Beyond that, specialized TSPs can offer their range of services directly to interested shippers - without the involvement of intermediate freight forwarders.

Measuring Performance: Since a large number of transport service providers use valid qualification ("Is the German minimum wage law observed?)" or meaningful evaluation ("How is delivery reliability to Poland?") associated with high effort, this task is performed by the PI transportation platform across all clients. For each transport carried out, the service provided is evaluated in terms of time and quality parameters and displayed on the platform in aggregated form. In individual cases, the TSP is given the opportunity to object to the evaluation of a client in order to prevent misuse. In such cases, the platform operator must intervene as a neutral "arbitrator".
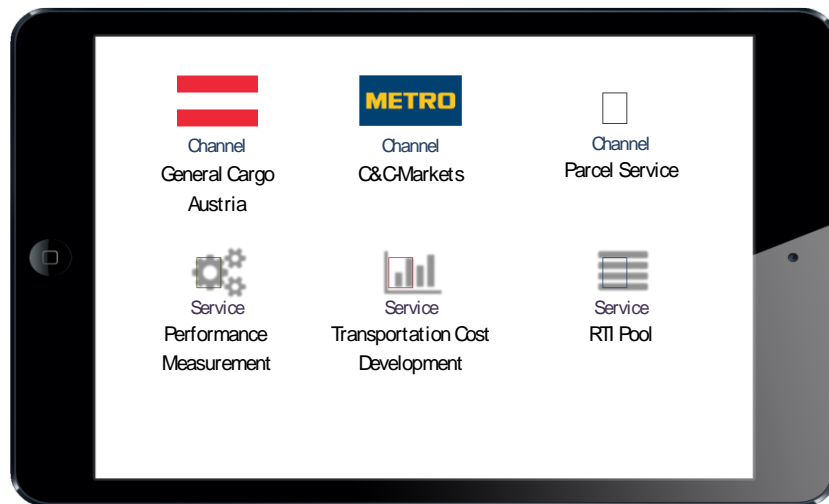
Figure 9. Demonstration Prototype of the G2PI Platform

The corresponding **functionality of the PI gateway** was experimentally programmed in Java by the project partner SATIAMO in the form of a web-based transportation management platform with integrated mobile apps and was evaluated in the course of the research project (see figure).

In addition, various service offers (services) can be docked to the platform, such as analysis tools to better support selection decisions (e.g. in the form of the question "Which transport partner has performed best in the last 12 months in the distribution of food in Poland?") as well as reusable load carrier functionalities (inventory management, repeat orders).

Benefit Evaluation

In the protoPI project, the benefits of the PI framework and the transportation management platform were examined through use cases of the companies involved in the project.

Reduction of transport costs
By using specialized TSPs in specifically defined PI Channels, transport costs can be on average reduced by up to 20%. This is usually due to the fact that the TSP concerned has a bundling option in delivery and can therefore distribute one-off stop costs across several customers (see the process costs example per pallet place on HUB Bundling in comparison to the Traditional Groupage System in table 2), as his total shipment usually consists of several individual shipments belonging to different shippers. Typically, a direct HUB delivery is more profitable than a groupage system if the total number of pallet places is 3 or more considering the transportation route in Fig. 4.

Traditional Groupage System	per pallet	Direct Delivery from HUB	3 pallets	4 pallets	5 pallets
Main run Upper Austria - Styria	€ 12,50	Main run (as direct run)	€ 12,50	€ 12,50	€ 12,50
Depot handling	€ 2,00	Direct stop costs (€ 50,-/ stop)	€ 16,67	€ 12,50	€ 10,00
Last Mile Delivery	€ 17,50				
Total Cost per pallet	**€ 32,00**	**Total Cost per pallet**	**€ 29,17**	**€ 25,00**	**€ 22,50**
			-9%	-22%	-30%

Table 2. Comparison of Process Costs between Traditional Groupage System and HUB Bundling

Since a typical shipper employs in practice between 10-15 transport service providers - from parcel services to general cargo - the PI channel approach appears to be extremely promising and practicable - also in view of the current significantly higher freight prices on the market. A monetary savings potential for the channel provider arises from the possible automation of scheduling tasks, as the transport orders are automatically passed on to the relevant transport service providers.

On the other hand, by creating a specific channel on the platform, the transport service provider has the advantage that he receives exactly those additional orders with which he has the greatest potential for consolidation and which thus offer him the greatest potential for optimization. This also allows him to offer a lower price. The fact that the platform is only an intermediary and not a self-employed freight forwarder means that the competitive thinking of freight forwarders to place orders on the platform is partly eliminated. This is facilitated by a neutral platform. Overall, the platform must be able to offer a nationwide service, but will be able to offer a lower price than conventional channels, especially in those relations where a specific channel exists (comparison of potential transportation tariffs in the "Channel Austria" vs. "Channel C&C markets").

Bundling in delivery

An additional traffic-minimizing savings potential of the PI channel platform results from the possibility of consolidating small items according to delivery addresses: Particularly in general cargo, there are often small consignments. If many small consignments can be consolidated to individual delivery addresses, these can be consolidated to fewer load carriers (e.g. not 2 Euro pallets with 4 cartons each, but 1 Euro pallet with 8 cartons) and thus the load in the truck can be increased, since another load carrier could be loaded.

Overall, the delivery consolidation significantly reduces the total kilometers driven and the delivery vehicle concerned can deliver a higher volume of consignments in the remaining time. Especially in the context of hyper-connected city logistics, the benefits resulting from bundling can be very high (Nayeon et al. 2018).

Savings in loading space due to the use of PI containers

With regard to the use of PI loading units, corresponding advantages and potentials of the developed PI-capable containers were shown by simulation calculations and comparison with the actual situation on the basis of the investigated application case of retail logistics in the area of store distribution. The space utilization advantage resulting from the improved stackability of the PI grid boxes is about 10-20%. With a functioning pooling model, entire return load transports could be omitted in individual cases. A modified grid box was used as a prototype of a PI container. With this, above all core functions such as stackability and the possibility of folding empty PI grid boxes could be implemented. Due to the same basic dimensions as with Euro pallets, the loading areas of conventional trucks can be used as well as with conventional pallets with this PI grid box. Due to the stackability or two different heights of the PI box, the full height of a truck can also be used (see fig. 10). With the historical data on the delivery rounds of the practice partner, the savings in parking spaces were determined by using PI boxes. If the boxes also have to be returned, the savings of over 80% are already very significant due to the foldability (based on a freight ratio of 5:1 for the return transport of the foldable PI grid boxes).

Figure 10. Improved stackability of foldable PI grid boxes

The results of the simulation model make it clear that a PI-capable, optimized transportation items can make the use of existing loading volumes much more efficient, especially with low pallet heights. However, due to the high investment costs for new RTIs, such measures are hardly profitable for transport service providers. From a practical point of view, such solutions must therefore be offered by specialized RTI pool providers (e.g. CHEP, Container Centralen, IPP, etc.).

Digitization of the transport order process
A further added value of the platform lies in the avoidance of manual scheduling/execution tasks. Thus, the platform is able to receive transport orders directly from industry and trade, to bundle these transport orders with others if possible and to automatically forward them to qualified carriers. The platform receives part of the savings for the brokerage function, the other part is passed on to the client through lower prices.

Overall results with regard to the "counting point" valuation model
Based on the Bosruck Tunnel reference point on the A9 motorway established in the project, around 800 trucks are travelling daily between the two regions of Upper Austria and Styria, based on the practice partners investigated. The average fill level of these vehicles was about 90% according to surveys carried out in the course of the project. Based on the bundling effects described above, the capacity utilisation of these vehicles could be increased to about 96%. This corresponds to a potential reduction of about 50 trucks per day. In addition, the savings potential calculated quantitatively in this way for the transalpine transports under consideration was evaluated and confirmed by quantitative interviews with 12 leading companies in the regional transport industry.

Research Agenda

Based on the results obtained in the demonstration and evaluation phase and further expert interviews with the project partners involved, a number of further research questions could be identified and divided into the following topic areas:

Information Technology: How to define physical standards and interfaces and prepare for integration into a global PI network? What measures can be taken to minimize the risks of such integration? How can existing concepts of intelligent load carriers be further developed to support the use of PI?

Organization and Business Models: How can existing networks be integrated or linked into a future PI platform? What new business models in logistics are created by PI? How can a PI business model best combine economic, social and ecological benefits? What critical masses must be reached in order to ensure the economic viability of PI hubs and PI services?

Logistics Processes and Business Models: How can logistics processes in the various branches of industry be sustainably improved and optimized by PI? Which PI penetration rate must be achieved in the logistics sector in order to be able to pursue a sustainable change towards PI? How do transport networks and PI services have to be designed in order to successfully implement the PI vision?

All in all, it can be said that the prototyping-oriented approach helps the PI metaphor to further conceptual development - and also meets with a high level of acceptance in practice.

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Comparison of Centralization and Decentralization of Physical Internet Through Gamification

Mariam LAFKIHI[1], Eric BALLOT[1], Shenle PAN[1]

[1] Physical Internet Chair

MINES ParisTech, PSL Research University, CGS - Centre de Gestion Scientifique

60 Bd Saint-Michel, 75272 Paris Cedex 06, France

Corresponding author: eric.ballot@mines-paristech.fr

Abstract: Centralization and decentralization are the two common organizations in freight transport. The first relies on a central authority who optimizes and establishes transport plans for all carriers for global- interest, while the second, presented by the physical internet in this paper, lets carriers optimize their own transport plans for their self-interest. The outcome - efficiency and effectiveness - could be different. This paper aims to use the concept of Price of Anarchy (PoA) to compare the outcome of the two organizations. Due to the complexity of actual freight transport market, this paper adapts the gamification methodology to investigate the two organizations. A freight transport game was developed for simulation. The outcome of the two simulated are then compared. The results show that the centralization outperforms in terms of global efficiency and effectiveness; while decentralization is better individual incentive. However, the PoA varies depending on information revealed.

Keywords: Physical Internet, Freight Transport, Centralization or Decentralization organization, Price of Anarchy, Gamification

2 Introduction

Freight transport has been dramatically growing due to increasing global trade and economic development. Nowadays, Freight transport systems (FTS) are more and more challenged by new markets and new technologies. This entails the need for innovative solutions to develop a more sustainable and efficient FTS.

From this perspective, recent logistics paradigms aim at decentralizing logistics organization for agility and sustainability. Montreuil (2011) and Ballot et al. (2014) proposed the Physical Internet (PI) as a shared, interoperable, and decentralized transport network, which aims at seamlessly interconnecting currently independent transport networks and markets to increase profitability and efficiency.

Different from integrated or centralized organization that involves a control by a central planner who optimizes and establishes transport plans for all collaborating carriers. Decentralized organizations, like (PI) allow carriers to optimize their own transport plans for their self-interest to maximize their individual profit; meanwhile a rule-based organizer will manage collaborative activities with respect to global interest. They offer greater independence and flexibility for carriers. However, they could be harmful to global optimum obtained by the centralized organizations.

Despite aforementioned theoretical advantages, the performance - efficiency and effectiveness - of decentralization still needs to be further investigated compared to centralization, especially in the framework of the Physical Internet with possible transshipment between carriers at hubs. The concept of "Price of Anarchy" (PoA) is used for performance comparison. In this work we study two questions, how to measure the performance of decentralized organization compared with centralized one, and how the strategy convergence will affect the performance of decentralized organization.

We aim to obtain some constructive and practical guidance and implications for companies who consider centralizing or decentralizing the transport management.

3   Methodology

To investigate the centralized and decentralized organizations in real practice, we adopted the gamification methodology and developed an online freight transport game. The methodology of gamification is adopted because of the difficulty to apply the two organizations for a real life case study, and because of the complexity of actual freight transport market that is highly dynamic and open. Gamification is often considered as an effective approach to simulate highly complex real-life cases (Hamari et al., 2014).

The game is composed by two versions: V.1 represents the current transport market, where carriers are encouraged to combine multiple shipments for economy of scale, but without the possibility of exchanging them, and V.2 which represents a PI network containing transit hubs to exchange and interconnect independent shipments to increase profitability and efficiency; in this version the shipment's reallocation is allowed.

The game is based on a combinatorial auction process that aims to find the optimal allocation of resources that minimizes the overall cost of the transport market by taking into account the interest of each player.

Figure 43: Online user interface of the Freight Transportation Game

Three scenarios have been played in both versions (current market and PI network) to compare the outcome of the centralized and decentralized organizations. It is important to note that, as input for all scenarios, transport requests and carrier maximal capacity are the same. The only difference of input is the price proposed by each carrier, and, therefore, transport plans and output are also different, as well as the total cost.

Scenario 1: represents the centralized model wherein a central authority optimizes globally the transport (e.g. minimizing the total transport cost), and proposes transport plans to all carriers. The later will execute exactly the plans proposed. For optimization, the authority should have complete information of the market and the carriers. In this scenario, the prices of requests are calculated and proposed by the centralized authority according to the market. As it is, this scenario can be considered as the optimal solution, and the upper bound of the level of performance.

Scenario 2: represents the decentralized model with no shared information. Each carrier will optimize his transport plans. Carriers set up a bidding price for each feasible request depending on their private strategies, then submit it to the organizer of the market. Their decisions are therefore selfish without considering global interest. The organizer will take into account all summited prices to allocate requests to carriers by minimizing the total transport cost. In this scenario, we assume that no information is shared between carriers.

Scenario 3: represents the decentralized model with limited sharing of information. In particular, we are interested in the question of how the strategy convergence will affect the performance of decentralized organization. For that, we decide to disclose the average margin of all carriers of Scenario 2 before running Scenario 3. In other words, this scenario has the same characteristics than the Scenario 2, the only difference is that, in Scenario 3 the organizer will communicate to carriers the average margin of the transport market, and let carriers take this information into consideration when proposing prices for request bundles.

The concept of PoA has been used to measure the performance degradation of the freight transport market due to the selfish decisions made by independent carriers in the decentralized organization. It has also been used to compare the performance of centralized organization (that yields the optimal social welfare) and decentralized organization (that could lead to the worst Nash equilibrium). In this study, we define the PoA as the ratio of optimal decentralized cost to the optimal centralized cost.

4 Experiment results

In this study, we discuss two types of KPIs: effectiveness and efficiency. The preliminary results show that the centralized model always outperforms in terms of global efficiency and effectiveness and it yields the optimal social welfare; while decentralization has better individual incentive for carriers. Regarding PoA, Scenario 3 of decentralization with margin information disclosing cost is higher in efficiency than scenario 2 of decentralization with no shared information.

Serval contributions have been made to the literature. First, we apply the gamification methodology and the concept of PoA to assess the performance of the two organizations. The innovative methodology may help researchers and practitioners better understand the challenges and stakes in the two organizations. Second, the developed game provides an efficient way to gather data for the future research work.

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Is Collaboration Necessary? Or: Might the Physical Internet be implemented by Internalization?

Sandra Stein[1,5], Matthias Prandtstetter[2,5], Fritz Starkl[3,5] and Gerald Reiner[4,5]

4.   Fraunhofer Austria GmbH, Vienna, Austria

5.   AIT Austrian Institute of Technology, Vienna, Austria

6.   FH Steyr, Logistikum, Steyr, Austria

7.   Vienna University of Economics and Business (WU), Vienna, Austria

8.   LRA – Logistics Research Austria, Steyr, Austria

Corresponding author: matthias.prandtstetter@ait.ac.at

Abstract: This paper discusses the necessity of collaboration in transport logistics, outlining two contrary case studies (retailer amazon and the small-structured fresh vegetables sector in Austria). We question if an internalization of crucial logistical activities might also lead to an implementation of the basic concept of the Physical Internet (PI). On a first glance, in-sourcing is contradicting the PI mindset as there is only little collaboration in this setting. So far, we consider that especially the PI community should investigate this topic of developments in more detail. If the PI, or the main concepts of the PI, could be realized via internalization as carried out by e.g. amazon, one should think about loosening competition rules. Furthermore, we would like to encourage this discussion together with ALICE via the organization of an event during one of the next ALICE plenary meetings with corresponding representatives on the podium.

Keywords: collaboration, internalization, competition, fresh vegetabels, retail

1   Introduction

Which kind of challenges is humankind facing now? What is driving us? And where does it lead us to? In 2018, the European Union identified five priority societal challenges underlying the next research framework programme "Horizon Europe" where targeted research and innovation can have a tangible impact, i.e., health, inclusive and secure societies, digital and industry, climate, energy and mobility, and food and natural resources (EC 2018). Considering these aspects and the trend towards a greater socio-economic and political individualization, fair and responsible action and management become more and more relevant for today's society. As a result, companies will be acting increasingly fair and responsible, assuming that fair and responsible action will guarantee profit and sustainable growth (cf. Schwab et al. 2019). In that context, logistics plays a central role in supporting companies to become "fair".

Four main drivers that affect "fair and responsible logistics" can be identified (cf. UN 2015, p. 21 and DHL 2015, p. 3):

• changing societies (growing consumer demand for more transparency and fairness, increase in the consumption of fair and responsible products),
• disruptive technologies (convergence of social, mobile, cloud and big data technologies to achieve more transparency in and access to (green) supply chains)

- climate change and
- stringent policies (increasing regulatory framework for compliance and anti-corruption measures and social and environmental standards for businesses). (cf. UN 2015, p. 21 and DHL 2015, p. 3)

"Fair and responsible logistics" even goes beyond common measures to reduce the environmental impact of logistics activities by challenging industry's sustainability agenda. One would be advancing the circular economy concept and closed-loop supply chains, e.g. by offering biodegradable packaging, reverse logistics concepts as "Uber for waste", or extensive renewal processes for consumer goods (cf. Islam, Huda 2018, p. 48, Jammernegg et al. 2018). Another one would be the fair access to solutions that will help the underprivileged to improve their living circumstances, e.g. by creating small sachets for hygienic products at prices that are affordable for low-income families, or empowering local entrepreneurs by strengthening local farming by sourcing directly from farmers (cf. Chen, Chen 2019). An increase of transparency and responsibility in supply chains by promoting and facilitating fair production and trade, comparable to Green Supply Chain Management (GSCM) would be another important key aspect of the trend to "fair and responsible logistics" (cf. Jayaram, Avittathur 2015, p. 237). Last, logistics and/or supply chain management can substantially contribute to the "base of the pyramid", cf. Reiner et al. 2015.

A possible concept to enable "fair and responsible logistics" could be the Physical Internet (PI).

However, we have to state that the concept of the PI has its weak points. E.g., collaboration is most often seen as the most challenging need on the path to the PI (cf. Pfoser 2017). Even more, one has to raise the question whether collaboration is necessary at all. In this context, we will mention some examples of a well working (partly) global logistics network serving up to billions of customers – e.g. amazon and alibaba. Their main corporate philosophy is, however, not to collaborate, but to internalize (which means in sourcing of as many processes as possible). However, main decisions are taken by the companies and – that is the most important implication within this paper context – without the need for cooperation with other (maybe competing) companies.

Up to now, it can be observed that collaboration in most logistical services suffers from a lack of confidence in competitors and other market participants. Logistical operations include data, which has to be handled privately. Logistic service providers may not (and do not want to) share relevant information with others, e.g., for bundling, or route planning. Thus, considering an elimination of trust issues, is it possible to achieve the same positive effects of the PI when only one starts at the beginning? For this, the use case of amazon (and alibaba) is presented here.

2   Internalization of logistics services

Obviously, whilst talking about logistics services, there are two main complementary strategies to be applied. The first one is out-sourcing, i.e. the (sub-)contracting of logistics services with external companies. The second one, unsurprisingly, is in-sourcing of all logistics services. Please be aware, that in-sourcing does not necessarily mean that all assets like personnel, vehicles, etc. are owned and/or paid by the company itself but that (main) decisions are taken by the company. On a first glance, in-sourcing is contradicting the PI mindset as there is only little collaboration in this setting.

2.1 The use case of amazon (and alibaba)

When talking about global logistics as well as PI, two companies come to one's mind: amazon and alibaba. Both in the retail (for everything) market. Moreover, they sell literally everything: That is, the goods to be delivered are from tiny, e.g. sewing needles, over huge, e.g. full-size rhinoceros, towards virtual, e.g. e-books or music. Obviously, logistics services cannot be "standardized" for every order. It can be assumed that it is hard to find a logistics service provider who can cover all different kinds and sizes of articles world-wide. So, one would expect that this market would require collaboration.

However, and this is on a first glance surprising, the main strategy of amazon seems to be to in-source all logistics services. E.g., in Vienna, Austria, amazon started to take over home deliveries from the Austrian federal postal service for the greater region of Vienna in autumn/winter 2018 (Der Standard, 2018). As reasons for this in-sourcing, amazon stated that internalization guarantees that order times with assured next-day deliveries (or even same-day deliveries) can be extended as negotiated release times with postal services does not need to be met. That is, from that point of view, internalization is essential as extra time needed for handing goods over logistics partners can be eliminated. At the same time, one has to question, whether the chosen approach has offers more benefits than just convenience for customers.

Amazon customers may have experienced weird situations, which, might be explained due to efficient logistics services. E.g., when ordering more than one time from the same product at the same time, it is not guaranteed that they are delivered within the same parcel. Even more, it is not assured that they are delivered on the same day or by the same logistics service provider. However, why? One explanation could be that the individual items are not stored at the same warehouse. Instead of consolidating the orders first and then send it to the customer, each warehouse packs the items and sends them directly. One now has to state the question: "Is this convenient for the customer?"

Likely, that consolidation takes place, as now all items independently from their origin warehouse have to be delivered to the delivery basis responsible for the last-mile delivery. In order to visit the customer just once (i.e., to save travel time and therefore costs), it might be cheaper to consolidate the items (which does not necessarily include a re-packing of the items into one box). That is, in-sourcing can have positive effects with respect to cost and emission savings.

Another showcase of cooperation through internalization at amazon is the concept of the marketplace. The marketplace concept provides individual companies the capability to sell their products via the well-known and accustomed look-and-feel of the amazon platform. In addition, companies can use the amazon warehouse and logistics services such as storage place and shipping partner such that companies only have to bear the economic risk while amazon (or their subcontractors) carry out all other operations.

Interestingly, this concept is exactly the idea often fostered by the PI community that warehouses have to be shared amongst companies. Instead of each company owning their own warehouse, all (amazon) warehouses around the world are open to all participating companies such that an even distribution of goods according to the PI idea can be achieved.

To be honest, both use cases of internalization as described above – if carried out carefully – have positive impacts from an economic point of view as well as from an environmental point of view. Even more, both use cases "mimic the PI idea" which is to cooperate in order to achieve these positive effects.

2.2 Food logistics in Austria – The use case of fresh vegetables

In 2014, a study was carried out in Austria to identify research, technology and innovation potential at interfaces between transport and logistics (cf. Stein et al. 2016). The scope of the study consisted of analyzing supply chains of varying complexity in the automotive, fresh vegetable, CEP services, and recyclable materials sectors. From the results of the study, valid statements on collaboration in the food logistics sector, especially for fresh vegetables, can be derived.

Austrian vegetable and horticulture, including fruit and potato production, represents an important sector within domestic agriculture, accounting for around 11% of production value. Pure vegetable production amounted to approx. 3% of the agricultural production value in 2012 (cf. BMLFUW, 2013b, 17). With the exception of field vegetable production in market fruit farms, Austrian vegetable production is mainly carried out in small and medium-sized production units. The average area used in horticultural vegetable production is 1.40 ha and in field vegetable production 5.81 ha. However, it is assumed that vegetable cultivation will lead to a further reduction in the number of farms, with a simultaneous expansion of the areas under cultivation and higher yields per hectare, or an increase in the number of planted trees per unit area. In the course of increasing the degree of specialization of individual farms, the crop rotation is adjusted to the quantity demanded, so that the number of crops decreases (cf. Hambrusch and Quendler, 2012, 11ff).

Supplying the population with regional vegetables is becoming increasingly important. The (Austrian) origin plays a particularly important role in consumers' decision to buy vegetables. This shows the confidence of consumers in product safety and product quality of Austrian vegetables, as well as the efficiency of existing quality assurance systems. In addition, environmental aspects, such as short transport distances, are playing an increasingly important role in consumers' purchasing decisions (cf. ibid, 2012, 50ff).

Within the scope of the horticultural and field vegetable survey 2004 (cf. Statistik Austria, 2005), latest data on vegetable marketing were collected: 76% of all gardeners sell directly to the end consumer in the form of a consumer market, their own shop, as well as via gastronomy and hotels. 32 % of the enterprises use resale to trade and 13 % resale to producer organisations or wholesale market (11 %).

2.2.1 Requirements for transport in the fresh vegetables sector

Both for the transporter and for own fleets, transport conditions result from the packaging requirements of the food retail trade. The protective function of the packaging is given top priority. Transport packaging must be temperature-resistant, stable, corrosion-resistant and hygienic, stackable, compatible and meet the economic requirements of the food retail trade. In principle, reusable transport packaging is used.

One aspect that must not be ignored in the transport process is the container types used in food retailing, some of which differ greatly from one trading company to another. For example, REWE Group works with foldable trays made by Container Centralen GmbH with dimensions of 600*400 mm in three different heights (110, 167 and 220 mm), which only have a height of

36 mm when folded (cf. REWE, 2009). This reduces waste on the one hand and makes the reverse transport of empties more efficient on the other (cf. REWE, 2010). At the same time, the retail companies have strict requirements with regard to the containers they deliver. For example, SPAR AG has specified that fruit and vegetables (unless otherwise agreed) must be delivered in STECO returnable packaging (cf. SPAR, 2013). These are foldable reusable plastic packaging produced by IFCO. Depending on the turnover, the size of the vegetable containers varies (higher turnover requires larger crates with more contents), as do the package sizes, which entails additional logistical work (due to the need-based order picking). Hofer KG delivers fruit and vegetables in non-folding pool crates.

Cooling zones

With regard to the transport of goods with different temperature requirements, so-called multi-chamber refrigerated vehicles have proven themselves, which divide the loading space into two temperature zones. This enables a more efficient use of the loading volume of a truck. Thermo- and insulating hoods are also used in the transport of temperature-dependent goods. This means that goods with very different temperature requirements can be transported, such as frozen goods (-18°C) together with fruit and vegetables (6°C) and ambient goods (20°C) (cf. Krautz, 2014). The cooling zones and insulating hoods ensure optimum product quality.

2.2.2 Specific characteristics of the fresh vegetables sector

Both consumers and retailers have high expectations of the quality of products. To certify this, products are labelled with quality seals and logos. In order to receive a seal of quality or a logo, products must comply with specified standards. The labelling of products with quality labels can be based on private law or on EU food quality regulations. Private quality seals are awarded by the brand owner, who himself defines the quality requirements and determines the number and form of controls (cf. BMLFUW, 2010, 106). In addition, there are quality and safety standards such as the International Featured Standard, which is intended to ensure uniform verification of food safety (cf. IFS Management GmbH, 2014a).

The International Featured Standard (IFS) and the worldwide GLOBALG.A.P. are among the Europe-wide valid and recognized standards. Quality seals are awarded to conventionally produced products. The AMA seal of approval and Pro Planet are relevant for fruit and vegetables in Austria

All products produced organically comply with EU Regulations (EC) No 889/2008 and (EC) No 834/2007. Organic farming aims to have the least possible impact on nature in the production of agricultural goods. The use of artificial fertilizers and pesticides is essential for organic production. Only living organisms or mechanical processes may be used. Only natural or naturally derived substances may be used as fertilizers. Great importance is also attached to the welfare of farm animals, animal welfare and animal species-specific standards must be met and go beyond the Animal Welfare Act. Genetically modified organisms (with the exception of pharmaceuticals) are prohibited. Within the EU, organic foods are labelled with the European Union's organic seal of approval. This is shown by a leaf consisting of stars on a green, white or black background. Below the logo there is a code of the authority or body responsible for control. The origin is also subdivided and labelled into "EU agriculture", "non-EU agriculture" (production of raw materials in third countries) or "EU/non-EU agriculture" (if the raw materials were partly produced in third countries) (cf. Regulation (EC) No. 834/2007, Article 24).

In addition to the EU organic seal of quality, there are many other seals of quality and private labels in Austria that identify organically produced products (e.g., *AMA-Biosiegel, SPAR Natur Pur, JA! Natürlich, Zurück zum Urspung)*.

Efficient Consumer Response (ECR)[22]

Efficient Consumer Response is the cooperation of all companies along a value chain and therefore of great importance for the vegetable sector. Like Supply Chain Management (SCM), ECR is based on the so-called pull strategy, since production and supply are geared to demand at the point of sale (cf. Ahlert and Kenning, 2007, 198ff). In contrast to supply chain management, which considers the entire supply chain, ECR focuses primarily on the processes between producers and retailers (cf. Meffert et al., 2012, 582). On the logistics side, an efficient, demand-driven replenishment of goods should be guaranteed. The aim is "to save resources by optimizing the processes between manufacturer and retailer (e.g. by reducing inventories) and to better satisfy demand (e.g. fresher vegetables through shorter delivery times)" (cf. Meffert et al., 2012, 584). The special feature of the food industry is that the goods turnover rate is much higher than in other sectors. Very precise planning is obligatory in order to avoid excessive losses due to spoilage on the one hand and to guarantee the supply of fresh goods on the other.

Identification codes

Different techniques for product identification are used in logistics and trade. The most important technology is a barcode, which is available in different versions. PLU (price look-up) numbers play a decisive role in retail as well. The most important identification codes used for fruit and vegetables are discussed below.

GS1 barcodes

When marking a product with a barcode, it is important to distinguish what the product is marked for. A distinction is made between consumer units for the scanner cash register, retail units (repackaging and overpacking) and transport units for standardized retail units, such as pallets (cf. GS1 Austria GmbH, 2014).

The end consumer units should be uniquely identifiable worldwide by their number. For standardized consumer units, this is guaranteed by a Global Trade Item Number (GTIN) (cf. GS1 Austria GmbH, 2014). Standardized end consumer units are equalized articles that the end consumer (consumer) pays at the scanner cash register of the retailer. Examples would be chocolate, milk, ready meals, etc. In the case of goods that are charged by weight, such as vegetables, for example, standardized end consumer units are not used because variable end consumer units are used here (cf. Austria GmbH, 2013a, 1). The barcode symbols used are EAN-13, EAN-8 and UPC-A (North American form of EAN-13) (cf. GS1 Austria GmbH, 2013a, 2).

In the case of variable end-user units, on the other hand, identification is more difficult. By restricting the number, the variable end-user units can be allocated to 13 positions exclusively nationally (not worldwide) (cf. GS1 Austria Gmbh, 2014). Areas of application are products which are calculated by weight and not yet weighed or per unit of goods sold, as well as pre-

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[22] ECR is a grocery industry supply chain management strategy aimed at eliminating inefficiencies, and excessive or non-value-added costs within the supply chain, thus delivering better value to grocery consumers. https://www.researchgate.net/profile/Paula_Swatman/publication/228588591_Efficient_Consumer_Response_a_ preliminary_comparison_of_US_and_European_experiences/links/0912f50bc0809a6378000000/Efficient-Consumer-Response-a-preliminary-comparison-of-US-and-European-experiences.pdf

packaged and excellent vegetables supplied to food retailers by the producer. The 13-digit article number has a 2-digit prefix, followed by a 5-digit identification number (HPID), then a field for the value of the variable unit and finally a check digit. The check digit is titled Modulo 10 (cf. GS1 Austria GmbH, 2013b, 1).

Price Look-up (PLU) Code

PLU codes are four- or five-digit numbers that make it easier to identify fruit and vegetable products at the checkout or during inventory. The code ensures that the correct price is paid by consumers without the cashier having to be able to identify the product. The four-digit codes are not assigned according to any particular system; they are random numbers assigned to a product. They are glued to conventionally produced products. The five-digit codes, on the other hand, identify biologically produced products or products containing genetically modified organisms. The digit 8 presented here means that it is a genetically modified product, the digit 9 indicates that it is a biologically produced product. The PLU codes are issued by the International Federation for Produce Standards (IFPS) and are not mandatory (cf. International Federation of Produce Standards and Produce Marketing Association, 2014).

2.2.3 Non-collaboration in the food sector due to…

Especially in the fresh vegetables sector, a small-structured supplier portfolio (smallholder farmers / gardeners) prevents logistical collaboration (in Austria). Producers face a large number of different seals of quality and (quality) standards and are confronted with high demands on his or her products. Whilst deliveries depend much on the time of harvest, the required quantities are based on an annual cultivation plan. However, retailers demand flexibility, and announce concrete order quantities approx. 1-2 weeks before delivery, which makes collaborative transport planning or routing difficult.

Moreover, food retail works with different types of containers, which makes picking more difficult, especially during preparation. Various types of containers also generate additional costs due to increased storage requirements. Customer-specific packaging is required. This prevents the goods from being handled quickly and leads to a negative effect on the freshness of the vegetables. At the same time, repacking is too time-consuming, so once products are packed for a trading partner, they cannot be sold elsewhere.

Mostly, transport is outsourced to the freighter, who also takes care of route planning. The maximum delivery time between the central warehouse and the branches is 18 hours. They are confronted with short order windows and short delivery time windows. Additionally, each actor works with his or her own IT solutions.

3 Conclusions and Discussion

As explained in the previous section, for some branches and/or companies (horizontal) cooperation is not the target. Even more, they focus on internalization and solely managing the whole supply chain. The question is, however, whether this approach – which is successful for at least some companies – finally leads to the same (positive) impacts as an ideal realization of the PI would lead. It is not easy to answer this question but from our perspective, we have to state that it seems to be likely that the main impacts will be met. However, especially in the European Union competition regulations are taken serious meaning that competition on the

market is fostered and therefore cooperation and monopolies are not allowed or at least are checked in detail.

As in the case of fresh vegetable logistics, logistical collaboration is prevented by its special supplier structure; which is the case in sectors such as automotive as well. Moreover, varying short term and long term planning horizons complicate collaborative transport planning or routing. Moreover, different types of containers that are used in different branches makes picking more difficult, especially during preparation. Various types of containers also generate additional costs due to increased storage requirements. Customer-specific packaging is oftentimes required. This prevents the goods from being handled quickly. PI boxes such as the MODULUSHCA box are first approaches to solve such challenges.

However, another additional question arises here: If one company starts to optimize its own logistics services and this company reaches a critical mass, it might happen that others "jump on the train" and cooperate (voluntarily or not) with this company. The result finally is, that competitors are collaborating through this large company. One good example for this procedure is amazon. Being large by itself (and having reached the critical mass), collaboration with competitors started via the marketplace concept. Nowadays, amazon even provides storage space within its warehouses and therefore other companies being direct competitors cooperate with each other in logistics services since they participate in the amazon network. That is clearly an indicator that the original goal of amazon, i.e. internalization of all process, led to a positive development towards an application of the PI.

Further research should tackle the question how 'fair and responsible' logistics could be measured, and how the impact of 'fair and responsible' for the PI could be proved. Moreover, there is need for research identifying how different future logistics scenarios could influence the development of competing logistical strategies. How the theory of the PI could be expanded by defining internalization as an element of the Physical Internet (or Intranet?) is a further aspect to be discussed.

So far, we consider that especially the PI community should investigate mentioned topics in more detail. If the PI, or the main concepts of the PI, could be realized via internalization as carried out by e.g. amazon, one should think about loosening competition rules. Furthermore, we would like to encourage this discussion together with ALICE via the organization of an event during one of the next ALICE plenary meetings with corresponding representatives on the podium.

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Maintaining control over sensitive data in the Physical Internet: Towards an open, service oriented, network-model for infrastructural data sovereignty

S. (Simon) Dalmolen MSc[1,2] , H.J.M. (Harrie) Bastiaansen PhD[2], E.J.J. (Erwin) Somers BSc[2]
S. (Somayeh) Djafari LL.M.[2], M. (Maarten) Kollenstart MSc[2,] M. (Matthijs) Punter MSc[2]
1. University of Twente, Enschede, The Netherlands
2. TNO, The Hague, The Netherlands
Corresponding author: S.Dalmolen@Utwente.nl

Abstract: *Changing market dynamics force organizations evermore to share data in supply chains. Misuse of the data shared can cause major damage to the business and reputation of organizations. Hence, being in control over the terms-of-use for sharing data (i.e., data sovereignty) is a key prerequisite for sharing potentially sensitive data. This, however, provides a major challenge as data sovereignty concepts are currently mainly provided in communities with their own specific data sovereignty solutions. This faces data providers with a threat of lock-in and major integration efforts in case of data sharing with a multitude of data consumers. As alternative, a network-model approach for providing generic infrastructural data sovereignty can overcome these challenges. Its technical concepts are currently maturing. Its business and service concepts however are still under development. This paper proposes an open, service-oriented, network-model approach for infrastructural data sovereignty. The goal is to support a broad variety of end-user and service provider options for maintaining sovereignty in the data sharing processes. It uses an illustrative and representative logistics scenario and describes how infrastructural data sovereignty may stimulate adoption of sharing of (potentially sensitive) operational data as required for realizing the physical Internet.*

Keywords: *Data Sovereignty, Network-Model, Service-Orientation, Open, Metadata, Terms-of-Use*

1 Introduction

Digitization is fundamentally changing supply chain collaborations, business strategies, business processes, firm capabilities, products and services (Bharadwaj et al. 2013). Organizations are increasingly working together to serve consumers through mutually dependent and co-operative supply chains. Improving the agility and flexibility of (supply) chain collaboration offers potentially major benefits but also poses major challenges, both from an organizational and a technical/IT perspective (Luftman et al. 2017).

In transitioning towards more advanced forms of supply chain collaboration, organizations are faced with a dichotomy. On the one hand, they are becoming ever more aware that data is a

valuable asset in the emerging data economy and should be handled by the organizations as such (Gunasekaran et al. 2017), (Marinagi et al. 2015). On the other hand, they require trust that the organization's data is handled in a controlled and secure way as a prerequisite sine qua non the organization may not be prepared to share its data. Consequently, there is a growing need for a 'data-centric' foundation provided by an (open) infrastructure for multi-lateral sharing (Nicolaou et al. 2013), which enables organizations to be in control over the conditions and terms-of-use under which their potentially sensitive data is shared. This is referred to as data sovereignty.

For logistics companies being data providers in Physical Internet supply chains maintaining data sovereignty over their sensitive data applies to a multitude of data consumers, e.g. other logistics companies, logistics service providers, authorities. This, however, provides a major challenge as data sovereignty concepts are currently mainly provided by (closed) communities with their own specific solutions. Consequently, the data provider is faced with both a threat of consumer lock-in by their community providers and with major integration efforts on defining managing and enforcing data sovereignty requirements for a multitude of data sharing relationships with different data consumers. Hence, for such multi-lateral data sharing whilst maintaining data sovereignty over sensitive data, a single-entry point for the data provider may give clear operational advantages in agility, reduced complexity, improved efficiency and lower costs. Generic and re-usable capabilities for defining and enforcing terms-of-use based on standardized protocols may yield major benefits. An open network-model approach for infrastructural data sovereignty for multi-lateral data sharing can offer such capabilities.

The technological concepts and components for the network-model approach are currently maturing. However, this is not (yet) the case for its business and service concepts, aimed at supporting a broad variety of end-user and service provider options for infrastructural data sovereignty within the network-model approach. To overcome this lack of maturity, the research question that we address in this paper is how to design an overarching technical, service and business architecture for a network-model approach for infrastructural data sovereignty. The novelty and main contribution as put forward in this paper is on service-oriented business architecture for data sharing support processes that allows data providers to maintain sovereignty over the sensitive metadata that is generated and managed in a network-model approach for infrastructural data sovereignty. The approach as proposed in this paper can contribute to (internationally accepted and standardized) development and deployment of such a network-model for infrastructural data sovereignty, which is key for wide-scale adoption.

The structure of this paper is as follows. Section 2 provides a representative logistics scenario illustrating the growing need for infrastructural data sovereignty functionality. Subsequently, the topic of data sovereignty as key prerequisite for sharing sensitive data is described in a generic and implementation-independent manner in section 3. The following section 4 addresses the benefits and potential of a network-model approach for infrastructural data sovereignty and presents current initiatives working towards that goal. A service and technical architecture for an open, service-oriented, network-model for infrastructural data sovereignty for multi-lateral sharing of sensitive data is elaborated in section 5 and section 6, in which the former addresses the service-oriented network-model architecture approach whereas the latter more specifically elaborates the service portfolio to be provided. The final section 7 and section 8 provide a discussion and the conclusions, respectively.

2 Illustrative logistics collaboration scenarios

To illustrate the growing need for infrastructural data sovereignty functionality, this section provides a representative logistics case on the minimization of the number of transport movements, governed by internal (business) and external (regulatory) policies. For transporters, minimization of number of transport movements may lead to efficiency and cost optimization. For society, potential benefits are in lower CO_2 emission, less traffic jams and higher safety in traffic-intensive areas.

Minimization of the number of transport movements requires supply chain collaboration. Two fundamental business capabilities to be supported in such supply chain collaboration (Dalmolen et al. 2012) are:

- *Supply Chain Composition,* also referred to as 'goal matching', in which shippers, Logistic Service Providers (LSPs) and transporters match demand for and supply of transport capacity.
- *Supply Chain Visibility,* also referred to as 'situational awareness', in which overview is provided over the full supply chain and context, e.g. through track and trace functions for shippers on the status and location of the loadings under transport.
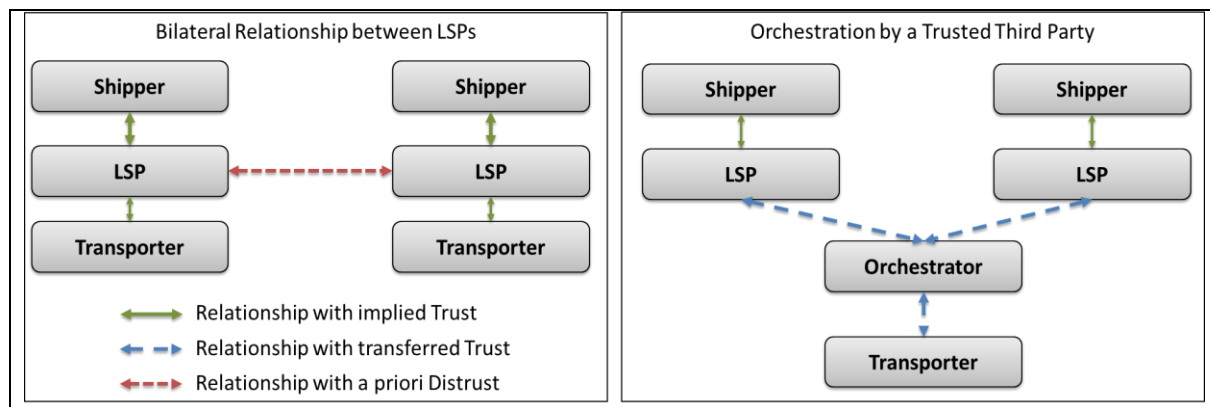
Figure 44: Trust Relationships for Typical Collaboration Scenarios: Bilateral Relationships between LSPs (l) and Orchestration by a Trusted Third Party (r).

Realization of these business capabilities may be achieved by typical collaboration scenarios, with their own type of trust relationships, as illustrated in Figure 44 for:

- *Bilateral relationship between LSPs.*

  This collaboration scenario requires the sharing between LSPs of (potentially sensitive) business data, e.g. on current and scheduled transport capacity. To protect this (potentially sensitive) data, the providing LSP will impose strict terms-of-use (in the form of (enforceable) access and usage control policies) for the shared data on the data consuming LSP.

  This collaboration scenario may for instance be applicable to long-distance road transport, e.g. between cities and/or internationally, by transporters under free and competitive market conditions, with cost efficiency as a major key for success. Minimization of the number of transport movements is the responsibility of the transporters themselves.

- *Orchestration by a Trusted Third Party.*

This collaboration scenario involves an independent and trustworthy intermediary orchestrator role that operates a (fair and independent). An intermediary orchestration role may either be imposed by regulations aimed at the societal needs for minimized transport movements or be established by (competitive) transporters for jointly optimizing their shared business goals on (e.g.) efficiency and environmental sustainability.

This collaboration scenario may for instance be applicable to local transport, e.g. for urban area parcel deliveries and/or inner cities shop supplies. Under influence of the explosive growth of number of parcel deliveries due to online shopping, there is an increasing demand by society to minimize the number of transport movements in urban areas and inner cities.

Figure 1 also shows several types of trust relationships for data sharing between the supply chain participants in the collaboration scenarios, which are respectively referred to as:

- *Data sharing relationship with implied Trust:* Data is (for instance) shared between stakeholders that are not direct competitors, but rather are supply chain partners with mutual benefit for collaborating. There is no direct motivation for / threat of misuse of the (potentially sensitive) data provided.
- *Data sharing relationship with transferred Trust:* Data is (for instance) shared with a supply chain partner, that also has a data sharing relationship with a possible competitor for which it must be prevented that he gets access to the (potentially sensitive) data provided. Hence, trust is to be established that sufficient mitigation measures are applied to prevent the supply chain partner from sharing the (potentially sensitive) data with the possible competitor.
- *Data sharing relationship with a priori Distrust*: Data is (for instance) directly shared with a possible competitor with the mutual goal to optimize the operational processes. There is a relationship of a priori distrust between the possible competitors. Hence, strong mitigation measures are required to enforce the required trust levels prior to sharing data.

The required capabilities for maintaining data sovereignty for the various types of trust relationships in the typical collaboration scenarios will differ. Moreover, they are currently mostly provided within closed communities, with their own specific solutions. This is referred to as the 'hub-model' approach. As described in the introduction, the hub-model faces data providers with a threat of consumer lock-in and major integration efforts in case of data sharing with multiple data consumers. An open network-model approach for infrastructural data sovereignty provides an attractive alternative. Its design principles, a service-oriented approach and the International Data Spaces (IDS) initiative as proponents of the network-model approach are described in the following sections.

3　Data sovereignty: key enabler for sharing sensitive data

Data sovereignty can formally be defined as *'a natural person's or corporate entity's capability of being entirely self-determined with regard to its data'* (Otto et al. 2019), i.e. allowing a legal person to exclusively and sovereignly decide concerning the usage of data as an economic asset.

3.1　Data sovereignty over both primary data and metadata

Clearly, maintaining sovereignty by the data provider applies to the primary, potentially sensitive, data that is shared between data provider and data consumer. However, maintaining sovereignty also applies to the secondary, derived, information on the data sharing transactions, referred to as 'metadata'. The metadata for data sharing stems from the required support

processes for managing data sharing agreements and transactions at the various stages of their life-cycle. The goal of the support processes for data sharing is to prevent misuse of the data shared by a data provider. They include the processes for the data provider and consumers to comply with internal policies (e.g. on terms-of-use, access and usage control) and with external policies (e.g. on regulations). Table 12 lists the main data sharing support processes, categorized according to the subsequent life-cycle stages for data sharing agreements and the associated data sharing transactions, together with the main metadata artefacts generated by these support processes for data sharing.

Table 12: Support processes for data sharing and metadata artefacts.

Support processes for data sharing	Metadata artefacts
Definition and exposure of an available data set • Definition and publication of a data set • Definition of a data sharing profile • Publication of a data sharing profile	• Data descriptor • Data transaction • Data request • Data response • Data sharing agreement • Access control policy • Usage control policy • Security profile policy • Service level • Terms-of-use • Commercial conditions • Juridical conditions • Contractual conditions
Making a data sharing agreement. • Definition of terms-of-use, incl. usage and access control policies • Definition of the commercial and juridical conditions • Negotiation, acceptance and signing of a data sharing agreement	
Performing a data sharing transaction. • Clearing of data sharing transactions, including non-repudiation • Data sharing, including binding of the transactions to an agreement • Settlement and discharging of data sharing transaction	
Logging, provenance and reporting. • Logging and binding of data transactions to data sharing agreements • Tracking, monitoring and reporting of data transactions to stakeholders • Auditing, billing and conflict resolution	

The data sharing support processes as listed in Table 12 require and generate metadata. On the one hand, the data sharing agreements are metadata in themselves. On the other hand, the management, control and administration processes over their associated data sharing transactions are a major source of metadata. These metadata artefacts as generated by the support processes are listed in the right column of Table 12.

3.2   Data sovereignty maintaining capabilities

Maintaining data sovereignty and preventing misuse of shared data implies providing a data provider with the enabling capabilities to be in control over who is allowed access to his data, for which purposes and under which usage control conditions, i.e. the terms-of-use, in compliance with their internal (business) policies and with external policies (e.g. on regulations), and consisting of:

- *Procedural data sovereignty maintaining capabilities:* these include administrative capabilities such as data sharing agreements (terms-of-use and conditions), certification and attestation, logging and data provenance, reporting and accountability.
- *Technical data sovereignty maintaining capabilities:* these include technical capabilities such as peer-to-peer data sharing, encryption and key management for data in transfer and in storage, sandboxing and containerization and policy-based admission control (Yavatkar et al. 1999) and enforcement and blockchains.

The procedural and technical data sovereignty enabling capabilities are closely related to the concepts of legal enforceability and technical enforceability of data sharing agreements, respectively. Legal enforceability ensures that by means of automation generated digital data sharing agreements and their associated data sharing transactions are correct and acceptable in legal procedures. Technical enforceability ensures for the data provider that the agreed-upon conditions under which data is shared are (securely) implemented in the open infrastructure for multi-lateral data sharing.

The pivotal concept in both the procedural and technical data sovereignty maintaining capabilities are the terms-of-use. These are expressed as a combination of applicable access control policies and usage control policies. Usage control is a generalization of access control that also addresses how data is used after it is released. Table 13 provides a list examples of (classes) of access and usage restrictions.

Table 13: Examples of (classes) of access and usage restrictions.

Access control restrictions (access control policy)	Usage control restrictions (usage control policy)
Stating which individuals, roles or systems are allowed access to the data provided.	*Stating (limitations on) how data may be used after it has been shared.*
- Provide or restrict data access to specific users - Provide or restrict data access for specific systems - Allow access to data - Inhibit access to data	- Provide or restrict data access for specific purposes - Delete data after X days/months - Use data not more than N times - Use data in a specific time interval - Log data access information - Share data only if it is encrypted - Control printing shared data

4   Infrastructural data sovereignty: the network-model approach

The capabilities for maintaining data sovereignty (as described in a generic, implementation-independent, manner in the previous section) are currently mostly provided by (closed) communities for trusted data sharing, with their own specific solutions. This is referred to as the 'hub-model' approach and is commonly applied for sector specific, closed, communities. As described in the introduction, it faces data providers with a threat of consumer lock-in and major integration efforts in case of data sharing with multiple data consumers. This section describes the open network-model approach for infrastructural data sovereignty, as opposed to the solution specific hub-model approach.

4.1   An open network-model for infrastructural data sovereignty

Figure 45 illustrates the transition from a solution specific hub-model approach towards an open network-model approach for infrastructural data sovereignty (Liezenberg et al. 2018).
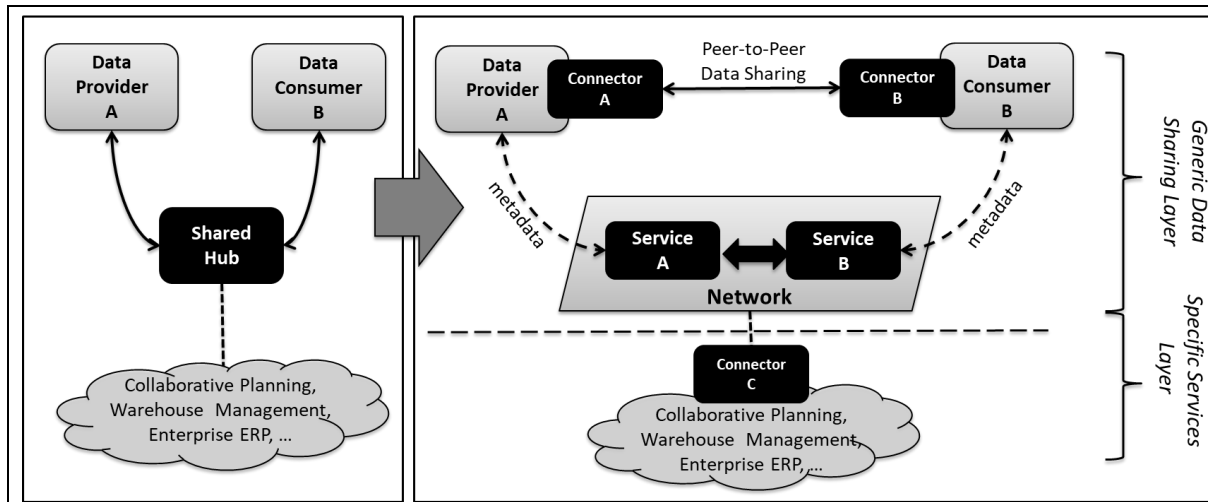
Figure 45: Transition from a Hub-Model Approach (l) to an Open Network-Model Approach (r) for Data Sharing (Liezenberg et al. 2018).

The upper part of Figure 45 depicts the 'Generic Data Sharing Layer' providing infrastructural data sovereignty capabilities, the lower part of Figure 45 depicts the 'Specific Services Layer' in which a multitude of specific value adding services can be supported.

The network-model approach is currently attracting major attention in overcoming the challenges associated to the hub-model. It provides generic infrastructural data sovereignty capabilities, enabling a single-entry point for the data provider with common and agreed upon protocols for defining and enforcing terms-of-use for data sharing. A network-model approach has previously been successfully developed and realized for infrastructural service provisioning in the banking and telecommunications sector.

For trusted data sharing using the network-model approach, the right part of Figure 45 shows three main leading architectural principles that are currently gaining acceptance for maintaining data sovereignty:

- *Peer-to-Peer data sharing.* To maintain data sovereignty by the data provider, local data processing is used in combination with peer-to-peer sharing of potentially sensitive data between a provider and consumer. For sharing the data, it is not stored in a centralized data base or controlled, forwarded or processed by an intermediary organization. As such, it prevents data providers from having to rely on intermediate external (trusted) organizations and from relinquishing full self-control over their potentially sensitive (meta)data to be shared.
- *Distributed infrastructure for support services.* Peer-to-peer data sharing as described in the previous bullet point has to be enabled by the support processes as listed in Table 12. These support processes will have to be implemented in a highly distributed infrastructure. In this infrastructure data providers and data consumers are subscribed to their own set of intermediary service providers providing their own portfolio of data sharing support services.
- *Openness for wide-scale adoption.* This network-model approach should be open to enable wide scale adoption and lower the barriers to participate. It has to be noted that for the various stakeholders in the distributed infrastructure 'openness' has its specific meaning (National Research Committee 1994):

- *Open to end-users:* it does not force end-users into closed groups or deny access to any sectors of society but permits universal connectivity. This is also referred to as creating a 'level playing field'.
- *Open to solution providers:* it allows any solution provider to meet the requirements to provide enabling components in the distributed and open data sharing infrastructure under competitive conditions.
- *Open to service providers and to innovation:* it provides an open and accessible environment for service providers to join and for new applications and services to be introduced.

In the network-model approach, data sharing is done on a peer-to-peer basis according to the first leading architectural principles. Nevertheless, this peer-to-peer data sharing may be used to populate a centralized data lake as part of a value adding service in the specific services layer, e.g. for logistics collaborative planning, warehouse management or enterprise ERP, as depicted in Figure 45. This may seem contradictory and may seem to make the generic data sharing layer in the upper part superfluous. It is noted, however, that also in these cases there is added value in the generic data sharing layer: (1) in the aligned and standardized mechanisms of communicating from data provider to service provider the terms-of-use under which the data is shared, (2) in the enforcement thereof in the domain of the service provider, and (3) in the added value of providing supporting functions for data sharing by external trusted roles as independent party.

In the distributed, business architecture of the open network-model, multiple and independent participants provide and govern their own services and solutions (Heikkilä et al. 2008), (Nicolaou et al. 2013). Nevertheless, they will have to be seamlessly interoperable in realizing and providing the overarching trust and data sovereignty enabling capabilities. To enable wide-scale adoption with low barriers to participate, they have a joint interest in defining and adhering to an agreed-upon reference architecture, ensuring the specific functions and business interests of each participant and supported by well-defined standards for interoperability. Such an open, service-oriented, business architecture for an open network-model approach will avoid strong monolithic implementations and prevent 'lock-in', by service providers. The following subsection describes current initiatives pursuing such an open, service-oriented, business architecture.

4.2   Initiatives on the open network-model for infrastructural data sovereignty

The open network model for maintaining data sovereignty is currently gaining major interest. This is reflected in both policy making and infrastructure development initiatives as listed in Table 14.

Table 14: Overview of policy making and infrastructure development initiatives.

National and European policy making initiatives
ETP ALICE: European Technology Platform 'Alliance for Logistics Innovation through Collaboration in Europe'
ETP ALICE assists the implementation of the EU Horizon 2020 research program. It is based on the need for an overarching view on logistics and supply chain planning and control for efficient logistics and supply chain operations. Its Systems & Technologies for Interconnected Logistics research and innovation roadmap identifies the need for new business models and data governance approaches with collaboration to enable trust and data sovereignty (ALICE 2018).
DTLF: Digital Transport & Logistics Forum

	The DTLF is a group of experts that brings together stakeholders from different transport and logistics communities, with a view to build a common vision and roadmap for digital transport and logistics. In its report (DTLF 2018), the DTLF Subgroup 2 'Corridor Information Systems', identifies the drivers for creating a common data sharing commodity and outlines the basic supporting roles for supporting such a common data sharing commodity.
National initiatives	
	For instance, to support data sharing in and over economic sectors and society, the Dutch government has recently released several direction setting policies (Dutch Ministry of EA&CP 2018), (Dutch Ministry of EA&CP 2019) in which the economic value of data sharing is outlined with the importance of an adequate data sharing infrastructure as a key enabler.
Infrastructure development initiatives on an open, network-model approach.	
iShare	
	The Dutch iShare initiative for the logistics sector realizes a uniform set of agreements for identification, authentication and authorization, such that organizations can share logistics data in a simple and controlled way, including with new and previously unknown partners (NLIP 2019).
AMDEX - Amsterdam Data Exchange	
	AMDEX is an initiative of the Amsterdam Economic Board to facilitate, local, European or international cooperation in a transparent open data market (Amsterdam Economic Board 2019). It will offer infrastructure and common rules to secure a trusted and safe environment that interested partners can join to create platforms for real-time data-driven cooperation.
FIWARE – Future Internet WARE	
	FIWARE is a framework of open source platform components providing a set of APIs for the development of (smart) applications in multiple vertical sectors. An open source reference implementation of each of the FIWARE components is publicly available for fast and low-cost deployment. FIWARE was funded by the Seventh Framework programme of the European Community for research and technological development.

In the following subsection, the IDS initiative as listed in the table will be further described.

4.3 The International Data Spaces (IDS) initiative

IDS is currently gaining major international traction for realizing an open infrastructure for trusted, multi-lateral, data sharing. The IDS reference architecture (Otto et al. 2019) is aimed at enabling the trusted sharing of (potentially sensitive) data, whilst maintaining sovereignty. It can be considered an architectural elaboration of the Trusted Multi-Tenant Infrastructure (Trusted Computing Group 2013). Figure 46 depicts and describes the main roles as distinguished in IDS.
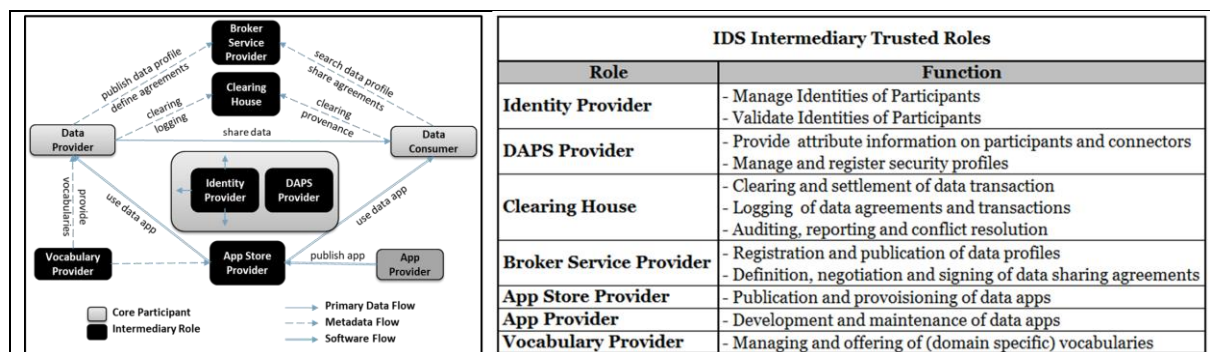
Figure 46: Roles in the IDS Reference Architecture (l) (Otto et al. 2019), together with a Functional Description for the Intermediary Roles (r) (Dalmolen et al. 2018).

The 'Intermediary Roles' in the IDS reference architecture act as trusted entities provided by trusted third parties (TTPs). In addition to the roles as depicted in the figure, the IDS distinguish roles for providing certification and (remote) attestation functions. IDS adhere to the leading architectural principles as described in subsection 4.1.

5 Service-oriented infrastructural data sovereignty

Maintaining sovereignty by the data provider over the metadata associated to his data sharing activities gives rise to operational challenges. An area of tension exists. On the one hand the stringent data sovereignty requirements ask organizations to keep the control over this metadata by storing and processing it as much as possible within their own (security and trust) domain. On the other hand the manageability and cost-efficiency thereof tend organizations to transfer the management and storage of metadata to external and specialized organizations such as an (IDS) Identity Provider, Broker Service Provider and Clearing House. As such, service-oriented infrastructural data sovereignty addresses the topic designing and managing the data support processes and their associated metadata in Table 12.

As described in the previous section, an open, service-oriented network-model provides major advantages to support the large variety of 'intermediate' architectural options that may be commercially and technically viable between the extremes of on the one hand full self-control and on the other hand outsourcing of the supporting data processes and their associated metadata. This section describes how interaction patterns between the various roles in such an open network-model for multi-lateral sharing of sensitive data may be realized.

5.1 Metadata interaction patterns for infrastructural data sovereignty

Figure 47 is an elaboration of the network-model approach depicted in Figure 46. It shows multiple instances of the intermediary roles that will coexist with a data provider and data consumer in general being subscribed to different instances, i.e. their 'home' intermediary roles.
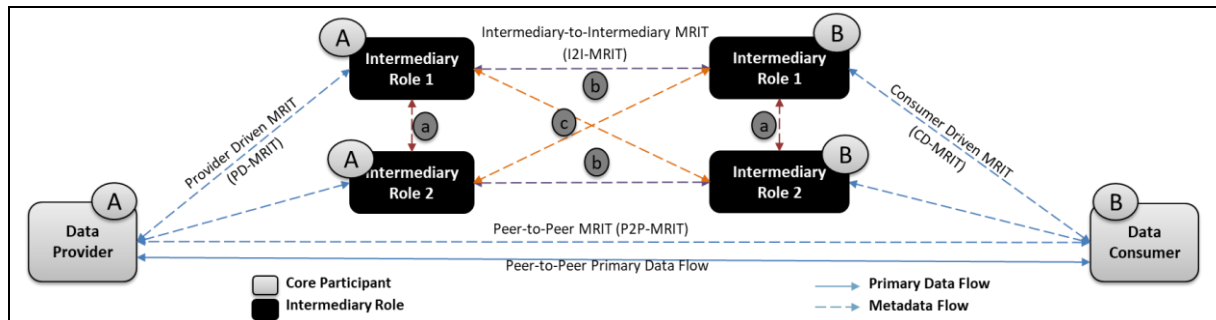
Figure 47: Metadata Interaction Patterns within the Generic Data Sharing Layer in a Distributed Open Network-Model Approach.

The figure shows the various metadata interaction patterns within the generic data sharing layer, distinguishing:

- *Provider and consumer driven metadata interaction patterns,* in which the data provider and consumer orchestrate the sharing of metadata with the intermediary roles they have subscribed to.
- *Intermediary-to-Intermediary metadata interaction patterns,* in which the intermediary roles of the various data providers and consumers orchestrate the sharing of metadata amongst them.

The suitability of both types of metadata interaction patterns for sharing metadata between roles in the distributed open infrastructure for multilateral data sharing is evaluated on the following criteria:

- *Maintaining sovereignty over the metadata by the data provider and consumer*

  Maintaining sovereignty over their metadata makes it essential for data providers to be in control over the proliferation chain of his metadata. Proliferation along a chain of interconnected intermediary roles by means of Intermediary-to-Intermediary metadata interaction patterns implies loss of such control and having to trust and rely on intermediary roles that are potentially not even known to the data provider.

- *Complexity of the overarching interoperability architecture*

  The widescale adoption of agreed-upon (and preferably standardized) interaction protocols strongly depends on the complexity and number of standardized interconnections to be realized by the various intermediary roles in the overarching role model. Having to implement and adhere to standardized interaction protocols for a multitude of types and instances of intermediary-to-intermediary metadata interaction patterns may be (too) complex, both from the development and deployment perspective.

  It is to be noted, that this complexity may be technically overcome as has been demonstrated in the 'old-school' world of pre-divestiture telecommunications at the end of the previous millennium. In their regulated environment, a limited number of (mostly non-competitive) major telcoes had a common interest in closely collaborating in developing standards for interoperability to achieve globally interoperable services. In the current liberalized situation for data services however, such a centrally governed development and deployment process is non-existent. Hence, definition and adoption of agreed-upon intermediary-to-intermediary interoperability protocols are a far less viable option.

On these criteria, the provider driven, and consumer driven metadata interaction patterns are to be preferred over the intermediary-to-intermediary interaction patterns. They give the data provider and consumer with the required control for maintaining sovereignty over their metadata. No direct intermediary-to-intermediary metadata sharing beyond the direct control of the data provider and consumer are required, preventing them from having to rely on trusted third parties.

The following subsection describes how the preferred provider driven and consumer driven metadata interaction patterns may be realized in an open, distributed, architecture for multi-lateral data sharing.

5.2 Policy enforcement framework for data sovereignty

The combination of the procedural and technical data sovereignty enabling capabilities (as described in subsection 2.1) constitute a data sovereignty framework for the supporting life-cycle processes for data sharing. They will have to be technically implemented by means of a data sharing connector as shown in Figure 48.
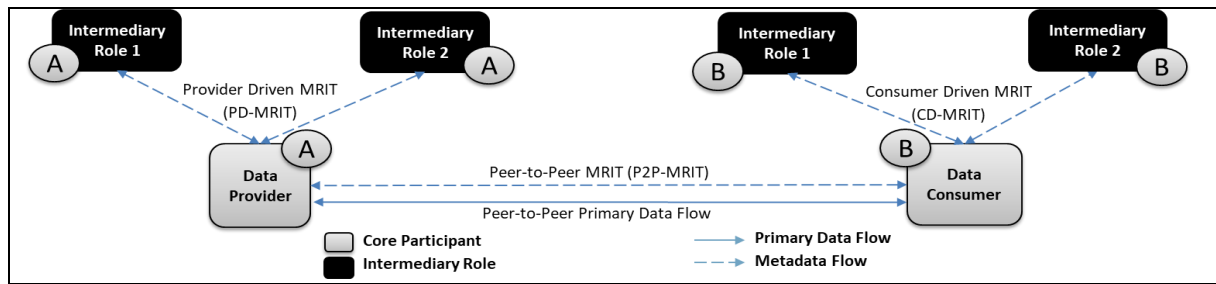
Figure 48: Runtime Environment for Metadata Flow Control based on Data Sharing Connectors.

As figure 5 shows, a data sharing connector consists of an app execution environment in combination with a policy execution framework:

- The *App Execution Environment (AEE)* runs a set of containerized apps of which the input and output data flows are being controlled by the associated PEF. These could be the apps of the intermediary roles. Typically, the apps in the AEE provide the procedural data sovereignty capabilities for legal enforceability.
- The *Policy Execution Framework (PEF)* includes capabilities for technical enforceability of the agreed-upon terms-of-use, access control policies and usage control policies and collaboration of the PEF-instances in the connectors of the local and remote data sharing endpoints. Typically, the PEF provides the technical data sovereignty capabilities for technical enforceability.

For the IDS reference architecture as described in the previous section, the data sharing connector is referred to as an 'IDS connector', currently being standardized under the terminology of 'Security Gateway' (DIN SPEC 27070). It consists of an execution core container, with the AEE and PEF, that is able to retrieve certified data apps from intermediary roles from an app store. The execution core container has a data router for routing incoming and outgoing messages through the correct data apps. Furthermore, it is enabled to enforce access and usage control policies.

6 Service elaboration for infrastructural data sovereignty

As described in the previous sections, an open service-oriented business architecture provides major advantages to support the large variety of 'intermediate' architectural options that may be commercially and technically viable. The following subsections describe how this can be realized for the basic main functions of processing and logging of sensitive (meta)data.

6.1 Services for processing of sensitive metadata

Utilizing the capability of the AEE in the runtime environment of the data sharing connector (as depicted in Figure 48) enables the intermediary roles to provide their supporting services for the data sharing support processes as listed in Table 1 by means of apps executing locally within a secure, containerized, connector. This way the data provider maintains sovereignty over the associated metadata as it does not (have to) leave the local data provider's or data consumer's connector.

An illustrative and representative use case entails the supporting subprocess on the definition of terms-of-use, including the usage and access control policies as provided by an intermediary and trusted broker service provider role. A main added value and distinguishing factor for a specific broker service provider can be in minimizing the complexity for defining and configuring the applicable terms-of-use for their subscribed data providers, thus minimizing the required skills and IT-savviness for the data provider, lowering the barriers of adoption. In this scenario, the broker service provider offers a set of terms-of-use templates to be used by its

subscribed data providers. The quality and ease-of-use of the templates will be a main competitive advantage. The templates are provided by means of a data brokering app running in the data provider's trusted data sharing connector. This data brokering app fulfils the role of the delegated data brokering service (including negotiation and signing), executing locally in the data provider's trusted data sharing connector, i.e. within the data providers domain and under control of its local policy enforcement framework. As part of the delegated data brokering app installation and configuration process, its associated access and usage control policies are provided and instantiated within the data provider's policy enforcement framework, preventing from misuse or data leakage of the associated metadata.

6.2   Services for logging of sensitive metadata

For the supporting life-cycle sub-processes for 'logging, provenance and reporting', a broad variety of options may be supported in an open, distributed, architecture. Such supporting sub-processes are typically enabled by services provided by a clearing house intermediary role. Similar as for the illustrative and representative use case described in the previous paragraph, the service of the clearing house intermediary role may be provided by means of an app of the clearing housed executing locally within the secure data sharing connector of the data provider or consumer. This approach enables various service alternatives to be supported with respect to locally (i.e. within the domain of the data provider or data consumer) versus centrally (i.e. within the domain of the clearing house) logging of metadata:

- *No centrally logging of metadata.* This reflects the strictest approach to maintaining data sovereignty in which the data provider keeps the data sharing support processes and associated metadata under his own full-control and within his own (security and trust) domain.
- *Centrally logging of hashed metadata.* In this approach, the data provider keeps the data transaction metadata within his own (security and trust) domain, whilst providing hashed metadata to an intermediary role for logging, i.e. his subscribed clearing house. In case of conflict resolution, the clearing house can act as trusted third party by verifying the validity of the logged data by the data provider by means of the hashes.
- *Centrally logging of encrypted metadata.* In this case, the data providers metadata does not log metadata in his own (security and trust) domain. The metadata is logged by his subscribed trusted third-party clearing house, preferably in an encrypted format. Management of the encryption keys may remain under control of the data provider.

Illustrative examples for which these various forms of logging of metadata apply are e.g. for the data provider for logging metadata on the data provided for the case of conflict resolution, and for the data consumer for logging metadata and data provenance to report on compliance to the agreed upon terms-of-use.

7   Discussion

Data is crucial for companies and their daily operations, as well as for the longer term strategies. The data sovereign is important to be in operation in the future. Sharing data is essential to achieve operational excellence. These two opposing forces therefore make it challenging. In Chapter 2 a logistic example is given with different variants of trust between the partners themselves.

Especially in the orchestration scenario, in which the trusted third party plays a crucial role, data sovereignty is essential. Currently you see in daily practice that a port community system fills in this functionality. Unfortunately, the shipper is not often in control of his own data. An

additional side effect that you often find in practice is a vendor lock-in in terms of software and business functionality. The current proposal can address the challenges described above.

To implement these business scenarios forces the stakeholders (shippers, LSP's, transporters) to share sensitive data in the logistic value chain, requiring a trusted multi-lateral data sharing infrastructure to spur their willingness to share such data. As such, they give rise to new challenges: (1) on compliance to internal business policies for trusted data sharing with stakeholders that could potentially be competitors and compliance to external regulatory policies, (2) on privacy regulations such as General Data Protection Regulation (GDPR) and competition laws, as applicable to this specific scenario. The use of data sharing agreements that are enforceable, both legally and technically (as described in the previous section), may provide the means to the stakeholders to gain the required level of trust for being willing to share their (potentially sensitive) data in in support of these business scenarios.

Implementation of these business scenarios requires that shippers, LSP's, transporters and other service providers in the logistic value chain share (potentially sensitive) business and operations data. As such, they give rise to new challenges:

- *Compliance to internal business policies for trusted data sharing:* to reap the indicated benefits of exchanging data, operational data which may be valuable and business-sensitive has to be shared with stakeholders that could potentially be competitors. A trustworthy infrastructure based on solid agreements and contracts and a technical secure data sharing infrastructure are a prerequisite for convincing stakeholders to exchange such data, i.e. an interoperable, multi-lateral, trusted data sharing infrastructure.

- *Compliance to external regulatory policies:* to share data, different regulations are introduced by European law makers. Notwithstanding the inherent complex role of data and algorithms, an increased understanding is needed about how data regulation should be applied in case of data platforms. The following high-level challenges have been addressed in the literature. For example, (BDVA 2019) emphasizes from practical point of view that there are questions on how "to incorporate and adjust for the effects of the regulatory landscape in data market e.g. how to be compliant, when, where and which regulation comes into effect, how to gather knowledge on implementing the regulation etc.". Another challenge that has been addressed by law scholar and the European Commission's future approach towards sharing data in competition policies. They expect that Commission's approach will likely be speedier enforcement through complementary regulatory measures and adjusted rules in merger control and online vertical restrictions.

8 Conclusions

A primary objective of this paper has been to describe the need and architectural approach for infrastructural data sovereignty for multi-lateral sharing of sensitive data in an open network-model. A technical and service perspective has been proposed for transferring (outsourcing) data sharing support processes and their associated metadata to external, trusted, and specialized organizations. The expectation is that the concepts as described in this paper will improve the data provider's sovereignty and control over both their sensitive primary and secondary metadata, in a world that is ever more realizing that data is a valuable asset to be protected and exploited. It may lower the barriers for organizations for sharing their data in the transition towards a data-centric global information society.

As the technical components of the data sharing concepts as described in this paper become more and more available, adequate governance needs major attention to stimulate wide scale adoption and prevent from a lack of uptake. This applies to both governance of its development

and deployment. Openness and interoperability through standardization are major enablers for success.

Standardization must focus on interoperability of the data provider and consumer with the supporting intermediary roles in an open network-model. At the same time, to optimally support service-orientation for infrastructural data sovereignty, standardization should not be (too) prescriptive with respect to various service options that may be provided by these intermediary roles. As such, conforming to the architectural considerations as described in this paper, standardization should focus on and be limited to standardization of the (information models for the) metadata artefacts and the interaction messages and protocols for conveying them between the various roles in the open network-model approach. It is to be noted that the main concepts of the IDS architecture and their interoperability requirements as described in this paper are currently being standardized as DIN SPEC standards, (DIN SPEC 27070), (DIN SPEC 16593-1).

Leaving the uptake to individual commercial users or sectors may not be an adequate approach to wide-scale adoption, as it may not be contributing to their core business, vision and ambition. Public-private cooperation may provide a better option to success. Support by governments and authorities in jointly developing the data sharing architecture into a broadly available public utility may be envisioned, supported by adequate commercial implementations and marketing power to develop, deploy and exploit the open infrastructure, e.g. by independent service providers or telecommunication operators.

9 Acknowledgement

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Interoperability in Logistics: An Ontology Alignment Approach

Majid Mohammadi[1], Wout Hofman[2], Yao-Hua Tan[1]

1. TUDelft, Delft, The Netherlands
2. TNO, The Hague, The Netherlands

Corresponding author: m.mohammadi@tudelft.nl

Abstract: The logistics sector consists of a limited number of large enterprises and many Small and Medium-sized Enterprises (SMEs). These enterprises either have developed proprietary information systems or use Commercial of the Shelve (COTS) systems tailored to their business processes. It is a large number of heterogeneous systems interoperable via a large variety of (subsets of) open -,or proprietary standards. These standards typically reflect the same data sets in distinct ways so that there is a large variation of non-interoperable solutions. As a result, interoperability of information systems of different enterprises takes a lot of development and configuration time leading to high costs, with or without using an intermediate system for data transformations. (Semi-)automatic ontology alignment may solve this issue and support organizations in creating interoperable solutions. This paper presents experiments on applying ontology alignment to logistics.

Keywords: ontology alignment, systems integration, logistics

1. Introduction

The supply and logistics sector consists of millions of large and Small and Medium-sized Enterprises (SMEs). Its size in the EU only is estimated 878 billion Euro (2012)[23] with over 1.2 millions of enterprises (Satta & Parola, 2011). Besides proprietary developed software, these enterprises can choose to use Commercial Off The Shelve (COTS) software from over 200 different suppliers (US)[24]. Each of these systems will have its proprietary database scheme.

The challenge is and has been to integrate the business processes of enterprises and their supporting IT solutions. Development of open standards addresses this challenge. Although these standards were developed, they did not solve the problem. Different implementation guides of (different versions of) open standards have been developed (Hofman, Towards large-scale logistics interoperability based on an analysis of available open standards, 2018)), leading to implementations that are only interoperable with additional efforts and costs. These implementation guides support process interoperability (Wang, Tolk, & Wang, 2009), which implies they will have a particular function for business processes. There are also different open standards providing the same business functionality, e.g., a transport order developed by UN/CEFACT or one of the Uniform Business Language (UBL). To address differences in implementation guides of different open standards with identical or similar functionality, commercial organizations provide transformation services between various data standards.

Applying open standards and commercial transformation services reduces the transformation challenge, but the development and implementation of implementation guides of these open standards still take too much time for implementing supply chain innovations like agility and resilience (Wieland & Wallenburg), and synchromodal planning (Behdani, Fan, Wiegmans, & Zuidwijk, 2014). To reduce these development and implementation time for interoperability

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[23] https://ec.europa.eu/transport/themes/logistics-and-multimodal-transport/logistics_en
[24] https://www.capterra.com/logistics-software/

between any two organizations, this paper explores the application of ontology alignment (Euzenat & Shvaiko, 2010). Ontology alignment has resulted in different algorithms, that are tested in a competition, the Ontology Alignment Evaluation Initiative (Shvaiko, Euzenat, Jiménez-Ruis, Cheatham, & Hassanzadeh, 2018). The SANOM algorithm will be applied to ontology alignment for supply and logistics (M. Mohammadi, W. Hofman, and Yao-Hua Tan, 2019). The holy grail of ontology alignment in supply and logistics is to create semi-autonomous alignments between database schemes of different organizations, thus enabling what one could call 'plug and play' (The Digital Transport and Logistics Forum (DTLF), 2017): plug a database scheme into an open data sharing infrastructure and be able to share data with relevant business partners. Plug and play requires an open data sharing infrastructure providing standardized services (Hofman & Dalmolen, 2019).

First of all, this paper introduces ontology alignment, the OAEI, and the SANOM algorithm. Secondly, an experiment for aligning two logistics ontologies is presented. The results of a first experiment will be the basis for upcoming experiments. The result will be discussed in the context of the OAEI competition.

2. Ontology alignment

Ontologies are the proper tool to formalize the objects of a domain along with the relations that these objects have. Ontologies have been used extensively in various domains to model the underlying concepts in a formal manner. In logistics, there are also several efforts to model various aspects of data sharing between business processes of different stakeholders and to take advantages of the benefits of ontologies.

Since ontologies are created subjectively by different experts of a domain, the discrepancy among different ontologies of a domain is inevitable. Ontology alignment is the effort to reconcile the heterogeneity between different ontologies which state similar concepts of a real-world domain. In this regard, one needs to consider the sources of heterogeneity in different ontologies and use appropriate strategies to find similar concepts in two ontologies. Basically, there are two strategies for finding similar concepts coming from two types of heterogeneity. The first strategy is to consider the name of concepts and try to align the concepts with similar names. It is due to the fact that domain's experts might use different terminology for the same concepts in that domain. To gauge the similarity among concepts, one technique is to use string similarity metrics to consider the sole. Yet this technique cannot detect identical concepts with, for instance, synonymous names. For this type of heterogeneity, the use of an external resource is important. To date, WordNet is the most comprehensive resource that can boost significantly the result of ontology alignment. Another similarity is computed based on the position of the concept in the ontologies. For instance, if two concepts have many superclasses in common, then chances are that those classes are identical even though they are not named similarly.

Simulated annealing-based ontology matching (M. Mohammadi, W. Hofman, and Yao-Hua Tan, 2019), or SANOM, is an ontology alignment system which takes advantage of the well-known simulated annealing to find similar concepts in two given ontologies. Figure 1 displays the architecture of SANOM for aligning two ontologies. According to this figure, it is first required to parse the ontologies and store them into an object called *Lexicon*. Then, the similarity computations module calculates the similarity of each pair of concepts from two ontologies and store them in a hashtable called *matrix*. Prior to executing the simulated annealing, the *warm initialization* is conducted which produces a good initial guess. Then, both the initial guess and the hashtable is given to the simulated annealing and it will finally reach

to a proper alignment by considering both the name similarity in *matrix*, and the structural similarity in the fitness evaluation of states in the simulated annealing.
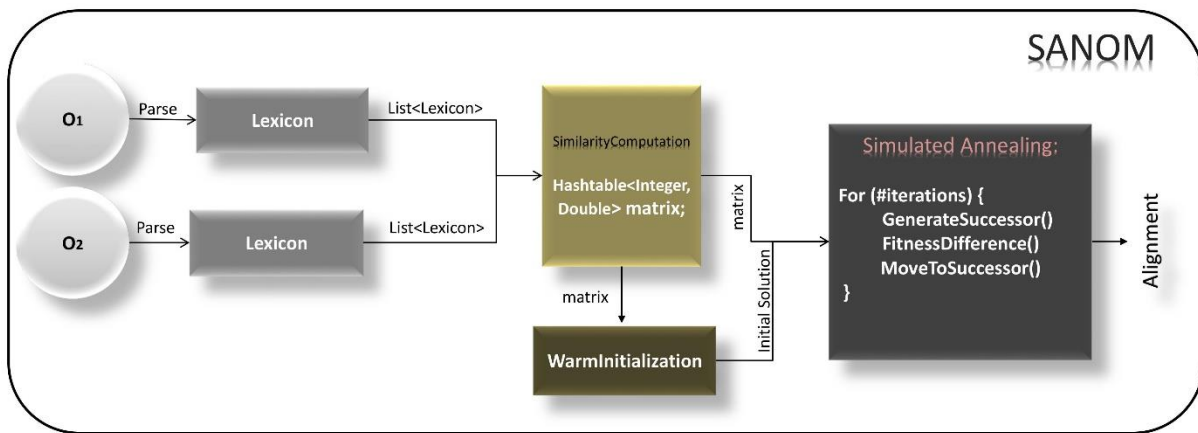
Figure 49 The architecture of SANOM

3. The experiment

This section introduces the experiment where the SANOM algorithm is applied for aligning two ontologies. There are still choices to be made with respect to the experiments that will be discussed first.

3.1. Choices for the experiment

The OAEI considers a common ontology that is used to generate other ontologies. Ontology alignment algorithms are applied to align the latter ontologies to the one that is used for generating them. This context differs for supply and logistics. First of all, ontologies are not common in supply and logistics. Open standards, their implementation guides, and database schemes have to be transformed into ontologies to enable alignment. Secondly, the following alignment choices need to be considered:

1. Database scheme alignment – one could consider the alignment between database schemes of different organizations. This option is not considered feasible since databases provide more functionality than interoperability between two organizations; they support an organization in its business.

2. Functional view alignment – this option considers creating a functional view of for instance a transport order on two database schemes that will be aligned. If ontology alignment would provide optimal results, this would be an ideal situation since it does not require any formulation of open standards. It is however also complex, while it requires to align many structures all using potentially different terminology.

3. Open standard alignment – alignment of two open standards. This could be a first start which does not require any involvement of organizations (yet). Open standards are publicly available. However, the development of an ontology from an open standard might be complex, depending on the supported functionality. An open standard for a transport order may for instance cover all transport modalities and all types of cargo.

4. Implementation guide alignment – alignment of implementation guides of an open standard. For this purpose, organizations will have to provide their implementation guides.

5. Alignment with a Canonical Information Model –integration of IT applications of one organization can be via a so-called Canonical Information Model (CIM, (Hohpe & Woolf, 2004)). This approach can also be applied for external integration, i.e. between IT applications of different organizations. It requires time for constructing a CIM, but in case the CIM can be used for automatic alignment between functional views of database schemes, it will support the aforementioned 'plug and play'. There are different options using a CIM, like:

   a. Alignment of a functional view with the CIM;

   b. Alignment of an open standard with the CIM;

   c. Alignment of an implementation guide of an open standard with the CIM.

The proposal is to conduct the first experiment by aligning implementation guides of open standards with a CIM that has been developed in EU funded projects. This experiment can be completely controlled. The CIM is already represented as ontology, called LogiCo[25] and an implementation guide of an existing open standard will be produced that is expected to contain concepts represented by the CIM.

3.2. Setting of the experiment

Like stated, the experiment is conducted by the alignment of ontologies derived from implementation guides of open standards, with and without using LogiCo as a CIM. These choices will be further elaborated.

Using LogiCo will have some risks with respect to the experiment; it might not support the functionality of an implementation guide. To reduce this risk, an implementation guide of an open standard needs to be aligned as much as possible with LogiCo. Therefore, it is worthwhile to list the foundational concepts of LogiCo:

- **Activity** denotes some action and is relevant for the purpose of logistics, such as, for example, the activities of transport, storage, transshipment, loading, and unloading. Some activities are atomic and can be used to compose more complex activities.

- **Event** represents an occurrence of interest for the execution of a certain activity. In contrast to an activity, which denotes an action that is continuous in time, an event denotes an occurrence at a specific moment in time. For example, the departure of transport means from a location of origin and its arrival to the destination can be regarded, respectively, as starting and ending events for the transport activity.

- **Actor** represents organizations, authorities or individuals that offer or require activities and operate on resources related to these activities. An actor can have a **Role**, for example, customer and service provider, or shipper, consignee, forwarder, and carrier.

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[25] Ontology.tno.nl

- **Entity** represents something that is used or exchanged during an activity. We specialize an Entity in a **Spatial Entity**, which represents tangible objects, such as an equipment or a person, and an **Intangible Entity**, which represents intangible objects, such as a modality, a characteristics or a dimension. We also define a **Temporal Entity**, which represents the start time, end time or time interval associated to activities and events. To this regard, since time is a basic (foundational) concept relevant for logistics, but common to other domains, we re-use the time ontology proposed by W3C (http://www.w3.org/TR/owl-time), instead of specifying our time ontology from scratch.

- **Location** represents the geographical area or geographical point used to define the place of origin and destination for entities and activities. Location can have different levels of granularity. Location can be coarse-grained for scheduling, since in long term planning it is sufficient to specify approximately the place of origin and destination, such as, for example, the Netherlands or the port of Rotterdam.

- **Moveable Resources** are characterized by the capability of moving on their own or being contained in another entity for the purpose of movement, and **Static Resources** are used to host and/or handle moveable resources.

An implementation guide has been constructed for an open standard representing document data for road transport. The open standard has been developed by UN/CEFACT for electronic waybills, with a specialization to the eCMR for road transport. The eCMR is an XML Schema Definition (XSD) that imports a number of other XSDs, where these XSDs import others in their turn. The eCMR XSD assigns one specific document type, the CMR, to a generic representation of data that can be stored by all types of transport documents. Thus, the core structure should as well be applicable for documents shared in other modalities. To conduct the experiments, part of the eCMR XSD is represented by an ontology. Representing the complete eCMR XSD by an ontology would be too time-consuming, we have not found open source tools to generate an ontology from an XSD. Only those parts of the eCMR XSD were chosen that could be aligned to LogiCo.

A second experiment was conducted by creating an ontology for shipping instruction, which is a transport order for sea transport. The functionality should thus be similar to that of an eCMR, with the exception that the transport mode differs. The data structure of an international booking site for sea transport provides the basis for this shipping instruction.

Figure 50 eCMR ontology

Figure 51 Shipping Instrcution Ontology

3.3. Results of the experiment

The first experiment was the alignment of the two ontologies representing implementation guides of open standards. The second experiment was to align these ontologies with LogiCo. The alignment is not satisfactory. Only concepts representing common roles of organizations in the three ontologies can be aligned with each other, but not other concepts. This is the same for alignment between the two implementation guides of open standards and these implementation guides with LogiCo.

This mismatch of alignments is due to naming conventions that differ between the three ontologies used. For instance, the eCMR has concepts like 'SupplyChainConsignment' and 'LogisticsPackage' where these concepts are not present in the other ontologies. The concept 'SupplyChainConsignment' is also not expected to be part of a shipping instruction ontology, since the latter represents a consignment. In general, it is not common in supply and logistics standards to use a type of prefix 'SupplyChain-' for naming concepts, which makes alignment only possible to those open standards that use the same prefix for naming. The same applies to 'LogisticsPackage'. In LogiCo, this concept is 'Moveable Resource' whereas, in a shipping instruction for containers, it should equal 'container'.

Furthermore, shipping instruction has additional roles, due to delivery conditions. Besides a consignor (which is equal to a shipper) and consignee, also notifies will be mentioned. These notify have to be informed when containers arrive at a port of discharge.

Besides these differences in the naming of concepts, which will require a common data dictionary like the United Nations Trade Data Elements Directory (UNTDED)[26]. This naming difference might be solved by annotating the CIM with terms used by other ontologies. A next experiment is required with an annotated CIM.

Another difference is that these open standards represent the transport services of enterprises like carriers. For instance, a shipping line is able to transport a container between the hinterland and a port and position a container for stuffing at the location of a shipper or only transport a container between two ports. The difference is known as carrier - and merchant haulage respectively and is, in fact, a combined service. This combined service is however not represented by an eCMR, nor by LogiCo. However, the eCMR contains another modeling issue, namely that of modeling a shipment that can consist of more than one consignment. The shipment is used for data sharing with a carrier; the consignment for data sharing between a shipper and a forwarder.

These differences cannot be solved by ontology alignment. It would require agreement on modeling. Two modeling principles could be to specify transport services that cannot be decomposed in other services and to model data sharing between two stakeholders only (Hofman & Dalmolen, 2019). Associations between a shipment and its consignments are thus only internal by for instance a forwarder combining consignments into one shipment (i.e., a Less than Container Load or LCL container). An authority like customs that wants to access data of consignments in containers, the so-called data pipeline (Heshket, 2010) can do so by monitoring data sharing between shipper and forwarder and forwarder and carrier (Hofman,

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[26] https://www.unece.org/tradewelcome/un-centre-for-trade-facilitation-and-e-business-uncefact/outputs/standards/untded-iso7372/introducing-untded-iso7372.html

Dalmolen, & Spek, 2019). Notice also that a carrier is never allowed to know the exact content of a container[27].

A third difference is the representation of cargo. There are three different concepts used by these three ontologies, namely LogisticsPackage, Moveable Resource, and container. One could argue that a container represents the actual cargo, but it also has packages stuffed inside. The container can be a specialization of a Moveable Resource or LogisticsPackage', although a Moveable Resource might not be equal to a LogisticsPackage. What is required besides agreement on the naming of concepts, is the associations between those concepts. The following figure shows an example of proposed concepts and their associations, where each association can carry properties. It is based on a concept of Digital Twin from simulation (Boschert & Rosen, 2016), where a digital twin can be specialized and will be in a place at a time. The same place can contain more than one digital twin, for instance containers stacked in a yard.
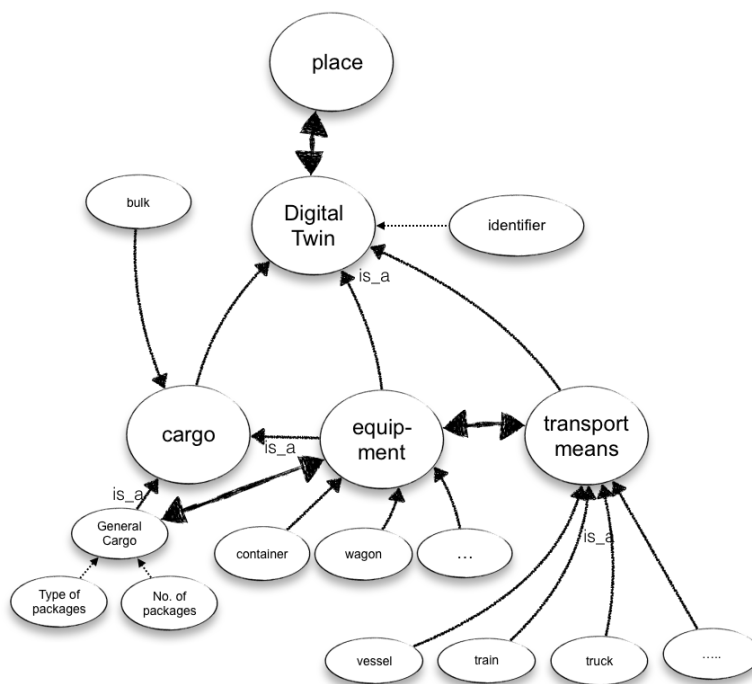
Figure 2: Modelling cargo and transport means

A question that arises is: why do these differences not arise in the context of the OAEI? Although we did not study this in detail, two potential answers could be given. First of all, the aligned ontology all stem from one ontology. Thus, the ontologies that have to be aligned with the upper one used for generating them, will all contain similar functionality. A second difference could be that the ontologies represent a domain that uses common agreed dictionaries, potential implicit ones formulated by scientific papers and books. Everyone modeling the domain will thus develop similar concepts. This could be for further study.

4. Conclusions

This paper presents an experiment of ontology alignment for supply and logistics. The experiment considers the alignment of ontologies representing implementation guides of two open standards and the alignment of each of these ontologies with a Canonical Information

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[27] www.rotterdamrules.com

Model represented as ontology (LogiCo). The experiments did not give satisfactory results due to differences in naming convention and systems modeled by the ontologies.

A second experiment will be performed by annotating the CIM with the terminology used in one of the implementation guides, namely the one of representing the shipping instruction. We assume that this will improve alignment results.

In view of the challenges encountered for alignment of implementation guides of open standards, it is safe to assume that alignment of (functional views of) database schemes represented as ontologies will even be more difficult. We cannot expect that database schemes use the same naming conventions and they will also have different structures.

Furthermore, it is our expectation that ontology alignment will only improve if there is a common understanding of what needs to be represented by an ontology or the CIM used for alignment has to be extended with knowledge of business service composition to address all possible standards. In the latter case, the alignment algorithm may also have to be extended.

What is not yet addressed in alignments, is the possibility that two or more concepts are merged into one or one concept is split into two or more concepts. This type of merging (and splitting) can be on a concatenation of strings, but could also consider calculation functions (e.g. length x width x height = volume). Data transformations between for instance units or code values are not part of ontology alignment and are thus not considered.

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Supply Chain Visibility Ledger

Wout Hofman[1], Jacco Spek[1], Simon Dalmolen[1]

1. TNO, the Hague, The Netherlands

Corresponding author: wout.hofman@tno.nl

Abstract: *Improved situational awareness, also known as Supply Chain Visibility, contributes to better decisions with the ability to synchronize processes and reduce costs. It requires data sharing by events of for instance positions, speed, and direction of vessels, trucks, barges, and trains, and Estimated Time of Arrival (ETA) and – Departure (ETD) of these transport means. Whereas the data structure is called 'event', the progress of the physical processes is expressed by 'milestones'. These milestones are related to (groups of) physical objects, modelled as Digital Twins. Groups of Digital Twins are those that are offered at a given time and place for transport and have to be available together at another time and place, also called shipment or consignment. Such shipments and consignments are uniquely identifiable between a customer and Logistics Service Provider; Digital Twins of different or the same shipment(s) can be regrouped into other shipments. Based on this Digital Twin approach and business transactions representing shipments or consignments, this paper presents a Supply Chain Visibility Ledger propagating events with milestones.*

Keywords: supply chain visibility, distributed ledger, blockchain, semantic technology

1 Introduction

The lack of or limited situational awareness of the various stakeholders involved in supply and logistics chains causes unnecessary delays and - waiting times, fines imposed by customers for delays, and unnecessary priority shipment for products required by a customer, and stock reduction (Parjogo & Olhager, 2012), (Urciuoli & Hintsa, 2018) (Caridi, Moretto, Perego, & Tumino, 2014). These all lead to higher costs, increase the carbon footprint, and contributes to waste. In general, improved situational awareness will contribute to decision making (Endsley, 1995). (Near) real-time supply chain visibility addresses these issues.

However, supply and logistics chains can be complex. International supply chains involve many enterprises and authorities, each with their heterogeneous IT systems either tailored Commercial Off The Shelve (COTS) or proprietary developed. Data is duplicated by messages between these systems, including various formats and implementation guides of open standards (Hofman, 2018). Many of these systems are not yet able for real-time processing of events generated by physical assets (IoT – Internet of Things). Different solutions are being developed addressing these issues, each with their (proprietary) interfaces. Tradelens and the Electronic Product Code Information System (EPCIS (Global Systems One, 2014)) are two examples. Identity mechanisms supported with delegation (iShare, 2019) are introduced to access the status of logistics chains. These various solutions have a so-called publish and subscribe (Erl, 2005) model in common, for instance in a bilateral collaboration or based on delegations.

This paper provides an alternative solution for real time status sharing between all stakeholders in supply and logistics networks by Distributed Ledger Technology (DLT). Subscription mechanisms are based on transactional relations between stakeholders and the associations between the various physical objects, like a container transported by a vessel. Additional rules are specified by which status information is propagated downstream in chains towards the final destination, especially the predicted status to address the aforementioned issues.

First of all, supply chain visibility is analyzed and illustrated by two use cases. Secondly, the solution is specified illustrated with a first demonstrator. Finally, the relation with available standards is analyzed and conclusions are presented.

2 Supply chain visibility

This section introduces the concept of supply chain visibility, illustrated with two typical use cases. The first use case demonstrates supply chain visibility for direct transport, meaning there is one transport operation. The second one demonstrates transshipment of containers via a port and coordination issues involved.

2.1 A generic approach to supply chain visibility

Supply chain visibility can be defined as 'awareness of and control over end-to-end supply chain information – including insight in sources of data and whereabouts of goods – enabling agile, resilient, sustainable as well as compliant and trusted supply chains' (Wieland & Wallenburg). Other definitions state 'the ability to be alerted to exceptions in supply chain execution' or 'capturing and analyzing supply chain data that informs decision-making, mitigates risk, and improves processes' (Caridi, Moretto, Perego, & Tumino, 2014). Basically, it supply chain visibility is about improving decision-making by increased situational awareness (Endsley, 1995). Supply chain visibility has many advantages in terms of costs and time (Caridi, Moretto, Perego, & Tumino, 2014) based on process synchronization. It reduces inventory and contributes to customer service by on-time delivery and providing customer visibility. Process synchronization requires sharing of knowledge of the location of physical objects, and in case these physical objects are transport means, their speed and direction, any relation between physical objects like a container transported by a truck, and a prediction of a time for completing a particular logistics operation. These times can be various, like:

- For transport operations, the following predicted times are relevant:
    - Estimated Time of Arrival (ETA) of a transport means at a location, e.g. a vessel in a port.
    - Estimated Time of Departure (ETD) of a transport means, or the combination of the Actual Time of Arrival (ATA) and a predicted duration of a call of a transport means at a location.
- For transshipment operations, the estimated discharge and loading times of cargo objects like containers of and on transport means are relevant. An estimated discharge time provides for instance an indication for the next transport leg to pick up the cargo objects.

These types are basically relevant for synchronizing different transport operations, or what can be called 'transport legs', of a logistics chain. Any disturbances caused by for instance accidents, incidents, lack of qualified personnel, weather conditions, and maintenance of both on physical assets used to facilitate transport operations and the infrastructure used (e.g. roads and inland waterways with locks), will influence these transport operations. They will cause delays that have to be known to the next transport leg.

Administrative procedures may also cause delays. Examples are missing documents or data of a particular shipment like a Certificate of Origin, lack of a confirmation by an authority like a customs release, a physical inspection of cargo by a customs authority, and payment of the previous transport leg. Providing authorities supply chain visibility, improves their decision processes, which may lead to less or unnecessary delays (Urciuoli & Hintsa, 2018), (Caridi, Moretto, Perego, & Tumino, 2014) and contribute to safety (Hofman, Spek, & Ommeren,

2018). Supply chain visibility may include both data of cargo and their itinerary with estimate times of arrival.

Thus, process synchronization of transport operations also has to meet particular condition imposed by formal procedures, optionally providing additional data (optional multiple filing reference), and agreements between stakeholders involved, like specified by for instance the INCOTERMS used in international transport. The INCOTERMS specify for instance which of the stakeholders has to pay for which part of a logistics chain. An example is 'free delivered' mostly applied in eCommerce where a shipper pays transport charges.

2.2   Direct transport

Direct transport is a single modality transport by one carrier between a shipper's and a consignee's location, for instance from a supplier of material to a production plant of a customer or delivery of consumer products to a cross-docking center of a retail chain. Road transport is the main modality used for direct transport; most other transport modalities require additional transshipping for pickup and last mile delivery of cargo. There are two options for arranging transport, specified by the INCOTERMS 'ex works' and 'free delivered': either the shipper organizes and pays the transport (free delivered) or the consignee (ex works). Transport is according to national or international CMR conditions, with an accompanying document representing the contractual agreement (the 'CMR'). When accepting the cargo, a carrier is able to make notes regarding the condition of the cargo; a consignee can do the same at the destination. These notes can include for instance damage remarks and losses of packages.

Direct transport considers two milestones, namely the pickup and acceptance and the drop off and delivery of the cargo by a carrier. Sharing of the milestone of the drop off is called 'Proof of Delivery', which can trigger payment of transport charges and products delivered to a consignee. Before picking up the cargo, a carrier may inform a shipper of its ETA. Sharing an ETA may reduce waiting time of a carrier and allow a shipper to prepare the cargo at a proper gate (Hofman & Rajagopal, 2015). In-between pickup and drop off, shipper and consignee are both interested about the Estimated Time of Arrival and any deviations (too late or too early; (Urciuoli & Hintsa, 2018)): a shipper to inform its customer upon request and a customer to synchronize its processes with the arrival of the cargo. Concluding, there are four milestones:

- ETA of a truck at the premises of a shipper;
- Pickup of the cargo by the carrier;
- ETA of the truck and its cargo at the premises of the consignee
- Drop off of the cargo by the carrier.

Sharing these milestones is on basis of contractual relationships. A carrier shares this information with his customer, either a shipper ('free delivered') or a customer ('ex works'). In case a shipper acts as customer to a carrier, that shipper might inform its customer, acting as consignee, of for instance an ETA and any deviations. The carrier and the consignee will inform a shipper of the Proof of Delivery. In case a consignee acts as customer of a carrier, the carrier will inform the consignee of ETA of its truck at the premises of the shipper, pick up and (deviations of) an ETA at the premises of the consignee. The consignee will inform the shipper of the Proof of Delivery.

2.3   Container transshipment in a port

A more complex case is that of transhipment of containers via a port like the port of Rotterdam. Transshipment consists of arrival of a vessel in a port, discharge of containers, and on-carriage of these containers to the hinterland. Various enterprises are involved utilizing different

modalities for on-carriage. Furthermore, there are a number of conditions that have to be met, before on-carriage can take place. These conditions are known as 'released' and have to be known to a carrier for on-carriage and a terminal where a container is transhipped. Release consists of:

- Commercial release – transport charges for sea transport are paid. In case the INCOTERMS are 'free on board', a consignee or his agent will pay transport charges. Basically, a shipping line and forwarder acting as consignee's agent share the commercial release status, including their banks.
- Customs release – a container is released by customs for its next transport leg. Customs issues a release to the shipping line responsible for sea transport. This customs release may require an declaration for the next customs procedure issues by the consignee or his agent, e.g. transit, import, or (temporary) storage under customs regime.
- Discharged – a container is physically present at a terminal of a stevedore.

Figure 1 visualizes the formal relations of the various roles involved in transhipment. The arrow points from a customer to a service provider, where customs also acts as a type of customer based on legal obligations. Sharing the relevant release information can be organized via the shipping line that is aware of commercial – and customs release, and physical availability of a container based on its contractual relation with the stevedore. This release status can be shared with the forwarder that shares it with its carrier. Formally, a carrier can inform a forwarder on its ETA at a terminal for picking up a container, whereas a forwarder synchronizes this information with a stevedore. We have to note that current practice is to directly synchronize between a carrier and stevedore; we will show however that a distributed ledger can serve as a technology supporting this synchronization according contractual relations.
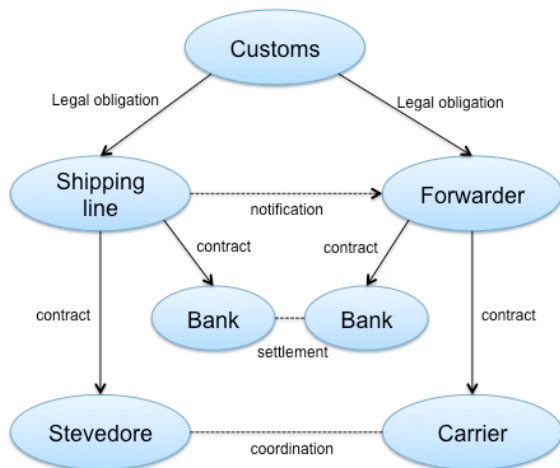
Figure 1: value chain for container transshipment in a port

On top of sharing this release information, also other milestones similar to those of direct transport need to be shared. For instance, the ETA of a vessel at a terminal is relevant for synchronization with departure of the previous vessel at that terminal[28] and the ETA of a truck at a terminal needs to be shared. Furthermore, a forwarder would like to inform its customer, the consignee, of arrival of the cargo at its final destination. In case there is one transport leg between a port and the final destination, an ETA of that leg can be shared via a forwarder to the consignee. In case of more than one transport leg, i.e. on-carriage is split into two (or more)

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[28] https://www.portofrotterdam.com/nl/tools-services/pronto

transport modalities, the forwarder might also require to inform the first transhipment hub and the carrier from that hub to the final destination.

3 Towards a Supply Chain Visibility Ledger

Like indicated, the underlying business case is that of process synchronization of all stakeholders and improved decision making. The use cases demonstrate the type of milestones that might be shared amongst the various stakeholders. This section presents an ontology for data structures and the rules for sharing these milestones in supply and logistics networks. A demonstrator supporting the use case of direct transport illustrates the implementation of the rules and the ontology.

3.1 General concepts

Conceptual, transactional relations formulate the subscription to events. A transactional relation is defined in two ways. First of all, a customer and a service provider share an order like shipment of particular cargo, a service provider informs a customer of the status of that order by sharing relevant milestones. Relevant milestones are those of direct transport, potentially extended with intermediate locations relevant to the customer like the location of border crossing or an (air)port where responsibility for transport is handed over (see the use case of port transshipment). The second type of transactional relation is based on an enterprise providing data like a customs declaration to an authority and waiting for status information of that authority. The data will have a unique identification, e.g. a Movement Reference Number for a customs declaration, and contains identifications of one or more physical objects subject. In this proposal, an enterprise acts service provider and an authority as customer.

Secondly, the concept 'Digital Twin' is introduced (Boschert & Rosen, 2016): a Digital Twin is a data representation of any physical object, e.g. a container, a truck, a vessel and a product. Any subscription, either an order or a declaration, considers at least one Digital Twin. The concept 'Digital Twin' will be elaborated when specifying an ontology as a basis for data structures in the ledger.

3.2 The choreography for sharing events

The interaction choreography (Object Management Group, 2011) of a customer and service provider is depicted as sharing events based on relevant order - and declaration data. Since, however, the Supply Chain Visibility Ledger does not support ordering, customers enter relevant order data that needs to be confirmed by service providers. Note that any service provider can have a customer role in its turn. Furthermore, any service provider can insert associations between physical objects, thus creating links between orders with their customers and their service providers. For instance, customer orders can be bundled into one shipment by for instance stuffing pallets of those customer orders into one container (LCL or Less than Container Load). On the other hand, pallets of one customer order can be shipped by two or more containers.

Figure 2 shows the choreography supported by the Supply Chain Visibility Ledger. It has basically two flows, the first of entering orders and creating associations between Digital Twins (see next section on data structures), and the second for sharing events. Events can be submitted by any actor, either in its role as customer or service provider. Each actor, e.g. an organization or a Digital Twin, can have both roles, where in general a Digital Twin will have the role of service provider.
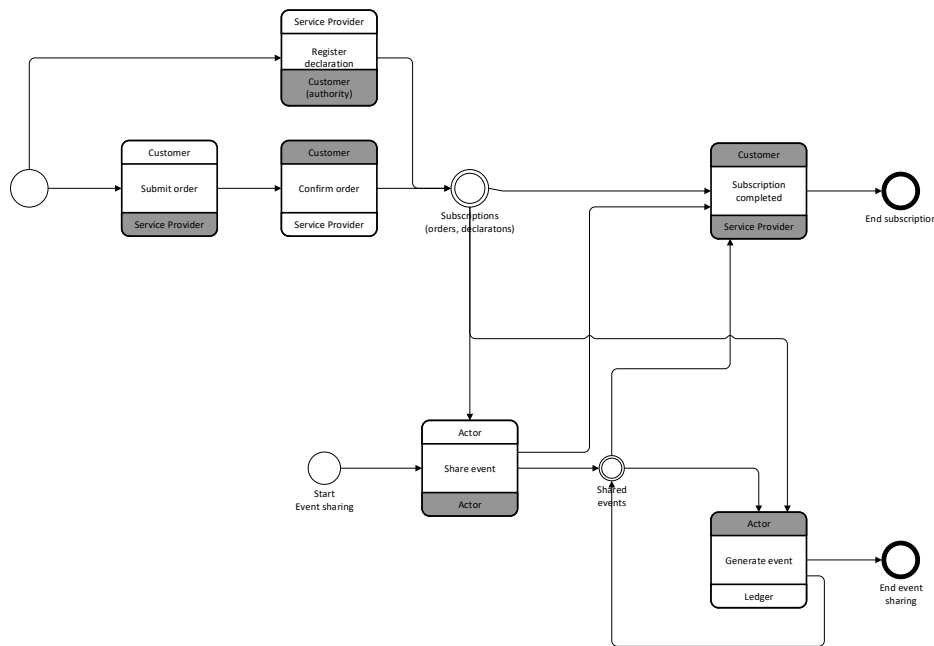
Figure 2: choreography supported by the supply chain visibility ledger

The flow to register subscriptions consists of five steps:

- A customer submitting an order to the ledger;
- A service provider confirming the order, thus establishing a subscription;
- A service provider submitting a declaration to the ledger;
- Completion of a subscription: either all cargo of one customer order has been delivered at its (required) destination or an authority has shared the status information. Completion is triggered by identifying that a shared event is the final one: the place of the cargo object given by the event is identical to the place of delivery of the cargo object in the order, all cargo objects mentioned in the order have this place, and the time of arrival of the cargo in the place of delivery equals (within a time interval) the time of delivery mentioned in the order.

In an ideal world where everyone uses a Supply Chain Visibility platform or ledger, associations between any two Digital Twins are entered with an event submitted by the actor making this association, e.g. load a container on vessel. The following actions are feasible for the subtype 'general –' and 'bulk cargo' as a subtype of 'cargo':

- Combine general – or bulk cargo of different customer orders into one order to a service provider, containers of different shippers are transported by the same vessel,
- Split general – or bulk cargo of one customer order to different orders with one or more service providers.
- A combination of both, namely splitting general – or bulk cargo of one customer order to different orders and combining it with general – or bulk cargo of other customers orders.

An actor can submit an event to the ledger in its role as customer or service provider, as shown in figure 2 by 'share event'. The role of the actor submitting the event should be part of the event, resulting in the following actions:

1. If a service provider submits an event to the ledger (activity 'share service provider event') an event is shared with a customer based on a confirmed order only if the place of a Digital Twin in an event equals the place of acceptance, - delivery or some

intermediate place mentioned in the customer order. A cargo object of an event can only be linked to customer orders that are not yet completed. In case a cargo object can be associated to two (or more) orders, it can only be associated to the one that is either not yet completed, or where the timestamp of the milestone given by the event is within the time interval between time of acceptance and – delivery and the place is either the place of acceptance or delivery of an order. This case represents that the same container is transported from a port to the hinterland that can re-appear the same day in the port.

2. If a customer shares an event to the ledger, this event should relate to an object or an identification mentioned in an order of that customer that serves as subscription. The event is directly accessible by the service provider. There are different cases like a forwarder sharing a customs – and a commercial release with a carrier or a shipping line sharing a commercial release with a terminal. In both cases, the event has to contain uniqueness of its provenance, customs and a bank respectively. A carrier can thus only pick up a container after a terminal as authenticated the customs release. Record integrity of the releases needs to be provided.

An event submitted by a service provider or customer is always stored in the ledger. It can trigger a new event, either submitted to a service provider or a customer. In its turn, this new event is also stored and can trigger generation of a new event. Whenever it is not possible to generate a new event, the process of sharing events ends. It means that none of the following conditions can be met that are implemented by 'generate event':

1. Event is received by a customer. The following rules are validated for generating a new event:
   a. The receiving customer acts as service provider in an order that contains the Digital Twin of the received event. A new event is generate to that customer. The condition is formulated as: <u>IF</u> The Digital Twin in the received event occurs in an order of that customer in its role as service provider <u>AND</u> (<u>IF</u> (the milestone is departure and the place in the event place of acceptance in the order <u>AND</u> the time of the milestone is in the period mentioned in the order) <u>OR</u> (the milestone is arrival and the place of the event is the place of delivery in the order <u>AND</u> the time of the milestone is in the period mentioned in the order) <u>OR</u> the milestone is pass and the intermediate place is in the order) <u>THEN</u> generate new event to the customer of the order.
   b. The Digital Twin is associated with another Digital Twin that appears in one or more order. There are two cases identified for these orders (they can be formulated in more detail like the rule before):
      i. The receiving customer acts as customer. The only relevant situation for generating a new event is where the milestone of the received event is arrival at place of acceptance in the next order. In case the milestone is an ETA prediction, the next leg represented by the order can be informed in case the ETA does not fit with the time period for start of the next leg.
      ii. The receiving customer acts as service provider. The service provider will generate a new event to a customer as described by the first part of 'share event'.
2. Event is received by a service provider. If the service provider also can act as customer, i.e. it has outstanding orders with other service providers, the event will be shared with those service providers that have the place of acceptance or – departure and the Digital Twins that are concerned as part of the order with them. The time of release also has to fit with the period mentioned in the order.

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Sharing a release like a customs – or commercial release is only feasible if that release refers to a particular place, for instance a terminal. Thus, it is not sufficient to specify only a release milestone, but also where the release takes place.

3.3   Data structures

The data structures for the interactions are based on an ontology of all data that can be shared. The concept of 'Digital Twin' (Boschert & Rosen, 2016) is core to this ontology: a Digital Twin is a representation of any physical object in the real world with information. As the following figure shows, transport means and cargo are the main subtype of Digital Twin. Cargo in its term has the subtypes of equipment (e.g. containers, trailers), general cargo consisting of number and types of packages (e.g. pallets), bulk cargo (e.g. liquid bulk like palm oil) and transport means (e.g. a truck with its trailer on a ferry or railway wagon). A Digital Twin has an identifier like a container number or Automatic Identification System (AIS) identification. A business transaction, which is an instance of a business service, has a unique identification and so will have orders and events. Actors have one of two roles in a business transaction: customer or service provider. The role can be modelled by a property of the association or as a separate list of potential roles, since other roles like shipper, forwarder, and carrier can act as customer and/or service provider.
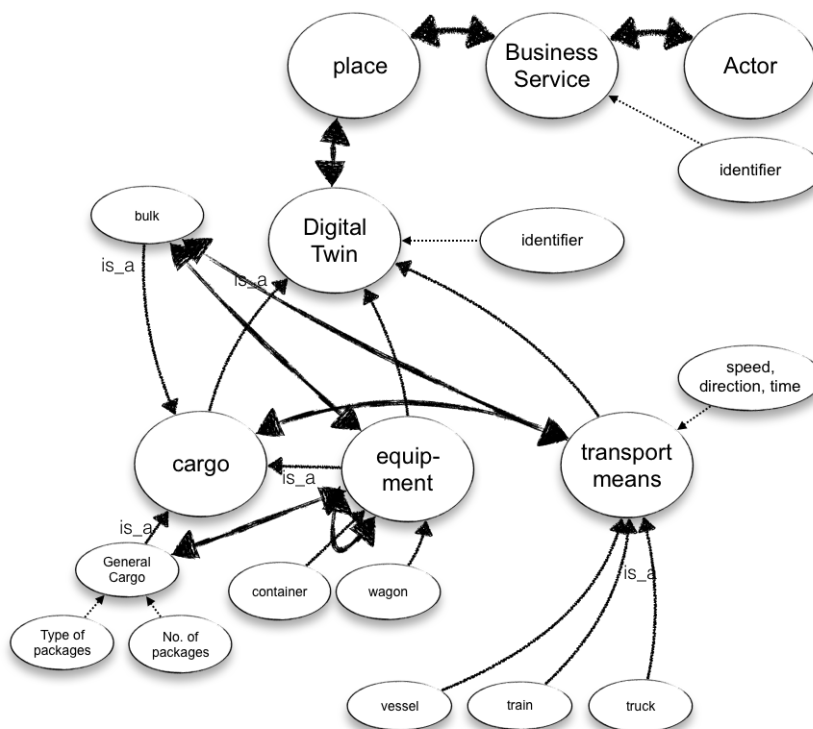
Figure 3: an ontology for supply chain visibility

Each Digital Twin has an association with 'place', where place represents physical locations like terminals, warehouses, (air)ports, and distributions centres. Two types of places are foreseen for transport: the place where transport starts (place of acceptance) and where the service is completed (place of delivery). In some cases, these places have different names like port of loading and discharge for sea transport or pickup and drop off for road transport. Additionally, an intermediate place is required like border crossing place. Each of these places is represented by an association with the following properties:

- An agreed or planned time with an uncertainty expressed by a period. A timetable of a transport means like a train can for instance have a planned time. A flight schedule is a similar construct.
- A timetable, voyage scheme, route, or flight may have a unique identification. It expresses a sequence of places that are called upon by a transport means.
- The estimated time at which a particular Digital Twin will be arrive or depart from a place, with an uncertainty.
- The actual time of arrival or departure.

A turnaround period can be expressed as the difference between a time of departure and arrival. The route of each instance of a Digital Twin can thus be configured by customer orders containing the instance of a Digital Twin, e.g. a container and its various transport legs. It may also be the case that within a customer order, a customer not only requires data on the start and end of the transport leg, represented as place of acceptance and – delivery, but also an intermediate place like place of border crossing, for instance to decide on the customs procedure at crossing.

Conceptual structure				Implementation structure		
Data properties	Order	Event		Implementation structure	Order	Event
Actor				Actor		
customer	x	x		customer	x	x
service provider	x	x		service provider	x	x
identifier	x	x		identifier	x	x
Digital Twin				milestone		x
Identifier	x	x		timestamp		x
Digital Twin - place of acceptance				encrypted hash		o
alternative role	x	x		provider of the hash		o
planned time	x			Digital Twin		
estimated time		x		Identifier	x	x
actual time		x		type of Digital Twin	x	x
Digital Twin - place of delivery				place of acceptance	x	
alternative role	x	x		time of acceptance	x	
planned time	x			place of delivery	x	
estimated time		x		time of delivery	x	
actual time		x		intermediate place	o	
Digital Twin - intermediate place				time at intermediate place	o	
alternative role	x	x		place		x
planned time	x			time		x
estimated time		x		Speed (transport means)		o
actual time		x		Direction (transport means)		o
Place - name	x	x		Digital Twin associaton	o	o
General cargo - equipment	o	o		time	o	x
number of packages		x				
planned stuffing time	x					
actual stuffing time		x				
planned stripping time	x					
actual stripping time		x				
Cargo - transport means	o	o				
planned loading time	x					
actual loading time		x				
planned discharge time	x					
actual discharge time		x				

Figure 4: conceptual and implementation data structures

Associations between the subtypes of Digital Twin represent that a subtypes are contained by or contains another subtype. Such an association also has properties like the number of packages of general cargo that is contained by a container or the volume of bulk cargo carried by a vessel.

Time is another property of these associations, i.e. the planned and actual time of constructing or deleting the association like the planned time of loading or discharge of a container from a vessel.

Primarily, the milestones 'arrive', 'depart', 'construct', or 'delete' are foreseen. The construct and delete milestone will be made specific to an association:

- Stuff or stripping of general cargo in container(s);
- Load or discharge cargo from a transport means.

Secondly, milestones like ETA or release are identified, where a customs can provide a customs release and another stakeholder a commercial release based on payment of transport charges by a bank.

This ontology is the basis for a data structures, one for orders and the other for events. These data structures can be processed by the activities in the choreography according to a data matrix for each activity in the choreography (figure 4). According the specification of that activity, a customer or service provider can store (initiating role) or retrieve the data on the ledger.

For implementation purposes, this conceptual data structure can be further simplified. The subtypes of Digital Twin can be 'type of Digital Twin' and 'place of acceptance' and '-delivery' can become properties of a Digital Twin. The aforementioned milestones are part of the implementation structure. Figure 4 also shows the implementation structure (x: data is required; o: data is optional). This latter structure allows visibility of all types of Digital Twins, including sharing their milestones. Also, the provenance of particular milestones has to be traceable. A hash of the event is inserted, where the hash is encrypted with the private key of the one that has submitted the event. Since such an event can have a relative low amount of data, a generated string can be inserted in the event that is used to calculate the hash.

3.4 Demonstrator of a Supply Chain Visibility Ledger

A first demonstrator is developed for a case where a shipper has outsourced a shipment to a forwarder and the latter utilizes a carrier. The demonstrator does not implement the property 'time', implying that all identifiers of shipments/consignments and Digital Twins are unique. Secondly, the demonstrator reflects the real world assumption that not all actors utilize the ledger. It implies that the choreography is extended by adding the association between Digital Twins of an order in which an actor has the role of service provider and those orders in which it has the role of customer. This latter extension results in the time sequence diagram shown by figure 5. Another simplification shown by this figure is the implementation of two milestones, namely load and discharge of Digital Twin(s). These milestones are generated by the carrier and propagated to the shipper via the ledger.
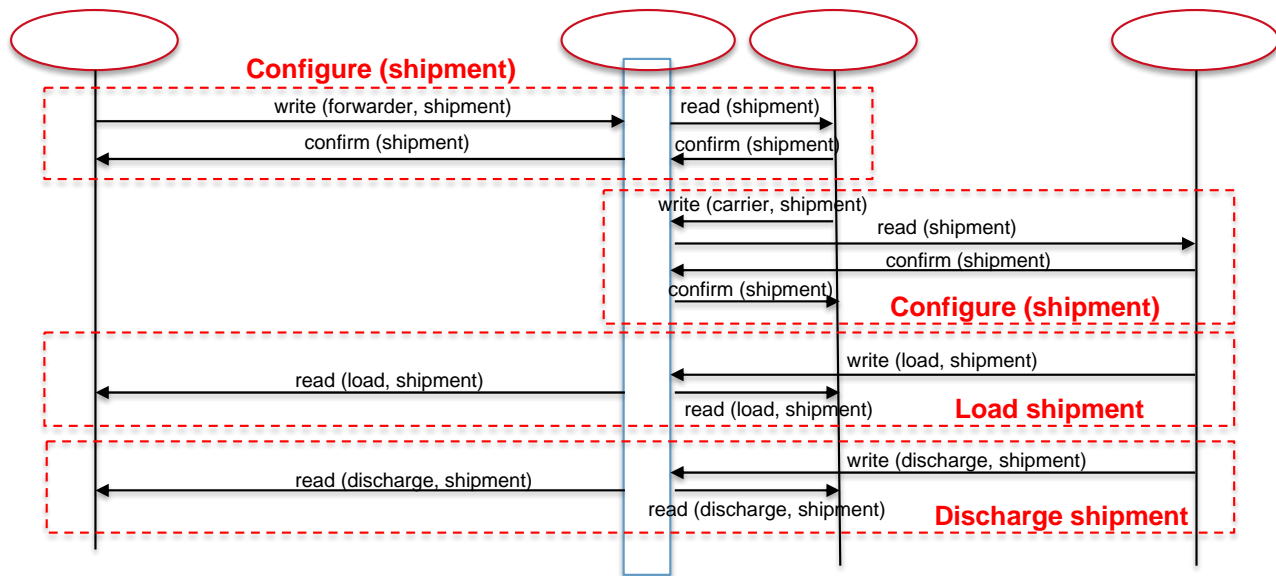
Figure 5: time sequence diagram for the demonstrator

Transaction confidentiality is an important aspect of the Supply Chain Ledger. It considers two aspects, namely the ability that only an intended recipient is able to read the data (Hofman, Spek, & Ommeren, 2018) and it is impossible for users of the ledger to trace back which users shared particular data. Transaction confidentiality makes the ledger completely private, thus supporting commercial sensitivity. Each user has a keypair acting as its identity that is verifiable. Transaction confidential is achieved by a user, which we will call submitter and is intending to share data with another user, generating a new identity, i.e. keypair[1]. Payload data is published to the ledger via this new identity, where the data and a signature created by the submitter are encrypted with a symmetric key. Details for unlocking data, the so-called payload unlocker, are shared with an intended recipient by creating yet another identity, i.e. keypair[2]. Each recipient also creates a new identity, i.e. keypair[3], for receiving the data. The payload unlocker contains keypair[1] and a signature of the original submitter of the data proving the integrity of the symmetric key, where the signature is made by encrypting the symmetric key of keypair[1] by the private key of the submitter. The public key of the submitter can also be shared in the payload unlocker, but could also be shared otherwise.

A second important aspect of the Semantic Ledger Technology is its validation of input data. Rules can be formulated in SHACL (World Wide Web Consortium, 2017) and validated using standard software components. A rule could be for instance for events that if the type of Digital Twin is 'container', the 'identifier' should have a particular format (4 letters, nine digits, and a check digit based on an algorithm), meaning that the software can validate container numbers given by an event. Another rule would be that the event should at least contain one Digital Twin of type cargo or transport means and their subtypes. These SHACL rules are stored on the ledger and can be accessed by anyone. Thus, data structures are separated from software code of the APIs provided by the Supply Chain Visibility Ledger.

4   Discussion

This section briefly discusses potential extensions of the Supply Chain Visibility Ledger and positions it with respect of (proprietary) Application Programming Interfaces (APIs). The ledger is also positioned in a context with other solutions, used by enterprises and authorities.

The proposed Supply Chain Visibility Ledger supports particular physical actions represented by milestones. Since IoT enables not only location based services, but also other types of services like monitoring the condition of cargo, the milestones can be extended. Cargo conditions can for instance be detected by temperature sensors to signal that the temperature exceeds a maximum or is lower than the minimal allowed setting which can be relevant to the quality of the cargo, shock sensors that can be used to trace potential damage to packages, seals that signal unauthorized opening of the cargo, especially containers, and weighing assets that detect the actual gross weight of cargo, for instance at loading a container on a vessel. The ledger can be used to share these sensor readings.

The assumption is that the ledger does not contain details of orders like container gross weight, delivery conditions, and transport charges. Such a data set may reflect a transport document like a CMR for road transport or a Bill of Lading for sea transport. The ledger can be used to share links to this data set reflecting access control, including a hash of the data set to assure record integrity.

In this paper, the ledger supports milestones that reflect the start and completion of an order between a customer and service provider, i.e. the place and time of acceptance and delivery. Additionally, intermediate places can be given for which milestones are required. A service provider can decompose a customer order in various transport legs and the customer might require to be informed of the status of each leg. Additional settings can be given in the order or can be considered as configurations of the ledger by a customer. This extension requires further elaboration.

The design and the demonstrator assumes an ideal world, where all users integrate with one Supply Chain Visibility Ledger. These users can be enterprises and authorities that require and share milestones of the physical processes. In the real world, we will have many Supply Chain Visibility Ledgers and – Platforms, each with their users and business model. Enterprises that do business with each other, can use different ledgers or platform and authorities don't wish to integrate with all ledgers and platforms. First of all, authorities will develop their ledger or platform, secondly, privately operated ledgers have to configure the proper subscriptions for authorities, and thirdly, all ledgers and platforms have to be interoperable, i.e. they have to be able to share data. The latter consists of two parts:

- Technical interoperability – the ledgers and platforms have to be able to communicate with each other.
- Functional interoperability – the ledger – and platform services have to be identical to allow users to share events. Functional interoperability requires agreement on the configuration of subscriptions and events with milestones.

Technical – and functional interoperability has to be standardized and adopted by each ledger - and platform provider. There are already (proprietary) supply chain visibility interfaces like the Open Trip Model (OTM[29]), Tradelens[30], and the Electronic Product Code Information System (EPCIS (Global Systems One, 2014)). These interfaces differ in functionality, e.g. OTM stems from road transport and expands to other modalities, Tradelens supports visibility of container transport by sea, and EPCIS is generic similar to the solution presented by this paper and needs to be configured with semantics. They are incompatible and a proposal is to develop one standard based on these inputs. Any implementation choices also need to be represented as options, like the provenance of a milestone.

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[29] www.opentripmodel.org
[30] Docs.tradelens.com

5   Conclusion and further work

Distributed Ledger Technology (DLT) can reduce complexity and automatically provide supply chain visibility to all stakeholders in a controlled manner by automatically propagating and -generating events. Complexity reduction is achieved by avoiding that individual stakeholders need to develop, implement, and maintain software for processing incoming events and generating new events. Two use cases formulate rules for such a distributed ledger, namely direct transport and transshipment in a port, resulting in a demonstrator implementing part of the functionality.

Transaction confidentiality is an important feature of the proposed visibility ledger. This paper briefly describes this topic. It has been developed as an extension to DLT, that is called Semantic DLT. Publications on this topic are in production.

The discussion illustrates that we are far away for creating an open infrastructure for supply chain visibility. A demonstrator of a Supply Chain Visibility Ledger can create awareness of the potential of Distributed Ledger Technology implementing the choreography. It can also be an instrument to further develop, validate, and improve specifications of an open supply chain visibility infrastructure and help steering a discussion to initiate governance of such an infrastructure. Validation of the demonstrator and extending the functionality can be in close collaboration in different use cases with users, both business and authorities. The validation would lead to formalization of the choreography, the semantic model, data structures for all interactions, and various implementation choices that have to be made.

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Data sharing in supply and logistics networks – development and implementation of extendable, standardized platform services for the Physical Internet in an open dynamic ecosystem of organizations

Wout Hofman[1], Simon Dalmolen[1]
1. TNO, The Hague, The Netherlands
Corresponding author: wout.hofman@tno.nl

Abstract: data sharing is the core of the Physical Internet. Data availability is expected to improve decision making, thus reducing costs and improving sustainability by better capacity utilization. Willingness of stakeholders to actual share data is not addressed by this paper; this paper focusses on capabilities of stakeholders to actually share the data. These capabilities are decomposed into technology, data sharing models agreed bilaterally by two stakeholders or in supply and logistics chains, and standard interaction patterns with supporting semantics. This paper present three basic innovations, namely a decoupling of supply and logistics use cases by constructing standardized platform services, introducing business services for identifying data requirements, and extendibility based on distributed development by re-use and extension of common models.

Keywords: data sharing, ecosystem, blockchain, International Data Space, platforms, business services, choreography, hyperconnected

1   Introduction

One of the features of the Physical Internet is hyperconnectivity of organizations and physical assets to improve decision making (Endsley M. , 1995), thus contributing to the societal challenge of zero-emission. Literature shows that the COx footprint of synchromodal planning can be upto 60% less than only using road transport, where synchromodality is on synchronization of transport legs with dynamic planning (Behdani, Fan, Wiegmans, & Zuidwijk, 2014). Several experiments with autonomous transport means like trucks, trains, and barges, take place, including truck platooning to reduce fuel consumption and contribute to sustainability. These logistics devices have computational capabilities and become more and more programmable.

Data sharing and interoperability are a prerequisite for decision support by individual actors that are hyperconnected. These actors, organizations and autonomous assets, currently require to make agreements on data sharing to reach process interoperability (layer 4 in the interoperability model of (Wang, Tolk, & Wang, 2009)). Coming to these agreements and implementing them takes time, which prevents implementation of innovative supply chain concepts like visibility, synchromodality, dynamic planning, agility, and resilience (Wieland & Wallenburg). It also prevents large scale adoption of innovations developed in closed ecosystems.

From a technology perspective, different solutions interoperate with their specific technical protocols, providing services to share data between different entities. On the one hand, these solutions function independent of their application, they can be extended by a functional entity providing functional services to users. On the other hand, these solutions provide particular

functional services on top of their technology services, for instance functional services to their users in a port community. Functional – and technical services of different solutions are not always interoperable. Different choices have been made, for instance regarding data syntax, data standards, and technical protocols. These lead to closed solutions, that are not scalable.

The functional services, which are called platform services (figure 1), require standardization. Figure 1 shows the relation between the various elements of a data sharing infrastructure for supply and logistics, expressed in terms of services, protocols, interfaces, and entities supporting the protocols whilst providing services (Tanenbaum, 1996). Standards can be made generic, but their implementation to a user will be specific, since that user will not utilize the full functionality. A user will require that functionality of a standard, that supports its business services. These business services formulate data requirements, that can be mapped to standardized platform services using ontology alignment (Euzenat & Shvaiko, 2010). Guidelines and tooling are required to support users to integrate with platform services.
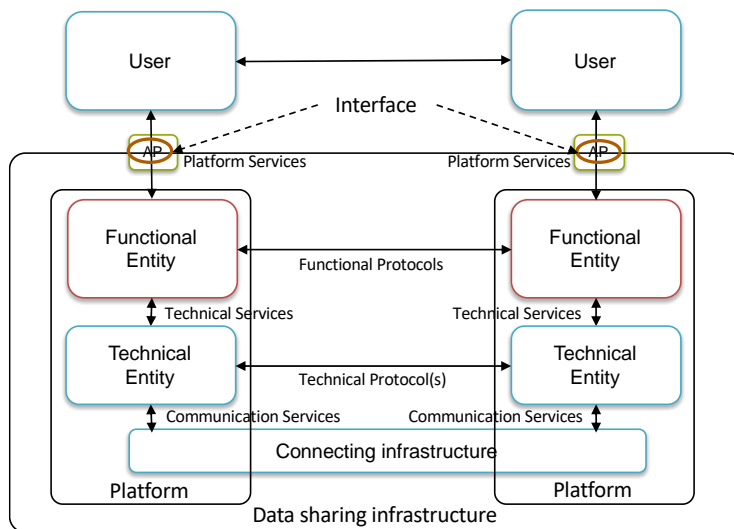
Figure 1: services, protocols, and interfaces of a data sharing infrastructure

Supply and logistics is complex in the sense that different modalities, different product types, and various trade and compliance regulations are applicable. Thus, we don't consider it feasible to construct one semantic model covering all data that can be shared amongst all stakeholders. At meta level, a modeling technique has to be applied that allows re-use of semantics. In the same way, the interaction sequencing needs to be specified. Thus, a choice for modeling techniques that caters for distributed development and implementation needs to be made.

This paper discusses four interoperability aspects for developing and implementing platform services, supporting business services: technical interoperability solutions, interoperability modeling techniques, conceptual interoperability, and guidelines. Achieving conceptual interoperability results in open data sharing solutions for supply and logistics, which is required to construct the Physical Internet and realize hyperconnectivity.

2 Technical interoperability solutions

This section briefly introduces some technical protocols, potential implementations of these protocols for data sharing, and a discussion with respect to these implementations to create an open data sharing infrastructure for supply and logistics.

There are a lot of technology and protocols available for data sharing between organizations, implemented with various business – and governance models. The most commonly known technology is that of Enterprise Service Bus, ESB (Erl, 2005) requiring a central solution with a governance model. Alternative solutions have been developed based on peer-to-peer technical protocols like ebMS (electronic business Messaging Services (Wenzel, 2007)). The latter supports an asynchronous reliable and secure peer-to-peer exchange of data that can be based on Collaboration Protocol Profiles and Agreements (Kotok & Webber, 2002). Yet other technical protocols are based on asynchronous queuing mechanisms like AMQP (Advanced Message Queuing Protocol), MQTT (Banks, Briggs, Borgendale, & Gupta, 2019), or Industrial Data Space Communication Protocol (IDSCP). Where queueing protocols are connectionless, IDSCP is a connection-oriented protocol. Most recently BlockChain – (BCT) or Distributed Ledger Technology (DLT) is introduced to construct immutable, distributed databases for data sharing in supply and logistics (Badzar, 2016), interconnected via the Tendermint protocol (see for instance (BigchainDB GmbH, 2018).

These different technological components can be combined to operate an infrastructure for data sharing. The current types are available:

- Peer-to-Peer network – the architecture of International Data Spaces (IDS) supports such a network based on connectors integrating with IDSCP. A broker provides a type of registry and a clearing house can be used for logging and audit purposes (Otto, et al., 2016). A connector has a local interface to for instance a sensor based on MQTT. There can be many brokers and clearing houses; a user, having a connector, should register with a particular broker and is able to share data. When registering with a broker, data sharing policies can be registered.
  Of course, peer-to-peer networks can be implemented by other technical protocols like ebMS or other protocols. A (distributed) registry will required for finding and sharing data with users.
- (Commercial) platforms – these platforms support the many-to-many data sharing, most often based on ESB technology. Each platform requires a particular configuration, so the configuration tools need to be integrated with each platform. The main advantage of these platforms is decoupling of technical protocols of their users; they provide all types of protocol conversions.
  Some of these platforms focus on specific communities, like enabling data sharing between all relevant stakeholders in a port community, support specific functionality like supply chain visibility, or support all types of data transformations. Each of these solutions has its particular governance – and business model, like community based with the relevant community stakeholders governing the solution or commercial.
- Distributed Ledger (Franklin & Hofman, 2018) – the data shared between any two stakeholders is stored in an immutable, distributed database. There are open standards to create a distributed database, e.g. Tendermint. Interoperability between distributed ledgers seems yet difficult, since in not only addresses technical – and functional interoperability, but also for instance the notary scheme used by the different ledgers (Koensa & Polla, 2018). Complexity of interoperability increases by implementation of so-called smart contracts, self-executing software code that automatically performs operations on the data, and combining data structures and process logic. Separation of data and process logic can be achieved by for instance storing data validation rules as SHACL (Shape Constraint Language, (World Wide Web Consortium, 2017)) on a ledger, where these SHACL files relate to a common ontology. Additionally, the same

technology can also be used for transaction confidentiality, addressing the issue of economic and private sensitivity of data.

Basically, a distributed ledger thus is able to share and store all type of data. One can distinguish three types of functionality for distributed ledgers: record integrity by immutable storage of a hash on the ledger, records by storing all relevant shared data on a ledger, or proof of ownership by storing tokens on the ledger (Lemieux, 2017). Tokens can serve as access control rights thus functioning as Linked Data (Heath & Bizer, 2011). These tokens can be combined with record integrity.

Each of these technical infrastructures has pros and cons, which will not be discussed in this paper. One could argue that a peer-to-peer network architecture like IDS can support all functional protocols, but it will require some type of centralized functionality. The centralized functionality, a broker and clearing house, can have many instances, where one instance acts on behalf of a community or a provider of the infrastructure. Although a broker and clearing house seem to operate at technical entity level (figure 1), they will only operate by storing data shared by the technical services of the technical level. Thus, a broker and clearing house combine functionality of technical - and functional entities. DLT seems promising, but current technology and their implementation still lead to closed solutions due to complexity of interoperability (Koensa & Polla, 2018).

Most probably, these solutions will all exist in parallel, constructing a distributed network or system-of-system (The Digital Transport and Logistics Forum (DTLF), 2017). These solutions should be interoperable at two levels, namely technical and functional, where functional interoperability considers the functional protocols (figure 1). Technically, they need to agree on protocols like IDSCP, ebMS, or other protocols like Tendermint used by BigChainDB. Functional interoperability can be split into vertical – horizontal interoperability:

- Vertical interoperability – two platforms or solutions providing similar services should be able to share data.
- Horizontal interoperability – two platforms or solutions providing complementary services should be able to share data.

Functional interoperability is not only required for the platform services, but also at registration level. Users of different solutions should be able to find each other and share data. At this moment, these peer-to-peer - like IDS and immutable distributed database infrastructures are data agnostic, implying they can be used to store or share any type of data. Community platforms are constructed to share specific data sets, e.g. load lists and manifests in a port, each with their specific registration functionality. To achieve functional interoperability, the platforms services need to be specified, which will be presented in the next sections.

3   Interoperability modelling

There are different ways to model interoperability between organizations, i.e. platform services providing business protocols (figure 1). For instance, authorities derive data sets and interaction sequencing from legal text, resulting in models like those of the World Customs Organization (WCO) data model (World Customs Organization, 2010). These interaction models support for instance global customs declarations, where each customs authority can construct its specific implementation guides (Hofman, 2018). These guides are available as unstructured (text) documents, XML Schema Definitions (XSDs), or in a proprietary data structure. Interaction models can be documented as sequence diagrams (Object Management Group (OMG), 2015).

Modeling supply and logistics chains is more complex. It requires specification of all stakeholders involved, their roles in the chain, the relation between these roles, and the data shared amongst, resulting in implementation guides of standards. Sequence – and activity diagrams can be applied as modeling techniques can be used to model the processes. For practical reasons, most probably data of business documents shared amongst stakeholders will be modelled as a basis for the implementation guides. These implementation guides will be documented as in the previous example.

There are three issues in the aforementioned approach that will increase interoperability costs. First of all, supply and logistics chains will change over time, stakeholders need to implement innovative logistics concepts like supply chain visibility, agility, resilience and synchromodal planning (Wieland & Wallenburg). These changes will affect the sequence – and activity diagrams that have been developed, they will have to be revised. The second issue is sharing semantics of implementation guides by XSDs or unstructured documents. XSDs have implicit semantics, based on element names. Semantics of these elements will be given in documents, which may lead to interpretation issues and thus implementation errors perceived as low data quality. For instance, data of a participating stakeholder is mapped to a wrong XSD element, which leads to processing errors at the recipient of that data. The final issue is that of data mapping of internal databases to the implementation guides. The complexity of this issue is inherent to the number of implementation guides to be supported, where these guides are part of data sharing agreements. Each implementation guide needs to be mapped to an internal data structure. Since one stakeholder may have many implementation guides with the same functionality (Hofman, 2018), for instance implementation guides of orders with their customers, such a stakeholder can develop one internal file for each interaction type (like one for 'orders'). Transformations can be developed by mapping internal files to implementation guides, resulting in XSLT files (XML Style Language Transformation). This may still lead to many transformations.

To overcome these issues, many stakeholders develop data sharing agreements in the context of framework contracts or legislation (Williamson, 1975). The following techniques are proposed to develop an open infrastructure; they will be applied to supply and logistics in the next section:

- <u>Interaction choreography of two stakeholders</u> – the interaction sequencing of any two stakeholders is modelled as choreography (Object Management Group, 2011). Internal processing rules based on outsourcing strategies of individual stakeholders participating in supply and logistics chains is outside scope. This provides an optimal way to construct models of supply and logistics chains by means of so-called transaction trees (Dietz, 2006). It also supports basic functionality like stuffing shipments of different shippers into one so-called Less then Container Load (LCL) container.
- <u>Data semantics represented as ontologies</u> - there are different solutions to modeling data semantics, e.g. One object models or entity diagrams. These models can however not always be shared amongst different tools. Data semantics can be represented as ontologies with the Ontology Web Language (OWL). OWL is an open standard that can be shared amongst different tools and can be re-used to construct ones own models. SHACL can be applied to formulate data requirements of individual interaction types based on these ontologies, thus supporting data validation and contributing to data quality. Data itself can be shared using any syntax, e.g. XML, JSON-LD, and RDF (Resource Description Framework), applying messaging, Application Programming

Interfaces (APIs), or Linked Data (Heath & Bizer, 2011). The use of these technologies will require functionality of platforms and solutions.

Semantic models can be applied in various context, e.g. modeling bilateral -, community – and supply and logistics chain data sharing. Semantic models can also be used as a canonical data model (Hohpe & Woolf, 2004) for integration in organizational networks like those of supply and logistics.

- Ontology alignment for data transformations – database structures of individual stakeholders are aligned with a semantic model for data sharing (Euzenat & Shvaiko, 2010). It requires these database structures to be expressed as ontology and applying ontology alignment algorithms (Shvaiko, Euzenat, Jiménez-Ruis, Cheatham, & Hassanzadeh, 2018). Most of these algorithms detect synonyms in different ontologies; more complex transformations like combining instances of two concepts into one instance of another concept or implementing calculation rules is still too complex for these algorithms. These algorithms require human supervision to validate the proposed alignments. The alignments can be represented in a specific language, called EDOAL, Expressive and Declarative Alignment Language (David, Euzenat, Scharffe, & Trojahn dos Santos, 2011), but this is not supported by platforms. Thus, transformation of alignments to XSLT may have to be developed.

  Ontology alignment can also be applied to support existing (implementation guides of) standards. XSDs should be represented as ontologies that can be aligned with other ontologies resulting in data transformations. Experiments with these types of algorithms for supply and logistics are reported in the IPIC2019 conference.

A semantic model can be applied as canonical data model of a data sharing infrastructure constituting various platforms and solutions (see before). Using OWL to represent a semantic model, allows for extendibility and distributed development of semantic models. Ontology alignment will enable individual organizations to plug their IT back office systems (semi-automatically) in such an infrastructure. To be able to support this functionality, a conceptual model needs to be specified specifying semantics of data shared in supply and logistics networks supported by various technical data sharing paradigms like messaging, APIs, Linked Data.

4 Supply and logistics business services supported by platform services

Like stated, platforms and interoperability modeling technologies still require functional protocols, for instance data sharing semantics and platform services have to be known. Also, data sharing agreements have not yet been addressed, they still would be required. This section introduces a conceptual model for interoperability in supply and logistics.

From an IT perspective, supply and logistics is simple. It is all about moving particular physical objects like containers or pallets with some means of transport, e.g. trucks, vessels, trains, and barges, from one location to another according timing requirements. Complexity is in construction of supply chains, the type of goods to be transported, dealing with exceptions (resilience and agility), and compliance with international and national regulations. This complexity is reduced by modeling bilateral interoperability (see the previous section) and by introducing the concept of business services, rooted in services science (Spohrer, May 2009). The application of this concept needs to relate to a semantic model expressed as ontology (see before).

Therefore, the following aspects will be addressed by a conceptual model for interoperability in supply and logistics:

- An <u>upper ontology</u> with the basic concepts and properties for data sharing in logistics, namely (figure 2):
    - o Physical objects – all physical objects that can be observed in the real world, including their associations. Examples are containers that can be loaded and transported by vessels. These physical objects are represented as 'digital twin' (Boschert & Rosen, 2016). SHACL can be applied to specify technical details of concepts and properties of a digital twin, like an identifier for a container (a container number) needs to have a certain structure.
    - o Locations – all locations that are relevant to supply and logistics operations, including their physical capabilities like 'storage', 'transshipment', and 'cross-docking'. These locations, or 'places', are known as terminals, warehouses, or railway yards. Locations can also be grouped into for instance ports, regions, and countries.
    - o Actors – data properties of actors that can participate in supply and logistics. Besides organizations, also digital twins can participate as actor, i.e. they can receive, store, process, and share data with others depending on their IT capabilities.
    - o Time – time is the most important for supply and logistics. It associates digital twins with a location, e.g. a container has arrived at a terminal, and constructs associations between digital twins, e.g. a container is loaded on a vessel at a time.
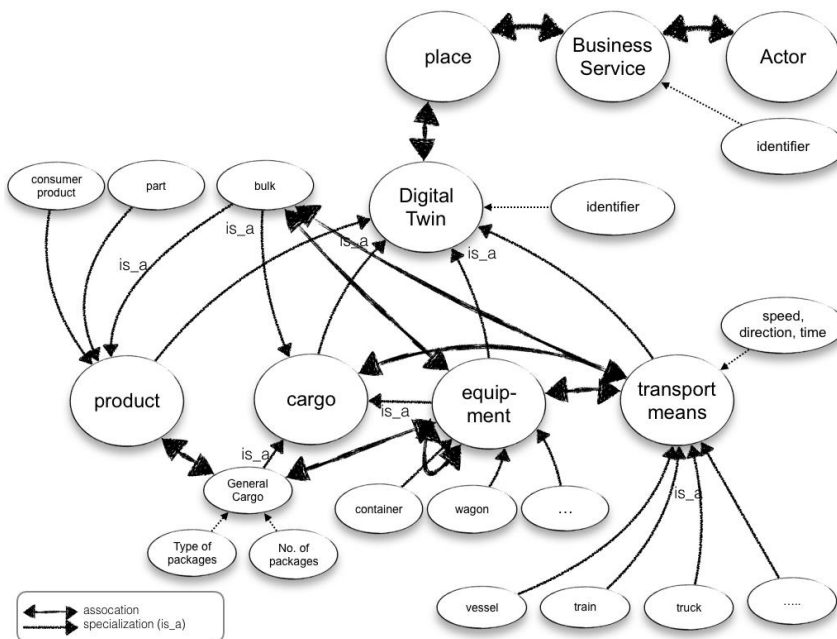
Figure 2: high level semantic model (upper ontology)

- <u>Views and extensions</u> – the upper ontology is a basis for creating particular views and constructing extensions. Views can be mode – and/or commodity specific. One can for instance construct a view for air transport and, at the same time, include extensions in this view that are only relevant to air. A commodity specific view would focus on interoperability of for instance container transport or commodity trading (Hofman,

2019). Finally, views and extensions can also be constructed from a legal perspective, for instance safety rules for transport means. Such a legal perspective may require additional data to be shared, that is not part of the upper ontology or another specific one, although data like dangerous goods details may also be shared amongst enterprises and thus be part of another view. If so, a rule could be to include extensions that are part of two views in the upper ontology to make them identical.

- Business services – these are the capabilities of service providers that need to be matched with goals of customers. Examples are 'transport', 'transshipment', and 'storage', but also handling legalities can be offered as business services. Business services comprise data of digital twins that can be handled, location(s), transport modalities, and time schedules. They can be expressed by time tables, voyage schemes, and flight schedules. In some occasions, business services can be composed like picking up returns when delivering goods.

  Specification of business services is the basis for actual business transactions. Furthermore, business services also formulate data requirements. For instance, if a service provider is able to transport containers by sea, container details need to be given and locations are known as port of loading and – discharge.

- Business transaction interaction patterns (Dietz, 2006) that specify data flows between a customer and service provider in the context of a business transaction. These patterns are specified as choreographies. Each interaction type of the choreography will have minimal data requirements like a transport order always requires data providing details of at least one type of Digital Twin, e.g. a container. where each interaction expresses minimal data requirements based on a semantic model, e.g. an order for a container transport service should at least contain details of one container. SHACL can for instance express data requirements of interactions.

  These interaction patterns add complexity to 'time'. A customer can have a request for a time when cargo is ready to be accepted and needs to be delivered ('expected times'), a service provider provides a planned time, during execution an estimated time of completion of a business transaction, and finally the actual time. Expected and planned times can be given as time windows (periods).

Interaction patterns can be decomposed in functionality like 'publish and find business services', i.e. a logistics marketplace, 'booking', 'ordering', and 'supply chain visibility'. This decomposition, which specifies the platform services (figure 1), can result in separate platforms or solutions, that have to be horizontal and vertical interoperable (see before). Horizontal interoperability of for instance a booking and ordering platform with a supply chain visibility platform will be based on order data (Hofman, Dalmolen, & Spek, 2019). Vertical interoperability between supply chain visibility platforms is based on interoperability of the supply chain visibility services provided by each platform.

The conceptual model, which can already contain technical details that can be validated by open source software, needs to be transformed in a technical model specifying for instance APIs. The technical model may include additional data not present in the conceptual model and/or can simplify data. An example of a technical model for Supply Chain Visibility is given by (Supply chain visibility paper).

5 Guidelines for data sharing in supply chains

And yet, there are many different supply and logistics chains, characterized by:

- Geography – global, regional, national, or city oriented supply chains. These supply chains are subject to different (inter)national and/or local (municipality) regulations. Statements like Certificates of Origin or Long Term Supplier Details are required for VAT purposes in relation to trade agreements.
- Number of stakeholders – the most simple supply chain involves a shipper, carrier, and a consignee, but more complex one have different transport legs with transshipment and/or bundling of cargo flows.
- Type of cargo – basically, three types of cargo are identified, namely bulk -, general – and containerized cargo (figure 2). These types of cargo require different assets for transportation, whereas the size, weight, and volume are also relevant. eCommerce shipments are for instance general cargo, but will require bundling of many small shipments into a bigger one.
- Cargo details – size, volume, and weight are already mentioned, but also the fact that cargo can be dangerous (e.g. chemicals) and requires temperature control for quality purposes (e.g. flowers and fruit) leads to different actions, including for instance quality surveillance.
- Delivery terms – these will define responsibilities and payment of transport charges.
- Framework contracts – many customers and service providers have framework contracts, thus do not require booking. These framework contracts may also exist between a large shipper and a globally operating carrier, thus providing details to a forwarder to use that particular carrier.
- Sensoring and autonomous assets – assets may have different types of sensors, interoperable via sensor platforms of these sensor providers, whereas the same assets will also have computational power, thus being able to act (semi-)autonomous.

The perspective of each actor in these chains will be different, a global forwarder perspective will for instance differ from a (global) carrier or shipper perspective. SMEs will yet have another perspective, they will require ready to use solutions provided by the platform services.

There are two approaches that can be followed, namely on-boarding with a platform that provides the standardized platform services or model and match one's supply and logistics chain(s) with the platform services of the conceptual model. On-boarding is feasible when the platform services are standardized, fit requirements of an individual user, are adopted by a critical number of users, and are provided by interoperable infrastructures. Supply chain visibility services provided by various (vertical) interoperable platforms could be an example for on-boarding. On-boarding requires alignment of internal databases with the platform services to implement the local interfaces (see figure 1).

Modelling one's supply and logistics chain(s) can be more complex. A globally operating shipper will for instance a global supply network meeting customer demands with various stakeholders involved. All the aforementioned variations will exist. A proposed approach is:

1. Use case(s) – identify one or more use cases, i.e. one or more relevant parts of a supply network that requires attention and can be improved.

2. <u>Business case</u> – develop a multi-stakeholder business case for the use cases based on standardized platform - and business services. Simulation can be applied as a means to develop a business case and identify improvements. Business cases are for instance driven by the introduction of new or changes to existing legislation, introduction of new technology providing opportunities, etc. or a requirement for cost reduction and improved efficiency.

3. <u>As-is</u> – model a use case with stakeholders involved, time sequence diagrams for data sharing and data semantics of the various interactions. The as-is situation will include compliance to regulations.

4. <u>To-be</u> – match the use case to the conceptual model by identifying the functionality of interaction patterns at interfaces between the various stakeholders and the data semantics modelled by the semantic model. This may lead to extensions of the conceptual model, for instance to be able to represent particular data by the semantic model or to identify new interaction types as part of the interaction patterns.

5. <u>Implementation</u> – implementation not only considers adaptation of business processes and thus human actions, but also the support of the to-be situation with platform services. Different stakeholders may use platforms of different providers, with differences in platform services. These platforms will have to be interoperable and harmonize their services to match with the to-be situation. Furthermore, each stakeholder will have to align its internal IT systems with the platform services, both at data – and at interaction level. A generic Access Point (AP) can be used for this purpose, providing the matching between internal IT systems and the platform services provided at the local interface of a platform provider (figure 1).

On-boarding and modeling and matching supply chains can be supported with templates and tools like multi-stakeholder business case tools, value modeling tools, and ontology development tools. However, there is not yet an integrated toolset able to support organizations in modeling and on-boarding their supply chains.

6   Conclusions and further work

This paper proposes the construction of extendable, standardized platform services for business services that can support all types of supply and logistics chains. Decoupling of these platform services from a user's perspective enables the development of a global open infrastructure building upon various technological solutions and hide complexity of such an infrastructure from users. The introduction of business services further creates a decoupling of users; they will be able to share data based on requirements of their business services.

Data sharing technology is expected to evolve. DLT and IDS for instance will evolve and platform service providers will improve their service offering to stay competitive. Like discussed in section 2, DLT and IDS implementations and platform service providers combine technical – and functional interoperability (figure 1). A separation of concerns of functional – and technical protocols is required using particular interoperability modeling techniques (section 3). By modeling data requirements of business services supported by a business process choreography and a semantic model, conceptual interoperability can be achieved. Like argued, supply and logistics chains come in many flavors, requiring a need for guidelines to use and extend the proposed conceptual models and integrate back office systems with standardized platform services (figure 1).

A governance structure is required that is platform overarching. It has to focus on platform services and their extendibility, business services, functionality required for ontology alignment, and underlying technical protocols, with the objective to create an open data sharing infrastructure with many technical solutions. Such a governance structure may be similar to that of the Internet, consisting of a Governance Board, an Architectural Board, an Engineering Task Force, and a Platform Service Provider Group. Users, i.e. enterprises and authorities, will be part of the Governance Board. The Architectural Board and the Engineering Task Force will provide input for standardization and requires participation of independent experts.

The development of such an open data sharing infrastructure should be driven by use cases, based on the basic concepts specified in this paper. Use cases will provide adoption. By creating guidelines, individual stakeholders will be able to adopt the solution, but this will take time. With respect to adoption, we identify three stakeholder groups: platform service providers, enterprises, and authorities. Platform service providers may fear to lose market share based on platform interoperability, but having harmonized platform services may also lead to an increase of market share by adoption of these services by enterprises through on-boarding. Enterprises require guidelines for using an open data sharing infrastructure, since each of them will not be able to create the solution on its own. They require collaboration with competitors and authorities to construct an open data sharing infrastructure, which is only acceptable if they set up the aforementioned governance structure before actually developing a solution.

Authorities have two roles, namely the one of legislator and governance of compliance to legislation. In the latter role, authorities have similar approach as enterprises, they will require optimal data quality for their function. They can enforce solutions based on legislation. In their role as legislator, authorities will have to focus on a level playing field, i.e. inclusion of SMEs. In the same way, data quality at the business-to-government (B2G) interface will improve if business-to-business (B2B) data sharing is facilitated. Thus, authorities can initiate the development of a data sharing infrastructure primarily supporting B2G, but at the same time also supporting B2B. Use cases with enterprises are required, for instance supporting new legislation like the electronic Freight Transport Information Regulation. One must note that authorities don't have good reputations in developing these types of IT based infrastructures.

Thus, there is still a lot of work to be done. Details are already researched (see the references of this paper). Next steps are also to investigate autonomous agents utilizing the proposed platform services, thus creating the Physical Internet.

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Smart Containers, Intelligent Cargo and Digital Infrastructure-11th July 2019 9:00 – 10:30

New Critical Aspects for the Future Information and Communication Infrastructure of the Physical Internet

New Critical Aspects for the Future Infrastructures of the Physical Internet

Dovile Zulanaite, Gerke Schaap and Nick Szirbik

university of groningen — faculty of economics and business

Introduction

Logistics businesses that handle containerized goods are forced to reduce their costs, by becoming more and more efficient. Nowhere is this more important that in the growing volumes of fast moving consumer goods (FMCG). Our research investigated various design related aspects for a subset of FMCG: fresh food (branded and packaged), pharmaceutical materials with special requirements, spirits and beverages that can be spoiled during transport. The case studies done for this design science research are specifically selected from logistics cases for diary products like milk and specialty cheeses. These cases are already exhibiting some of the characteristics envisaged for the future Physical Internet, like specific modularity and special containers. This research proposes an extension of the current proposals for the architecture of the information and communication infrastructure of the intended Physical Internet. These extensions are directly derived from the data accumulated during the case studies and pertain to the autonomous and decentralized activities necessary to achieve the high level of automation desired for the Physical Internet. The functional and physical extensions of the architecture take into account the global nature of the flow of perishable foods, the complexity of cross-border activities, the heterogeneous regulations that are in force and it is assumed that will persist in the future.

Current architectures

Current functional architectures (as the one depicted below) do not include specific functionality and the critical design aspects considered necessary for the container based logistics for these FMCGs.

Novel Critical Design Requirements and Guidelines

Initially, the main component under investigation was the PI container which will exist in a few modular sizes and will offer special functionalities like cooling, freezing, special atmosphere, monitoring and alarm triggering, detection of spoilage via sensors, communication of status, etc. Current developments in practice (i.e. like the specialized containers used by Envirotainer™), and the ones proposed by research have been starting points in the constructing a development framework for the future containers for PI that will transport FMCGs. After a methodological approach to engineering design, some – the ones considered the most important - of the original contributions to design guidelines and critical requirements are:

I.   First, for the containers themselves:

a.   Such containers should be envisaged as two connected but distinct components: one is the physical container itself, with all the necessary functionality, and the other is its associated software agent (or "digital twin"), which is existing in the cloud, and it represents the container in automatic auctions for shipments, reservations for transport, arrangements for routing and hub cross-docking, inspections and regulations related processes, payments, intelligent monitoring, control, alerts, and autonomous decision making – allowing for high levels of automation.

b.   For the physical part of the container, it has to provide protection and preservation of quality of the shipment, power generation or acquisition, mechanical strength for all sizes that enable automatic handling and stacking, plus the possibility of automatic inter-lock into appropriate transportation unit sizes. Also related to locking, it needs the capability to share, recharge, and transmit over power and communication links (e.g. a container at the bottom of the stack should be able to be constantly connected to its software agent, but it uses the communication devices of the nearby containers that have a line of sight to an internet connecting point – satellite, Wi-Fi, GPRS).

Hub and cross-docking critical aspects

II. Hub and cross-docking related:

a.   The containers for FMCG goods should have a separate fast moving channel through the PI hubs, and be handled and formed into inter-locked transport units together, allocated to faster moving transport.

b.   The hub should be also able to solve defective container functionality situations. For example, if a cooled container alerts its owner about an emergency status and potential loss of shipment, the hub (on the request of the owner), shall intervene and transfer the shipment to a working container (the container owner re-directs one of its empty nearby containers).

c.   Hubs can offer MRO (maintenance and repair) for containers – this is closely related to requirement above.

d.   Hubs can also help with wasted food shipments, container cleaning, and contaminated food waste disposal.

Human process related critical requirements

III. Administrative and heavy human-intervention related processes:

a.   Food, especially fast perishable specialty foods (non-frozen meats, living fish and shellfish, artisan cheese, bakery and patisserie products) need special paper work and visual inspection when crossing boundaries and differently regulated areas. Automating this processes is a huge challenge; for example companies like UNILAC (cross-docking cheese shipments through the Netherlands to the whole globe) have 70% of costs related to these processes.

b.   The producer and consumer of the product should be heavily involved in the regulation related processes (like export-import tariffs, standards, labeling rules). The idea for further automation is that each shipment is overseen by a triad of software agents: the digital twin of the container, and admin digital twins of the shipper and customer, working in tandem with the digital twins of the regulators and inspectors when necessary, with minimum escalation needed human intervention.

IV. Last mile delivery and container penetration:

a.   The PI should enable efficient logistics at the hubs, but also as well at the end consumer, indifferent of the infrastructure that exists in the consumer area.

b.   Networks for last mile delivery should extend the envisaged big PI hub network with city and rural micro-hubs, which can play also the role of temporary inventory points.

c.   The containers and micro-hubs should accommodate any means of local transportation, especially for the smallest containers, but also for the eventually decapsulated shipments on the last mile.

Next steps and future avenues for research

With respect to the evaluation, assessment, testing, and validation of these design aspects, scenarios have to be developed with the help of current logistic operators, to model the key performance indicators sought for solutions that offer operational interconnectivity over the whole supply chains of various FMCGs. The cost impacts and benefits of the designed solutions have to be assessed together with experts in logistic asset utilization, load handling, administrative issues, etc. In the end, both a simulation-based and field collection data proof of concepts should be gradually implemented, to get a crisper and more credible design framework for an FMCG driven component of the PI.

Both experimental simulation and empirical data collection will help demonstrate the technical, informational, and operational potential of the novel FMCG PI principles, recommend industry standards, and stimulate the logistic industry and market interest in the Physical Internet.

IoT enabling PI: towards hyperconnected and interoperable smart containers

Francesco Marino[2] and Ilias Seitanidis[3] and Phuong Viet Dao[3] and Stefano Bocchino[3] and Piero Castoldi[1,2] and Claudio Salvadori[3]

1.   Consorzio Nazionale Interuniversitario per le Telecomunicazioni, Pisa, Italy
2.   Scuola Superiore Sant'Anna, Pisa, Italy
3.   New Generation Sensors, Pisa, Italy

Corresponding author: fr.marino@santannapisa.it

Abstract: The Physical Internet (PI) concept is going to bring a disruptive change in the world of logistics, enabling effective and efficient supply-chain operation management. A key building block of the PI is the smart container, the physical dual of the Digital Internet packet which will provide unprecedented real-time visibility over the goods flowing in the supply-chain. Internet of Things (IoT) systems are expected to play a crucial role in the implementation of smart containers, providing the needed pervasive and hyperconnected sensing infrastructure. While IoT sensor networks have always been used as an effective means to collect and transmit information in a wide range of operational systems, the modularity and dynamicity of the PI scenario introduce a number of new challenges to be addressed in terms of system architecture and interoperability. The paper discusses the solutions that are being developed in the context of the EU H2020 ICONET project to tackle those challenges, paving the way to future developments of the PI.

Keywords: Physical Internet, Internet of Things, IoT system architecture for PI, smart containers, modularity, interoperability.

1   Introduction

The Physical Internet (PI) is a boundary spanning field of research launched by Montreuil B. et al. (2012), which aims to optimize logistics processes and enable effective and sustainable supply chains by applying the concepts of the Digital Internet (DI) to the physical world. The idea behind the PI is to connect and synchronize all logistics networks to create a collaborative physical network of networks, capable of autonomously optimizing the shipment of encapsulated goods of several types and sizes in compliance with different Quality-of-Service (QoS) requirements by means of routing protocols, tracking mechanisms and interoperability standards.

Though the lessons learned from the DI can guide the development of an efficient global logistic network, the PI is inherently different from the DI because of the nature of the transported items, which are physical objects in the first case and digital information in the second. Nevertheless, the PI will reach a level of pervasiveness and complexity that only a massive exploitation of the Information and Communication Technologies will allow supply chain and logistics stakeholders to manage. In particular, the Internet of Things (IoT) paradigm is expected to play a crucial role in filling the gap between the physical and the digital realms, strictly coupling them. In fact, IoT can provide the necessary technological layer to create digital twins of physical logistics flows, which can be operated by resorting to well-known and widespread DI concepts and technologies.

In this paper we build on the outcomes of the EU H2020 ICONET project, whose main goal is to extend the state-of-the-art research and development around the PI concept by designing a

new networked architecture for interconnected logistics hubs and by developing a cloud-based PI framework and platform. In this paper we investigate the role that IoT can play in the design of hyperconnected and interoperable "smart containers" as building blocks of the PI architecture. We report the requirements highlighted in this respect by the ICONET industrial partners and we propose possible solutions which will be tested in the ICONET Living Labs.

2 State of the art

The first relevant initiative towards the development of interconnected logistics at the European level was the EU FP7 Modulushca project, which focused on the design of modular and composable PI-containers able to establishing digital interconnectivity with each other. To achieve this goal the project stated that each PI-container must have a unique worldwide identifier in the PI networks (by using, for example, Electronic Product Code with Global Returnable Asset Identifier), and that PI-containers must always be trackable, monitorable and interoperable with each other and with other PI actors (by featuring long and short range communication technologies).

Montreuil et al. (2016) envisaged three modular categories of PI-containers, respectively the transport, handling and packaging levels, which allow containers to efficiently complement each other through encapsulation and composition, achieving this way a better use of the means of transportation.

Krommenacker et al. (2016) proposed the use of wireless sensors networks to facilitate the composition and decomposition of PI containers. In their setting wireless nodes are attached to each container and store information about the container. According to their transmission range the nodes create a spontaneous multi-hop network and expose themselves a single virtual container.

An holonic framework formalizing the encapsulation and composition mechanisms is presented by Sallez et al. (2016). Here containers provided with different level of activeness, namely the capability to acquire proprioceptive and exteroceptive information and take decisions, are made able to autonomously combine with each other to increase efficiency.

All the mentioned works envisage a massive use of sensing and communication technologies on containers to make them packets flowing in the PI. In this direction, several IoT products enabling the smart containers concept are today available on the market.

Just to mention a few, we cite the DHL SmartSensor, providing through GSM information about temperature, humidity, shock, light, and location data to customers which can be used by logistics companies to change the process and transportation route in case any of the conditions laid down by customers for their goods are not satisfied.

Another available solution enabling smart containers is offered by TRAXENS: TRAXENS-BOX S+ are permanently attached to containers and collect data such as GPS position, temperature, impacts, movement, and vibration. The sensors are connected via a wireless TRAXENS-NET network, through which data is transmitted to the TRAXENS-HUB cloud. Finally, we report the smart container logistics security seal by Ineo-sense, employing Clover-Net, LoRa, and NFC for communication and sophisticated sensors for monitoring.

3 PI Smart containers: architectural requirements

Smart containers are the physical duals of DI packets. Just like DI packets, they can be encapsulated (e.g., in a boat) and arranged in flows. Unlike DI packets, however, their retransmission as a result of loss or corruption implies costs and delays which are much less tolerated. For this reason, they must be avoided or at least timely detected. In other words, Supply Chain Visibility (SCV) for parts, components and products must be ensured

throughout all the network, from producers to consumers. Being consistently aware of the status of goods inside containers allows in fact to take proactive actions to avoid products deterioration or, in case unrecoverable damages are detected, to arrange proper countermeasures without waiting for the unserviceable goods to reach their destination or to identify who is liable for the damage.

To achieve this goal, smart containers must provide functionalities related to:

- **goods routing and tracking**: each PI "packet" has to be tracked, making its position available to all the stakeholders interested on the shipped goods (shippers, senders, receivers, customs, port authorities, canal authorities, etc). To enable the implementation of the goods' routing services (as in the DI), the PI platform has to know the correct position of the goods. In this scenario, IoT will support PI routing issues answering to the question Where? and When? (i.e., providing geo&time-referenced information).
- **goods continuous monitoring**: each PI "packet" has to be continuously monitored, making its status known at any time and answering to the questions "How?". To enable the implementation of the same service done by "CRC" in the DI, the goods has to be monitored to understand whether a packet is "corrupted" or not.

These user level requirements result in the following system architecture requirements:

- **IoT enablement**: to provide information about the PI packet an IoT communication infrastructure has to be set-up, enabling the communication from the field toward the PI platform. An IoT enabled PI environment requires the deployment (or the exploitation of already deployed) of an IoT network to communicate to the PI platform the data collected from the field.
- **Interoperability**: in fact the IoT environment must be able to communicate with the PI open platform and with the stakeholders involved along the supply-chain.
- **Modularity**: since the need of monitoring modular PI "packets" (packets, container, group of containers), also the IoT environment has to be modular, enabling the continuous monitoring and the tracking of the goods. Each PI module ("packet") has to be IoT connected, thus continuously providing information about itself.
- **Composability**: given the modularity of the "PI packets", they can be encapsulated into other packets, according to a hierarchy. This behaviour has to be considered also in the design of the IoT environment. All the IoT elements must be composable in networks to allow the monitoring of encapsulated goods.
- **IoT networks pervasivity**: since each PI packed has to be continuously monitored, it has to be connected with the PI platform all along the logistics chain (from the sender to be receiver). An IoT enabled PI environment has to provide a pervasive network solution, thus ubiquitously connecting the PI "packets" to the PI platform.
- **Edge computing enablement**: the exploitation of edge computing devices will enable the distribution of intelligence along the network. Edge computers are IoT devices equipped with computational capability and extended memory, positioned at the edge of the IoT data collection chain. Edge computers can enable the local data processing (e.g., detection of an alarm), the cooperation of the PI IoT environment with different operators (also on the field, e.g., truck drivers can understand what is happening within the transported containers) and external devices/infrastructure (e.g., Intelligent Transport Systems, communicating for example the transport infrastructure).
- **Resilience on data loss**: the PI IoT environment has to consider devices with local storage functionalities to maintain data when the communication with the remote platform is not available (e.g., in the middle of the sea or inside a tunnel). Alongside

there will be a need to extend global access to PI data nodes with increased satellite power, coverage and bandwidth.

While IoT sensor networks have always been used as an effective means to collect and transmit information in a wide range of operational systems, the modularity and dynamicity of the PI scenario, as shaped in the discussed requirements, introduce a number of new challenges to be addressed in terms of system architecture and interoperability. In the following subsections we extensively discuss such challenges and we propose possible solutions.

3.1   IoT system architecture for PI smart containers

The most general architecture for Industrial IoT systems is the so-called three-tier architecture pattern. This pattern includes the edge, platform and enterprise tiers, which play specific roles in processing the data and control flows and which are connected by three networks, namely the proximity, access and service networks (*Figure 52*).

The edge tier collects data from a wide range of sensors, actuators, devices, control systems and assets using the proximity network. The architectural characteristics of this tier, including the edge nodes' types and their breadth of distribution and location, vary depending on the specific applications.

The platform tier consolidates and analyses data flows from the edge tier and provides management functions for devices and assets which can be leveraged by the enterprise tier. It also offers non-domain specific services such as data query and analytics.

The enterprise tier implements domain-specific applications and decision-making support systems and provides interfaces to end-users including operation specialists. The enterprise tier receives data flows from the edge and platform tiers and issues control commands to them.

The tiers are interconnected by different networks:

- the proximity network connects with each other the edge nodes, typically organized as one or more clusters, and each cluster with a gateway which acts as a bridge toward other networks. The nature of the proximity network is application dependent;
- the access network provides the connectivity for the data and control flows between the edge and the platform tiers. It may be a corporate or a virtual private network, or a 4G/5G network;
- the service network enables connectivity between the platform tier services and the enterprise tier. It may be a virtual private network or the Internet itself.

Figure 52: Three-tier system architecture

Usually, the reference IoT architecture adopts a gateway-mediated edge connectivity and management pattern (Figure 53). This pattern basically comprises a local area network of edge nodes connected to a wide area network through an edge gateway. The gateway isolates the edge nodes and behaves as single-entry point toward the access network, breaking down this way the complexity of the IoT system by localizing operations and controls, so that it can easily scale up both in numbers of managed assets and networking. The gateway can also play the role of management and data aggregation point for devices and assets, hosting locally deployed control logic and data analytics processes.

The local network can be arranged according to different topologies:

- the hub-and-spoke topology: in this case the edge nodes are connected to each other through the gateway, which has a direct connection with the managed edge nodes, and the capability to interact with the platform tier conveying in-flow data and out-flow control;
- the mesh network topology: in this case some of the edge nodes have routing capabilities, and therefore the routing paths between edge and to the gateway may change dynamically. This topology is best suited to provide broad area coverage for low-power and low-data rate applications on resource-constrained devices that are geographically distributed.

In both topologies the edge nodes are not directly accessible from the wide area network, but they can be reached through the gateway, acting as an endpoint for the wide area network by providing routing and address translation. In this scenario, the gateway provides:

- Local IoT connectivity through wired serial buses and short-range wireless protocols. New communication technologies are continuously emerging in new deployments;
- Network and protocol bridging supporting various data transfer modes between the edge nodes and the wide area network: asynchronous, streaming, event-based and store-and-forward;
- Local data processing including aggregation, transformation, filtering, consolidation and analytics;

- Device and asset control and management functionalities to manage the edge nodes locally and via the wide area network;
- Site-specific decision and application logic relevant within the local scope.
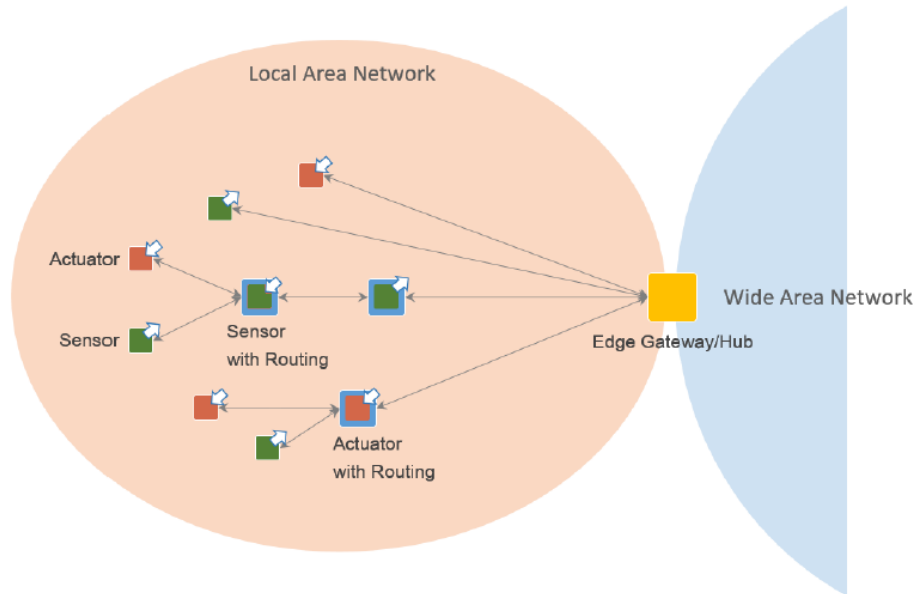

Figure 53: Gateway-Mediated Edge Connectivity and Management Pattern

Although widely tried and tested in several scenarios, the described patterns fall short in the PI context. Indeed, since smart containers are expected to be encapsulated in an unpredictable manner depending on wide range of ever-changing parameters, and since their physical characteristics may interfere with the communication technologies adopted in this context (e.g. containers are often Faraday cages preventing the use of a unique pervasive wireless technology), the PI gateways may not be able to reach a remote destination directly, but they can/must pass through a (not known in advance) hierarchy of gateways. In other words, PI gateways must be able to dynamically set up opportunistic networks to deliver their services. In this direction, in this paper we propose a recursive version of the gateway-mediated edge connectivity and management pattern, as depicted in Figure 54. In this architecture every single local area network, which can be mapped in the PI context to a smart container, has to interoperate with an arbitrary number of local area networks, resulting in IoT systems shaped as network of networks. To support this architecture PI gateways must be able to self-organize themselves in properly arranged networks by providing all the interoperability and security functionalities required by such a heterogeneous and challenging scenario. Moreover, since containers cannot know in advance which other containers they will have to interact with, interoperability mechanisms between the corresponding IoT networks must be put in place.
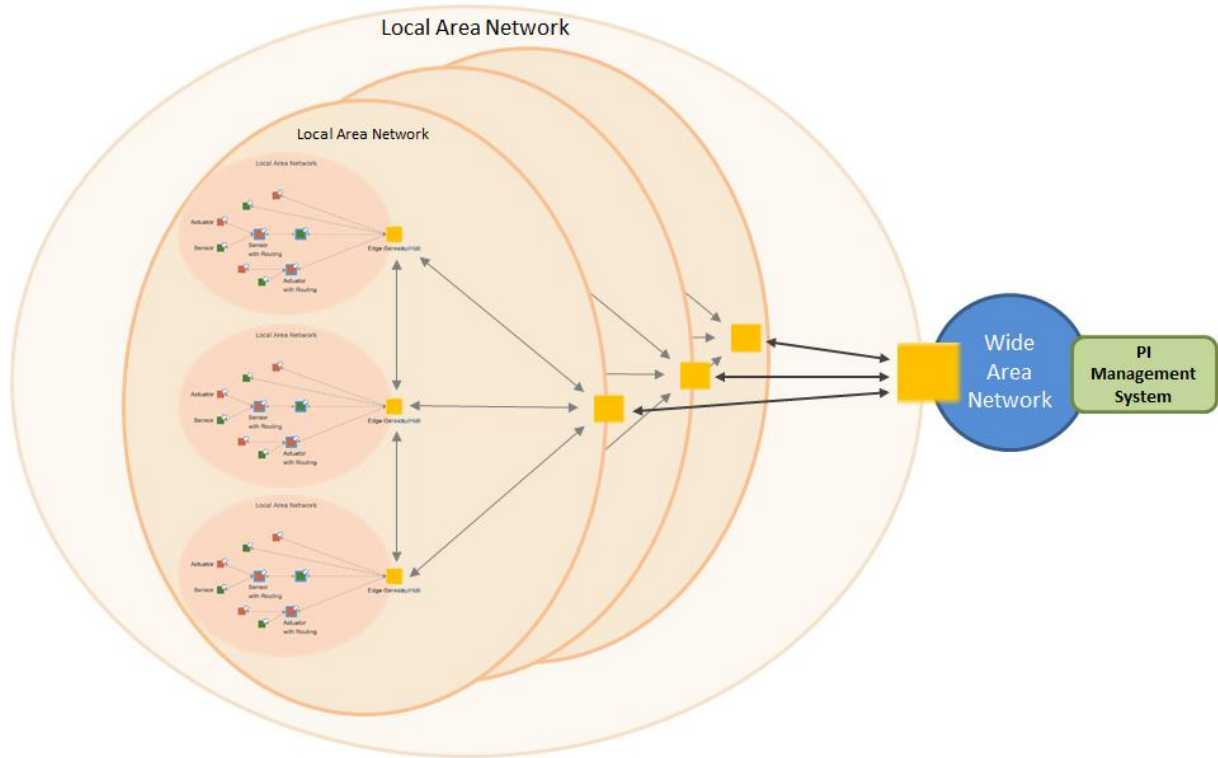
Figure 54: Recursive Gateway-mediated Edge Connectivity and Management pattern

4   PI Smart Containers: interoperability requirements

The IoT world is fragmented. This fragmentation is mainly due to the diverse options of connectivity for end devices provided by manufacturers. We have seen a dramatic growth of communication technology for IoT in the market, targeting different domains. Moreover, there is a variety of application protocols to connect to the Internet with many data formats that could be exploited. Besides, vendors tend to create their own IoT platform exploiting proprietary protocol that lead to the creation of vertical IoT silos.

The main goal of interoperability is to enable different systems to cooperate in a seamless manner. Broadly speaking, interoperability can be defined as a measure of the degree to which diverse systems, organizations, and/or individuals are able to work together to achieve a common goal. In essence, interoperability allows different systems to understand each other even though they speak in different languages.

Interoperability classification for the IoT domain is provided by ETSI (2008), which identify the following interoperability layers (*Figure 55*):

- **Technical Interoperability**: usually associated with hardware/software components, systems and platforms that enable machine-to-machine communication to take place. This level of interoperability focuses mainly on the communication protocols and the infrastructures/platforms for those protocols to operate.
- **Syntactic Interoperability**: usually associated with data formats such as RDF, XML, JSON.
- **Semantic Interoperability**: usually associated with the meaning of content and concerns the human rather than machine interpretation of the content. Thus, interoperability on this level means that there is a common understanding between two systems on the exchanged data.

- **Organizational Interoperability**: the ability to effectively communicate and transfer meaningful data even though they may be using a variety of different information systems over widely different infrastructures, possibly across different geographic regions and cultures. Organizational interoperability depends on successful technical, syntactic and semantic interoperability.
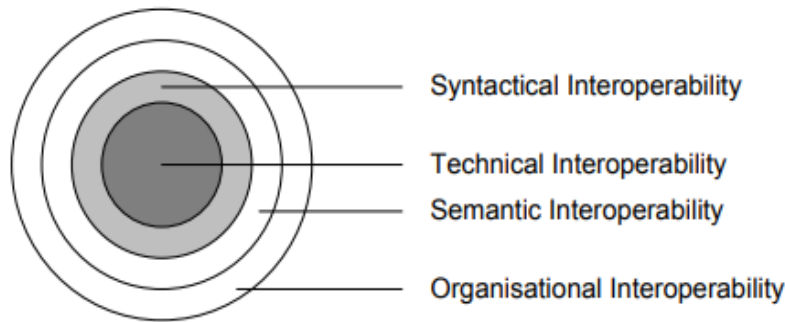

Figure 55: Dimensions of interoperability

Six generic interoperability design patterns (***Figure 56***) have been identified by IoT-EPI (2018) fostering the implementation of interoperable and easily reusable systems:

- **cross platform access pattern**, envisaging a unique interface specification for applications or services to access different platforms. This pattern allows different platforms from different providers to interoperate through a common interface.
- **cross application domain access pattern**, which extends the previous one by allowing services/applications to access information and functions not only from different platforms, but also from different domains contained in one platform.
- **platform-independence pattern**, which aims at allowing a single application or service to be used on top of different IoT platforms.
- **platform-scale independence pattern**, which hides different platform scales towards the connecting services and applications. The IoT platforms can be categorized according to their scale as server-level platforms which can manage a large number of devices and a huge amount of data, fog-level platforms which can handle data with limited spatial-temporal scope, and device-level platforms which allows direct access to sensors and actuators, and host a small amount of data.
- **higher-level service facades patterns**, extending the interoperability requirements from platforms to higher-level services. The purpose of this pattern is to enable the management of platforms, services, and functions through a common API. Thus, a service acts as a facade towards an IoT platform and use or process the IoT resources provided from different IoT platforms to offer value-added functionalities.
- **platform-to-platform pattern**, enabling existing applications to use resources managed and operated by other federated platforms as if they were offered by a single platform. This pattern facilitates the communication between two platforms in technical, syntactic, and even semantic manner. By implementing this feature, the pattern also supports the idea of effective communication between organizations/infrastructure defined by the organizational interoperability.
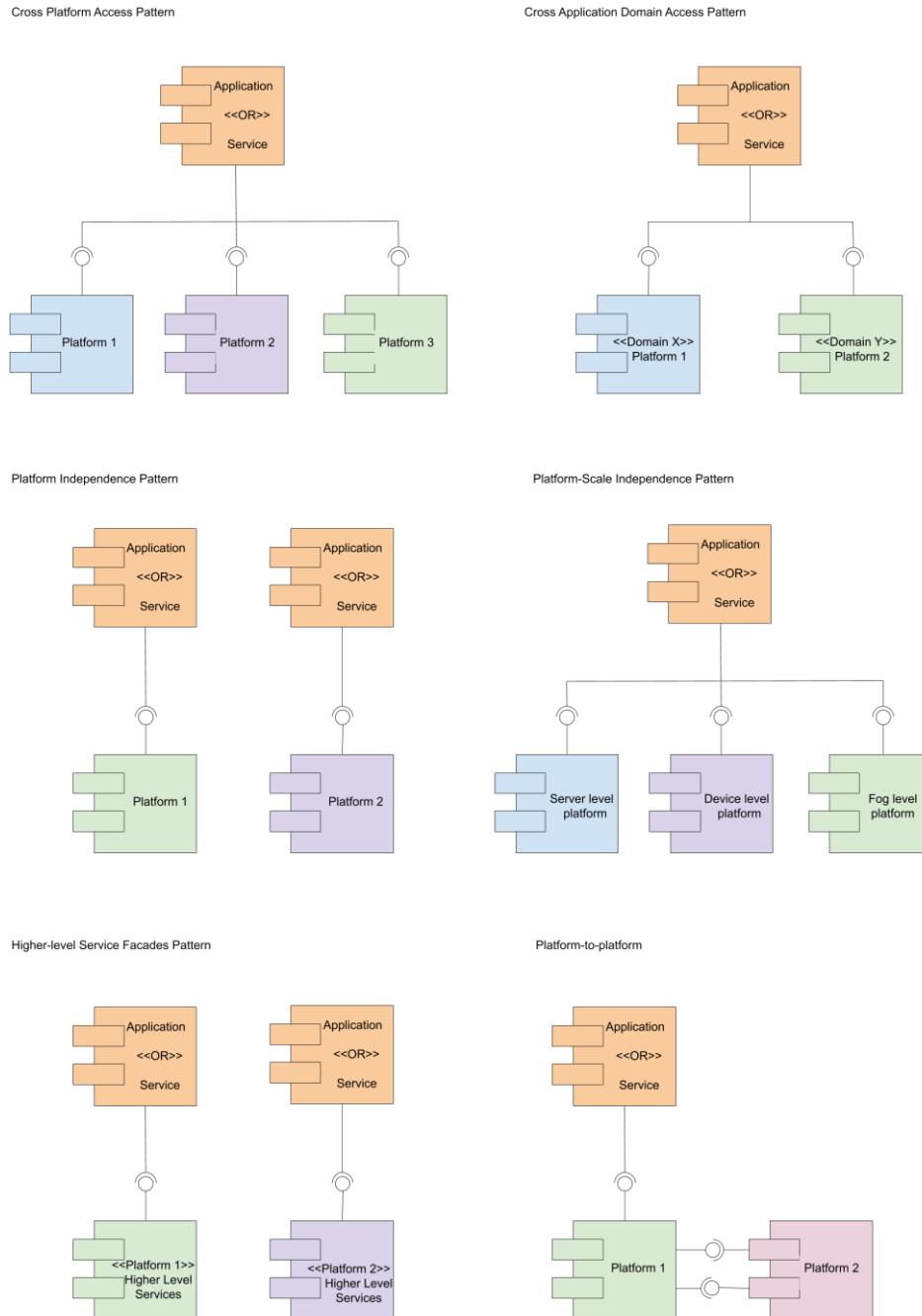
Figure 56: Interoperability design patterns

4.1 Considerations regarding interoperability within PI environments

One of the biggest issues within PI regards the cooperation of the different platforms owned by the different stakeholders involved in the logistics transactions, to realise an open PI environment. For this reason a common language has to be defined between the different platforms, implementing both the semantic and organisational interoperability (following the ETSI interoperability layers mapping, as depicted in Figure 57).

Regarding the IoT components, they are usually connected with the Cloud platform owned by the mentioned stakeholders. For example, the tracking information will be collected by the shipper platform and, afterwards, shared with the common PI platform. In this scenario, the IoT components have to satisfy the technical and syntactical interoperability, thus focusing on

the connection between sensor nodes and the IoT gateway, and the connection between the IoT gateway and the cloud server.
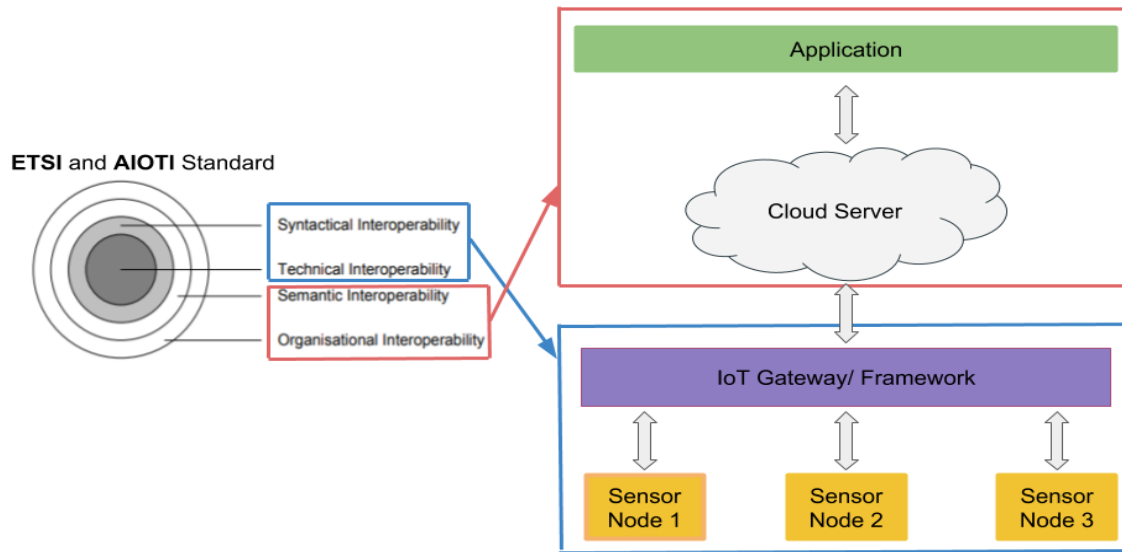
Figure 57 ETSI interoperability layers mapping

5   Validation activities

The validation activities of the work proposed in this paper will be realised within the Living Lab 2 (LL2) of the ICONET project, called Corridor-centric PI Network. This LL aims at the implementation of IoT solutions for transforming typical transport corridors into PI corridors, enhancing the reliability of intermodal connections, thus implementing the so called "synchromodality". The implementation of synchromodal logistics transaction will allow decision-making regarding delays, pulling forward loads and modal shift. LL2 will implement a fully interoperable IoT-enabled synchromodal corridor and it will be tested along the two corridors depicted in *Error! Reference source not found.* and *Error! Reference source not found.*.
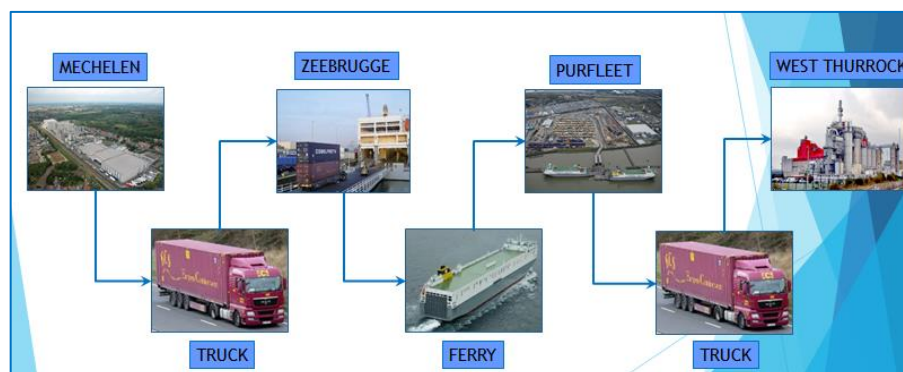
Figure 58: Corridor Mechelen (B) - West Thurrock (UK)
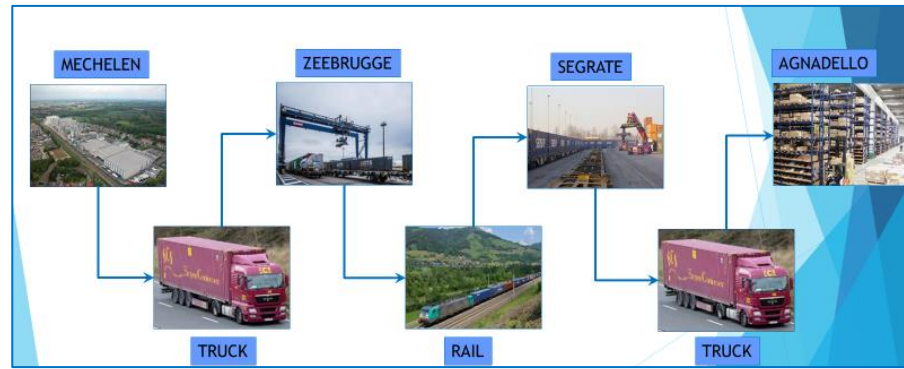
Figure 59: Corridor Mechelen (B) - Agnadello (I)

Particularly, in this LL the physical container will be upgraded to become a PI Smart Container, thus equipped with both IoT sensors, and an interoperable remote communication, to dispatch the data remotely toward the PI remote platform.

As discussed in Sec. 3, the PI Smart Containers will be evaluated in terms of the improvements they will be able to introduce with regard to the KPI depicted in *Table 15*.

KPI ID	KPI Name	KPI Description
KPI_01	**Goods monitoring**	Continuously monitor product position, time and quality, which will allow a better control of the logistic efficiency, and of damaged, lost and stolen products (answering to the following 3 questions: When, Where, How?).
KPI_02	**Product safety**	Improve the product safety, especially for perishable products (e.g., food or pharmaceutical products).
KPI_03	**Support decision making processes**	Supporting the planning activities and managing emergencies more quickly.
KPI_04	**Real time reporting**	Make real-time goods' information available and for all stakeholder involved in the transaction.

Table 15: Smart Containers KPIs

The instance of the generic architecture of *Figure 54* to implement the PI Smart Container is depicted in **Error! Reference source not found.**, where each container will be equipped with a n optimised and battery powered gateway capable to:

1. Collect data from sensors nodes deployed within the container (e.g., the presence of certain goods, the environmental temperature and the humidity, …).
2. Dispatch these data, remotely in a geo&time-referenced manner.

Figure 60: PI Smart Container network architecture

5.1 The considered devices

The considered hardware devices for the implementation of container tracking and monitoring services (and developed by New Generation Sensors within the ICONET project) are:

- The *FLEXX tracker*, that represents the first step toward the realisation of the "Smart PI-container". In fact, it will be in charge of collecting 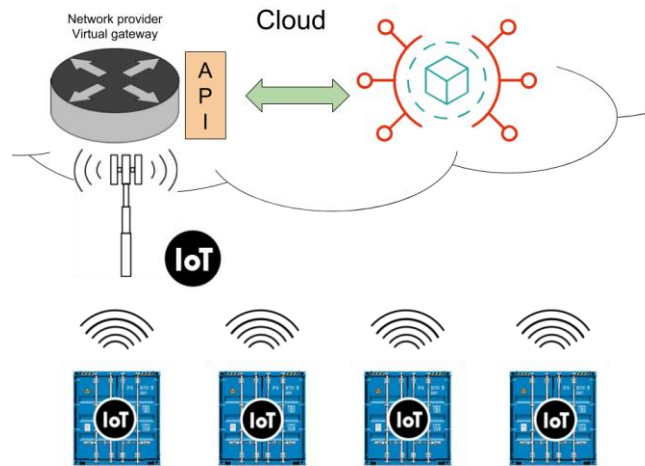position and time information of the considered PI-containers and dispatch those toward the Cloud platform, thus answering to the questions "Where?" and "When?". Moreover, on-board sensors will allow the container internal monitoring, thus answering to the question "How?".

- The *Micro-FLEXX gateway* will aim of implementing an advanced release of the Smart Container. This release will allow to track the container along the corridors, but also to: (i) monitor the presence of connected PI-packets encapsulated within it (e.g., monitoring pallets within the container, in a "groupage[31]" configuration); (ii) collect added value environmental data inside/outside the container, exploiting short range IoT protocols.

5.1.1 Implemented interoperability patterns

As defined in Sec. 4.1, the interoperability level considered to connect the IoT environment with the remote Cloud platform are the first two in the ETSI mapping (see *Figure 55*, i.e., technical and the syntactic level).

On the other hand, the interoperability patterns applied to connect the remote cloud platforms together with the IoT environment depends directly the considered protocol. In the scenario of FLEXX tracker and Micro-FLEXX gateway, the exploitation of a mobile IoT protocol (e.g., GPRS, NB-IoT, LTE Cat-M, …) allows the application of the Platform-to-Platform pattern at the technical level (see Figure 61), where the messages sent are managed by the intermediate platform owned by the telecom provider. This interoperability pattern will be considered for all the gateways in the case these are connected exploiting a mobile IoT protocol (exploiting JSON over HTTP representation), and it will enable the architecture depicted in **Error! R eference source not found.**.

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[31] Groupage is the same as LCL (Less than Container Load). Transporting a shipment with other goods in the container is referred to as LCL. That means that multiple LCL shipments with different Bills of Lading and different owners can be loaded in a single container. Any space used in the container is subject to a charge.
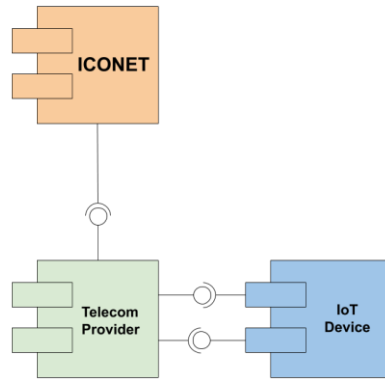
Figure 61 Platform-to-Platform pattern

6 Conclusion

The end PI goal is to realize efficient logistics transactions, in order to reduce their cost and their impact on the environment. In this paper we highlighted that IoT is a keystone technology of the PI framework, since it provides the continuous flow of information needed to implement the so-called synchro-modal functionalities. In fact, exploiting the data collected from the IoT sensors, the PI environment and the platforms on which it is based can retrieve the position and the status of the goods in a time referenced manner, answering to the questions: "When?", "Where?" and "How?".

To define an innovative and generalized IoT architecture capable of enabling synchro-modal functionalities in the PI environment we analysed the requirements highlighted by domain and TLC experts in the context of the ICONET project. The architecture we propose in this paper answers on the one hand to the inherent modularity of logistics, and on the other hand to the hierarchy derived by the encapsulation capabilities of packets, pallets and containers. For these reasons, an innovative, opportunistic and pervasive IoT network architecture is designed to provide connectivity to all the actors involved in the logistics transactions.

This report describes the need to implement both technical and syntactic interoperability functionalities for the IoT and the remote communication networks, thus simplifying the integration of commercial-of-the-shelf sensors nodes and the integration with the PI platforms respectively. From these considerations, a set of different protocols (standardized and not) and interoperability patterns are evaluated and selected.

The architectural and interoperability solutions presented in this paper are planned to be extensively assessed in the ICONET Living Labs, providing a sound ground for future PI development.

7 Acknowledgements

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Cognitive Logistics Operations through Secure, Dynamic and ad-hoc Collaborative Networks: The COG-LO project

Kostas Kalaboukas[1], George Lioudakis[1], Mariza Koukovini[1], Eugenia Papagiannakopoulou[1], Marios Zacharias[1], Nikolaos Dellas[1], Giacomo Morabito[2], Salvatore Quattropani[2], Marina Samarotto[2], Mitja Jermol[3], Miha Cimperman[3], Luka Stopar[3], Matej Senozetnik[3], Simona Bratusa[4], Alen Kahvedzic[4], Davor Justament[5], Ivana Kristic Buntic[5], Haris Marentakis[6], Aristotelis Maragkakis[6], Ebru Al[7], Erdem Özsalih[7], Akrivi Kiousi[8], Angela Dimitriou[8], Giussepe Galli[9], Enrico Pastori[9], Ettore Gualandi[9], Francesco Alesiani[10], Gulcin Ermis[10], Tobias Jacobs[10], Ioannis Mourtos[11], Stavros Lounis[11], George Zois[11]

[1] SingularLogic SA, N. Kifisia, Greece
[2] CNIT - RU at the University of Catania, Catania, Italy
[3] Institute Jozef Stefan, Ljubljana, Slovenia
[4] Posta Slovenia, Maribor, Slovenia
[5] Croatia Post, Zagreb, Croatia
[6] Hellenic Post, Athens, Greece,
[7] EKOL Lojistik, Istanbul, Turkey
[8] Intrasoft International SA, Luxemburg
[9] TRT Trasporti e Territorio SRL, Milano, Italy
[10] NEC Laboratories Europe GmbH, Heidelberg, Germany
[11] ELTRUN e-Business Research Center, Department of Management, Science & Technology, Athens University of Economics and Business, Athens, Greece
Kostas Kalaboukas: kkalaboukas@singularlogic.eu

Abstract: This paper outlines the approach followed by the H2020 COG-LO project to realize ad-hoc logistics collaborations. The main goal of COG-LO project is to introduce the concept of Cognitive Logistics Object (CLO): a *virtualized entity that participates in the logistics process, represents different actors such as parcel, truck, traffic light, supporting systems, etc. (depending on the case) and has a different capabilities (from basic functionalities up to autonomous decision making and actuation), which are configured per case.* In the context of COG-LO, a CLO will have different cognition capabilities, will be able to form ad-hoc collaborations by communicating with other CLOs using Social Networks of CLOs and negotiate optimal solutions in response to a particular event. The project will offer the necessary ICT services and demonstrate different collaborative models in both the Post Industry and Logistics Operators.

Keywords: *Cognitive Logistics, Social Internet of Things, Load Factor Optimization, ad-hoc Collaborative Logistics*

1 Introduction

Industry4.0 is a fact. The evolution of IoT and CPS technologies combined with big data analytics will change dramatically the way manufacturing and supply chain is organized. As supply chains are being more digitized, Logistics operators and all stakeholders have to embrace latest technologies in such a way that can achieve ease of access, quick information processing, security, and, most importantly, all of this in one place (TransEU, 2017). According to a Deloitte study (Lacey M. et. all (2015), the Internet of Things paradigm offers a variety of solutions that can cater for improved processes monitoring, optimization and response to changes/events. Such solutions can improve both the Logistics supply and demand processes.

Planning, route optimization, capacity sensing (the ability to detect open spaces in a warehouse, port or parking lot), traceability and improved planning are some of the offered qualities/services of these innovative solutions. The same [Deloitte] report points out that **Logistics4.0** can positively influence companies to improve their Logistics operations.

1.1   Logistics4.0 challenges

COG-LO tries to tackle the issue of ad-hoc collaborations and response to different events once a delivery has started. Our approach was based on the below challenges and market needs:

Challenge#1: Load factor and dynamic response to events /ad-hoc orders: Ad-hoc requests and unexpected events pose the need for more flexible logistics processes. In average, ~25% of the total delivery requests for EKOL Logistics (operating in Turkey and whole EU) is on the fly. This can be caused due to the dynamics of the market (e.g. customers with potential urgent deliveries such as medical, critical mechanical/electric parts, unexpected returns, etc.). Also last mile deliveries can be affected by traffic status as well. The result is late deliveries, which can lead to customer dissatisfaction and poor quality with implications also on critical contracts and SLAs. *Flexibility* in such case is of utmost importance. This is more important if we combine it with the load factor optimization. According to EKOL figures, the load factor varies from 15% in Latvia to 83% in Ireland. Logistics operators should be able to (re)schedule or re-plan (using different means) their deliveries making use of data generated by unexpected events (weather, external factors affecting the deliveries), missed deliveries (due to the absence of the recipient for example), traffic status, etc. This includes also decision-making capabilities with regards different and multi-modal delivery scenarios. Also *consolidating (merging) deliveries* can be a solution to this: how to collaborate and merge/consolidate deliveries in response to ad-hoc requests, in such a way that load factor, run empty rate and in general, resources utilization will be optimized.

Challenge#2: The growth of ecommerce and Cross-country deliveries: Globalization is increasing the level of cross-border e-commerce. This is evident considering that - according to DHL report (DHL, 2017) - *thanks to logistics networks and off-the-shelf solutions cross-border is easier than many think*. Nevertheless, inefficient cross-border delivery is consistently in the top three of biggest barriers for online merchants to sell in another EU Member State, as Ecommerce Europe's Cross-Border E-commerce Barometer 2016 (eCommerce, 2016), already showed in the past: logistics and distribution represent a difficult barrier to tackle for 33% of the companies selling abroad. This implies a synchronization of the cross-border deliveries with the involvement of all stakeholders. *Logistics Operators should agree on common information models and processes* in order to achieve smooth information processing along the delivery processes and traceability from all involved stakeholders. Whereas common information models have been introduced in various EU projects (e.g. EURIDICE, iCarco, e-Freight), *the main challenge is how to exchange such information over secure and private networks that will allow for better and collaborative decision making.*

Challenge#3: New collaborative models integrating the Digital and Physical Internet: In a recent study by CapGemini (CapGemini, 2016), it is argued that supply chains will transform from the isolated/atomic model to a more collaborative one. Currently, *supply chains are characterized by little level of collaboration, scattered approach and every stakeholder owning its business.* Logistics4.0 combined with the high involvement of consumers/ customers at the early stages of the supply chain poses the need of a *new future collaborative model*. According to the same study (CapGemini), the main characteristics of this future model will incorporate consolidation centres, multi-partner information sharing among key stakeholders; and consolidated deliveries using efficient assets. This model-scenario also complements with the issue of merging deliveries on the fly (see Challenge#1) where integration of physical goods

happens dynamically in a way to optimize load factor, deliveries and further operation costs. This new trend will lead to the *integration of both Digital and Physical Internet.* This extends beyond digital information sharing and optimization, where all Logistics stakeholders should work on (collaborative) physical integration that maximize the benefits to the end users.

1.2   Contribution and Structure of the Paper

The above challenges are the focus of the H2020 COG-LO project (www.cog-lo.eu). The main goal of the project is to create the necessary framework and tools that will enable future logistics processes to become cognitive and collaborative-interoperable by:

- adding cognitive behaviour to all involved Logistics Operation "objects" (freight, transportation means, systems, etc.), referred to as CLOs (Cognitive Logistics Objects) and
- developing the necessary communication and interoperable environment that will allow those cognitive objects to communicate with each other and share information through secure ad-hoc networks.

To achieve this, the project will offer the following:

- **New cognitive cargo-centric multi-modal transport models:** The project will formalize and model both the operational and system models, which will utilize the new concepts of Cognitive Logistics Objects, Cargo Hitchhiking and Cognitive Advisor. Those models will enable for more flexibility, improved decision making and ad-hoc collaborations.
- **A reference model for future Cognitive Logistics behavior:** This model will provide the necessary knowledge base & capabilities to achieve certain cognitive behaviour of Logistics objects. To achieve this, the project will integrate concepts from the areas of Cognitive Systems, Integrated Reasoning and Learning from local contexts.
- **Artificial Intelligence and data analytics tools with the necessary APIs,** enabling complex event detection, context awareness and decision support at both local and global level, as well as global reasoning, including understanding, assessing alternative and acting. Processing data will include multi-modal sources, structured, unstructured, and real-time data streams.
- **A comprehensive framework for security, privacy and trust,** that will ensure the inherent incorporation of these concerns in the COG-LO systems and operations in a by design fashion and in accordance to the associate regulations, particularly the GDPR. To this end, all appropriate mechanisms of *access and usage control and advanced cryptography* will be employed, considering data ownership, handling policies, and scalability, whereas a *blockchain infrastructure will foster for traceability, transparency and trust.*
- **A collaboration platform powered by Social Internet of Things:** COG-LO will put in place an infrastructure fostering ease of access to the underlying functionality by large logistics operators, SMEs and other stakeholders, enabling their seamless operational integration. This will be achieved through an innovative interaction framework based on dynamic ad hoc social networks referred to as the Social Internet of Things (SIoT). SIoT will allow CLOs to interact and "negotiate" potential alternatives/solutions considering their existing status/needs and exceptions identified.
- **Tweeting CLOs tool:** This will allow CLOs to exchange information in hybrid ad-hoc Social IoT networks about their status and possible needs for collaboration (e.g. opportunities for optimal loading & re-routing in case of exceptions).
- **Cognitive Advisor tool,** which realizes the cognitive behaviour of CLOs based on the reference implementation model.

The rest of the paper is outlined as follows. Section 2 describes the overall cognitive and collaborative logistics framework introduced by COG-LO, followed by the corresponding operational model (Section 3). A brief description of the COG-LO architectural aspects is provided in Section 4, whereas Section 5 outlines the three project pilots. The paper concludes with an outlook about the project innovation potential and anticipated market benefits.

2   The Cognitive and Collaborative Logistics Framework

COG-LO introduces a set of concepts, technological approaches and business models that will help the logistics, ecommerce community to adapt to the dynamics of their operations and improve collaboration. The main principles of COG-LO are illustrated in Figure 62.
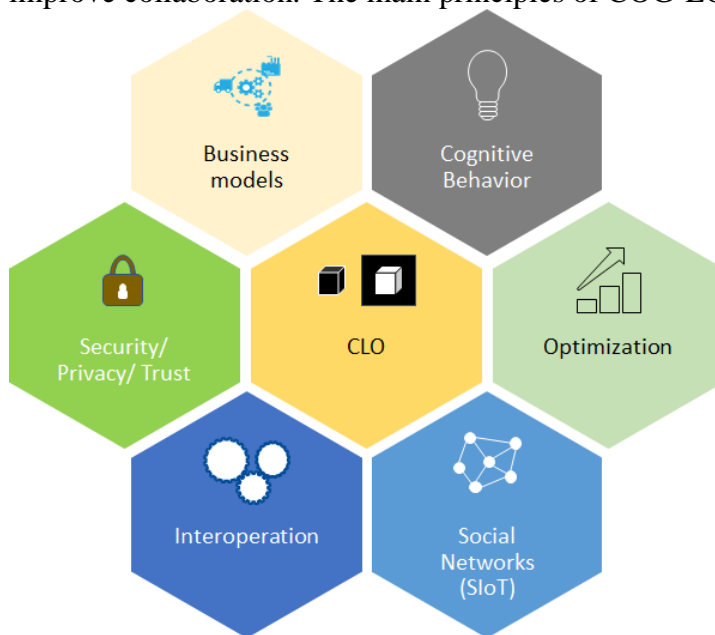
Figure 62: Cognitive Logistics

2.1   The Cognitive Logistics Object (CLO)

At the heart of the framework is the CLO. *A CLO is a **virtualized entity** that participates in the logistics process, (digitally) **represents different actors** such as cargo, truck, traffic light, supporting system, etc. (depending on the case) and **has a different capabilities** (from basic functionalities up to autonomous decision making and actuation), which are **configured per case**.*

If we try to elaborate on this concept, we have to analyse the main characteristics of the CLO:

#1: A CLO represents different actors in the logistics process*:* COG-LO has a distributed approach: it tries to digitize all involved actors and provide them with capabilities/ services that will allow them to exchange information, understand the context, communicate each other and each other and finally, assess the best alternatives in case of event. Such actors can be:

- The cargo at different hierarchical levels: parcel, palette. Container, etc.
- Transportation means (vehicles, trucks, trains, etc.)
- Supporting services/ICT infrastructure: backend solutions, ERP, warehouse management systems, traffic information systems, ITS, etc.
- Other actors such as: Hubs, parking places, e-shops, ports, etc.

#2: A CLO is a virtualized entity of all involved actors: Following the concept of Digital Twins the CLO will be a digital representation of the above actors (configured per case) in order to participate in different collaborative networks and actions.

#3: A CLO has different capabilities: the main advantage of Digital Twins is that in COG-LO we will be able to provide them different capabilities that represent actions/services and its behaviour in the context of the operations that participate. Those capabilities are the following:

Table 16: CLO capabilities

Capabilities	Explanation
Identification	I have an ID (Barcode, RFID) and I am identifiable
Receive information	Get information (read)
Send information	Sends information
is searchable	is searchable by other CLOs in the context of a social network of things
Specify range	Specify range for the social network to search for other CLOs
Basic processing	Basic calculations and processing: Check against rules, transform measures, etc.
Actuation	Initiating a service or action; example: I can initiate the process of rent a space in a parking slot.
Self-Awareness	I know my status: I know my position, my load factor, which information should I send, what I need for decision making, etc.
Sensing	I can get information relevant to me;
Search other CLOs	I can search for other CLOs in a specific range
Tweeting	I can talk with other CLOs
Decision making	Advanced information processing: Optimization, simulation, etc.

As seen in the table above, a CLO can have capabilities spanning from some basic functionalities (read-send) up to more sophisticated (self-awareness and decision-making).

The cognition is a set of capabilities that enables CLO to understand the information processed and/or contextual awareness, to process decision making as a collaborative part of common infrastructure.

#4: A CLO is configurable per case: It is up to the customer and based on the business/operational model to assign the level of intelligence and cognition in each of the participating CLOs. This approach allows flexibility and different configurations at pilot sites. For instance, in the ELTA urban pilot case, where a parcel is placed into a picking box and the box has to send the request to be picked up, the parcel has some basic functionalities (send information). In other cases, a van can be "cognitive" thus able to understand its status and "alter" behaviour by "talking to other CLOs". In the following sections (pilot deployments), we present the different CLO definitions and capabilities assignments based on the different business models.

COG-LO will provide the necessary tools to allow for Digital virtualization of all assets. Also will allow the system administrator will assign a set of capabilities thus enabling different configurations per case.

2.2 Business Models

Business models drive the behaviour of the system. it starts with the vision of how the company want to improve itself, given the challenges, opportunities and dynamics of the environment that operates into. In Deliverable *D2.1 - Business cases definition and scope analysis (draft-version)* we have identified the main drivers for changing the exiting model into more collaborative and digitized logistics processes. Such business models can be (COG-LO D2.1)

- Same day delivery
- Faster delivery
- Last mile logistics
- Crowd-logistics
- Regulated postal operations
- Other

Each one of the above has its particularities, constraints, dynamics and requirements both from process reengineering and digitization perspective. Business models define the strategic priorities and criterial for decision-making (SLAs, priorities, etc.). The applicable regulation and legislation is also an important factor that needs to be considered. For example, in the postal industry an important parameter is that postal offices *are obliged* to deliver any parcel irrespective of the distance in the country as a result of a highly regulated domain. This imposes a lot of trigger points (events by which the system will initiate), constraints, SLAs, potential decisions (based on the company's policies) and other factors that have to be considered in a decision making (optimization process).

COG-LO will provide a set of interfaces to model the process, the constraints, rules and characteristics of the pilot case. Different KPIs, priorities will be modelled for the optimization algorithms. Also, the system administrator will be able to model the whole workflow, the different events and potential decisions.

2.3 Social Networks of CLOs - Social Internet of Things (SIoT)

A distributed infrastructure, which is responsible for discovering and managing the social-like relationships between CLOs. The CLO (truck, warehouse, Parking spot, etc.) are potentially able to participate in communities of objects, create groups of interest, and take collaborative actions, joins different ad-hoc social networks (formed in a geographical range) and broadcasts the public information to the rest CLOs (belonging to the ad-hoc social network) in a secure way. For example, the vehicle publishes its specific information about the vehicle's status (what is being carried, destination, load status, etc.

By augmenting CLOs with the social dimension, two major advantages can be achieved:

- An overlay network can be built having the typical features of social networks, i.e., it is navigable and has a small diameter.
- Interactions are preferred between CLOs that are neighbours and more trustworthy.

The actor owning a certain CLO will set the policies that the CLO will implement to establish and maintain the social-like relationships. This is needed to allow users of the COG-LO platform to control the flow of their private information so guaranteeing an acceptable level of privacy, contributing to the overall by design data security and privacy approach of COG-LO. The following are possible types of relationships:

- *Ownership Object Relationship:* is created between CLOs that belong to the same owner.
- *Co-location Object Relationship:* is created between stationary devices located in the same place (this is also called co-geolocation).

- *Parental Object Relationship:* is created between CLOs of the same model, producer and production batch.
- *Co-work Object Relationship:* is created between CLOs that meet each other at the owners' workplace, as the laptop and printer in the office.
- *Social Object Relationship:* is created as a consequence of frequent meetings between CLOs.

All these social links are created on the basis of the profile of the objects (such as type, active services, installed applications), their activities (such as geographical mobility and transactions carried out) and the characteristics of their owner (such as his/her friendships relationship). It is then of paramount importance to implement the needed functionalities to verify that certain circumstances that bring to the establishment of new friendships occurred. In the resulting social network, every object looks for the desired service by using its relationships, querying its friends and the friends of its friends in a distributed manner; this procedure guarantees an efficient and scalable discovery of CLO and services following the same principles that characterize the social networks for humans.

2.4   Cognitive behaviour

It is a continuous and dynamic process for:

Modelling: Modelling the state of the infrastructure and a real-time observable digital object. It includes modelling the CLOs with different categories and properties, their interrelationships, dynamic parcel inflow and distribution objects with general and localized constraints. Processing these heterogeneous data enables real-time digital state evaluation/representation as a baseline for higher-level cognitive services operation. The infrastructure is represented as a digital graph, with dynamic parcel flow to be operated on.

Monitor: Real-time data, such as ad-hock events and final actions taken by execution CLOs are monitored and processed for real-time assessment of infrastructure state. The updates on current CLOs and relationships are processed to enable updated baseline for events categorization, constraints definition and evaluation of eligible CLOs for local decision-making evaluation.

Understand and Reason: Formalized knowledge base with dynamic knowledge enricher. The basic ontology knowledge base offers definition of basic domain concepts while knowledge enricher enables augmenting the basic knowledge base with additional concepts from web accessible document corpora (such as Wikipedia), as a context rich knowledge representation services.

Negotiate and decision-making: Communicates constraints and activities to be executed with SIoT on the level of executable CLOs (pickup/delivery vehicles). While obtaining additional real-time data, final decision is made based on global constraints of the event and local optimization. The decision can be negotiated iteratively, until final execution is confirmed by the executing CLOs. The complete process flow enables global awareness and effect size estimation with critical constraints evaluation, while performing final decision making localized/distributed (in example, by postal hub).

Cognition will be realized through a Cognitive Advisor tool. This tool operates cognition on different levels, namely as centralized cognitive services and decentralized (local) cognitive services.

Centralised cognitive services present knowledge formalization, complex event categorisation and infrastructure state modelling.

Decentralised cognitive services include predictive analytics, optimisation and negotiation on CLOs service execution level. The local cognition is operationalized by CLOs with cognitive capabilities, topically represented as postal hub (physical entity), which operates on dynamic fleet management, event handling, and negotiation with eligible CLOs.

2.5   Optimization

Optimization is needed for decision-making. The CLO once understands the context and various alternatives (other CLOs and possible actions in response to an event) it should decide on the best alternatives. To do this, it should make use of optimization algorithms, models and services configurable to different circumstances and operations. The optimization module is triggered by events that are detected based on different factors:

Load factor: An event can be fired by the changes in the load factors of vehicles while they are distributing goods. In this case, the optimization module can create optimal consolidation options for the vehicles considering their distance from each other, similarities of destinations or hubs to be visited, and availability of space.

Time: an event can be a regular event, or according to the plan (e.g. the end of a transport phase) or any delays or deviations from current plan, unexpected demands with strict delivery time bounds may require a fast re-routing or re-planning of distribution operations while they are still on the way. The optimization module should be able to provide the optimal and the most practical distribution scenarios to CLOs. In this case, as for all other cases, dealing with the communication delays between the CLOs (vehicles, hubs, centralized planners) and the cognitive advisor would be critical and requires the effort of all technical partners.

Cost: An event can be generated by unexpected costs that are caused by delays of trains, which require replacing the transportation mode with a costly one, breakdowns of the vehicles, delays in customs operations are other factors that require online re-optimization of distribution operations.

Ad-hoc demands: JIT oriented distribution processes may lead to low load factors for the sake of satisfying the ad-hoc demands urgently which is another case where effective and efficient optimization solutions are needed.

Resource restrictions: The actual working times or breaks of drivers, which may be different than the plan according to external conditions may trigger of a re-optimization with limited resources.

SLAs: An event can be generated when some condition in the SLA are violated or are expected to be violated, for example the maximum delay of the transport service.

COG-LO will offer an Optimization Module that addresses the above. This will also include pre-processing and post-processing steps, which are used for pre-process the transport network data, parameter tuning of the optimizer or refining the input and output while communicating with CLOs. These steps can be executed either off-line or on-line and depends on the specific problem definition. The Optimization Module is controlled by the Cognitive Behaviour, which is aware of the current and planned state of the CLOs and the business logic.

2.6   Interoperation

The first essential enabler will be common information models based on exiting standards that will allow for transparent exchange of information among different CLOs. Specifically, these models will provide for a unified way for information representation, capturing data semantics and being a fundamental reference structure for operational development and interoperability. They will capture a variety of concepts, including: a) data stemming from traffic information systems, vehicle data, and other devices; b) information related to enterprise resource and warehouse management; events, and other state data; temporal, spatial, and other context data. Nevertheless, modelling will not focus solely on data; all aspects of the system operation will be comprehensively reflected in the information models, including operations/services, and infrastructure elements themselves.

Given this semantic foundation, all interactions among the entities participating in COG-LO operations will take place through a message bus, which will provide for asynchronous and

synchronous communication, data and service access, security, privacy protection and trust establishment. A fundamental duty of the message bus in this direction will be the transformation of the Platform Independent Model (PIM) of the underlying components operational behaviour to a Platform-Specific Model (PSM). Moreover, it will provide a unified solution for accessing information stored in heterogeneous systems or collected on the fly, under a common transactional interface. Based on all the above, the message bus will by extension take over the important duty of orchestrating different services and among different systems, i.e. it will incorporate the appropriate mechanisms for the effective coordination of resources and their actions towards business objectives. According to the proposed approach, workflows will be in charge of orchestrating COG-LO operations and, therefore, COG-LO will put in place the means for workflow modelling, instantiation, execution, and orchestration. Fostering interactivity in the data-intensive COG-LO environments, the project will opt for a workflow management approach adequately capturing both control and data flows, at the same time considering their interdependencies with the participating physical objects. Additionally, adaptability of operational processes will also be supported with respect to all kinds of events, real-time data fluctuations and overall context.

2.7 Security, privacy and trust

COG-LO will introduce data security and privacy awareness into all involved systems and operations. In line with the principles of data security and privacy by design and the legal requirements thereof (e.g., the GDPR), it will be ensured that they will comprise inherent features of the system.

To this end, a fundamental pillar of all information exchange and processing will be a comprehensive policy-based access and usage control framework, which will be used to authorise all COG-LO operations. The framework will be rich in semantics and will consider all aspects that may affect respective decisions, including roles, attributes of all involved entities, contextual parameters, events that have occurred. The policies that will be specified therein and associated mechanisms will reflect necessarily the regulatory framework in force, but also the business rules and corporate policies of involved stakeholders, contractual agreements in place, as well as preferences and rights of affected data subjects.

Another important concept is trust, given that COG-LO offers above all a collaborative environment, in which sensitive data, from both a privacy and business perspective, are potentially expected to circulate among distinct operational and administrative domains. In this context it is important that trust is ensured at multiple levels: each entity has to in principle trust another collaborating entity, in the sense that trust relations must be contractually established; each entity has to be sure that communication indeed takes place with the trusted entity in question as claimed; it has to be ensured that the above are guaranteed based on undeniable, tamper-proof and traceable credentials.

3 COG-LO operational model

The above-described framework is configurable for different operations. In principle, the main functional operational model of COG-LO is presented in the figure below:
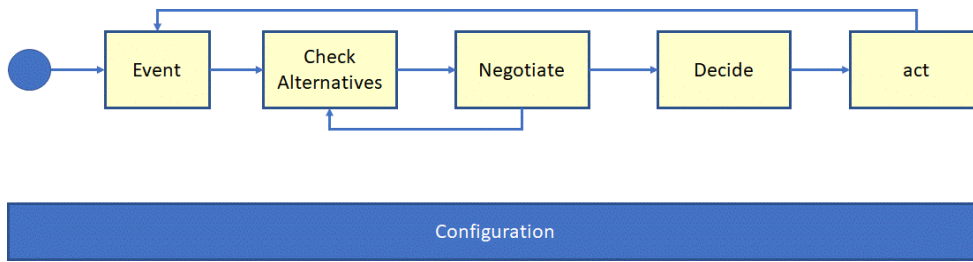
Figure 63: COG-LO Operational model

3.1 Configuration phase

In the configuration phase there should be an Administrator, who together with a COG-LO expert will proceed to the following activities (each of them will be supported by tools and interfaces that will be developed and offered at the final COG-LO prototype):
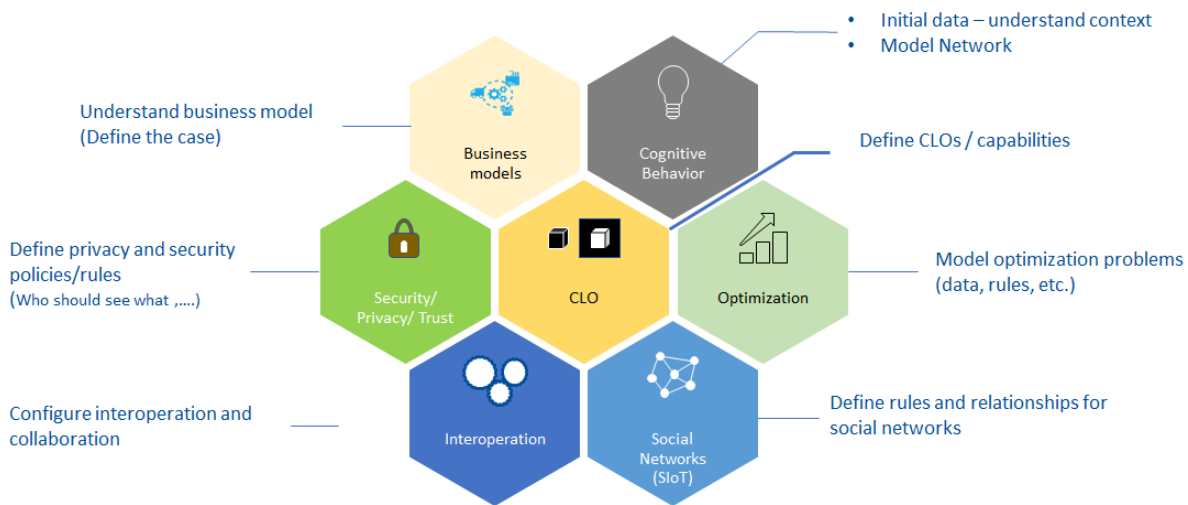
Figure 64: COG-LO configuration

Business models: Study the existing business models: where the company is standing now and what will be the future case for collaborative logistics? This is the result of a strategic analysis and prioritization and has to be clearly defined since it will drive the configuration of the whole system. In this context, the customer needs to model a to-be process model of the logistics operation, illustrating how the new business case will be and all the actors involved.

CLO: based on the operational model defined, the company need to identify the CLOs and assign some capabilities.

Cognitive behaviour: Define description of the initial state of infrastructure to build baseline digital representation of the network. This includes also redefining basic constraints, description of distribution fleet, data models, data integration frameworks (APIs) and final definition of CLOs: basic concepts and attributes/relationships (pickup/delivery points, distribution vehicles depo locations, etc.). The final objective is to consolidate heterogeneous multimodal data and build a model of digital representation of the infrastructure in terms of objects and relationships in real-time. All relevant optimization data should be provided, such as costs and business data, time constraints, etc. The more the data, and more fine grained information, the more COG-LO cognitive services will be utilized.

Optimization: Adapt and configure the optimization solver based on the company needs, the problem definition and algorithm capabilities. In this phase the input data from CLOs and other input sources, is transformed in a way that the Optimization Modules can understand and process to provide the optimal solution. Among this aspect is the problem definition itself, the input format, the event that trigger the solver to run and the output format. The problem

definition includes the cost function and the constraints that need to be met. Since solution may not be feasible, the configuration shall define what happens in case of infeasible solution or which constraints can be violated and which cannot.

Social Networks of CLOs: Define the rules and relationships for the social networks; deploy the method for navigating social networks and highlighting interest groups.

Interoperation: Define workflows (from high-level templates), Map company's information to COG-LO semantic framework and define collaboration rules (e.g. I need to leave always 10% free space for unplanned demand for return).

Security/ Privacy/ Trust: Define privacy preferences, access control policies and relevant rules

3.2   Real-time operation

COG-LO starts when the truck leaves the origin point (warehouse, sorting centre, etc.). We consider that a delivery/itinerary plan is produced and is available to be shared in a specific format.

Events

COG-LO will be always triggered by an event, which might be an anomaly of a given status that is not according to the normal situation. Events could be of the following types:

Table 17: Types of Events

Event type	Description/ example
Ad-hoc requests from customer	An e-shop, a warehouse that requests a new delivery. Could also be request for returns, etc.
Tweeting from other collaborative CLO	Someone "Tweets" to request a form of collaboration
Rules-based event generation:	Events based on the actual condition and context of the delivery. This includes load factor, costly pick-ups and other KPIs and others that are configured by the customer
Anomaly detection	Any potential anomaly that can happen during the delivery process such as: • Delay in schedule/ forwarding deliveries • Problem in vehicle • Traffic events • Weather, strike, other
Scheduled event (Cross-border deliveries)	A scheduled event that requires special attention and collaboration with other actors. This is more the case of cross-border deliveries.
Human-based events	Anything that is caused by the human factor such as: a sudden illness.

Those events will then trigger the assessment and negotiation phase where the CLOs have to understand the context and find optimal solutions.

Assessment phase (check alternatives + negotiate)

Once an event is found, the CLO needs to assess which are the "available alternatives". The CLO will establish a social network by defining a specific range. Through the SIoT, the CLO finds those CLOs because the latter always publish information about their status:

- I am a Truck with id X
- I carry Y type of cargo
- I have Z capacity
- My destination points are $d1, d2, d3$,….
- I can carry Q tons or other metric of cargo

The searching CLO then process the information published by the other CLOs according to the company rules, goals and KPIs and then starts "Tweeting" with them.

The main goal is to filter the available and eligible CLOs that will be considered in the decision making process.

Decide

Based on the context assessment and the available options, the CLO will perform the decision making process. Possible decisions can be:

- *Dynamic re-planning*. Re-planning has also the notion of a route with different modes (inter-modality).
- *Rerouting*: without changing the transportation mode, the truck or vehicle changes the route, in response to the particular event.
- *Cargo hitchhiking*: merging deliveries with other truck, which has the necessary capacity.
- *Parking, other*: in case of a traffic event, extreme weather conditions and other factors.
- *No action*.

The aim is to run simulation and optimization algorithms to suggest optimal solutions for the particular event.

Act

The action depends on the authorization of the particular CLO to initiate the solution that has been suggested. This implies an authorization to "approve" the optimal solution(s). COG-LO in the configuration phase will provide the functionality that will allow the system administrator to assign the authorization for a CLO to initiate specific actions and depending on the event.

The action refers to the realization of the optimal suggestion and can be of the following (indicative list):

- Start the process of request for cargo hitchhiking.
- Book a parking slot by calling the relevant service.
- Send rejection reply to a request.

4 Architectural approach

This Section delves into the architectural aspects of the COG-LO project, highlighting its main functional components. Furthermore, it identifies the relation of the project with the concept of the Physical Internet.

4.1 COG-LO and the Physical Internet

COG-LO vision is in-line with Physical Internet, in the sense that it creates a digital open logistics network for new collaborations and synergies that go beyond the traditional supply chains. With regards to the Physical Internet characteristics (Montreuil, 2011), COG-LO contribution is presented as follows.

- In Physical Internet, a CLO can be the π-container, the π-nodes and all other involved actors.
- A CLO (π-container) has connectivity capabilities: it is a connected object propagating information about its status and conditions.
- Using Social Internet of Things, COG-LO will be able to deploy different social networks of things in a secure/private and trusted way.
- Merging deliveries is a concept addressed in COG-LO. This is very similar to the physical internet vision, since it addresses delivery efficiency, cost and other KPIs through ad-hoc collaborations along the route. This is achieved through social internet of things, where CLOs switch among different social networks along the route.
- Similar to the Physical Internet, in COG-LO the CLO propagates information in the network about its status, capacity and potential needs. Through Tweeting CLOs tool, CLOs (π-containers, π-hubs, etc.) will negotiate for potential synergy.

- COG-LO creates new business opportunities for Logistics Service Providers and other stakeholders (ICT, etc.). New collaborations may arise and in different markets as consequence of better utilization of the logistics assets.

4.2   COG-LO system architecture

From technical perspective, the above framework will be realized through the following architectural approach:
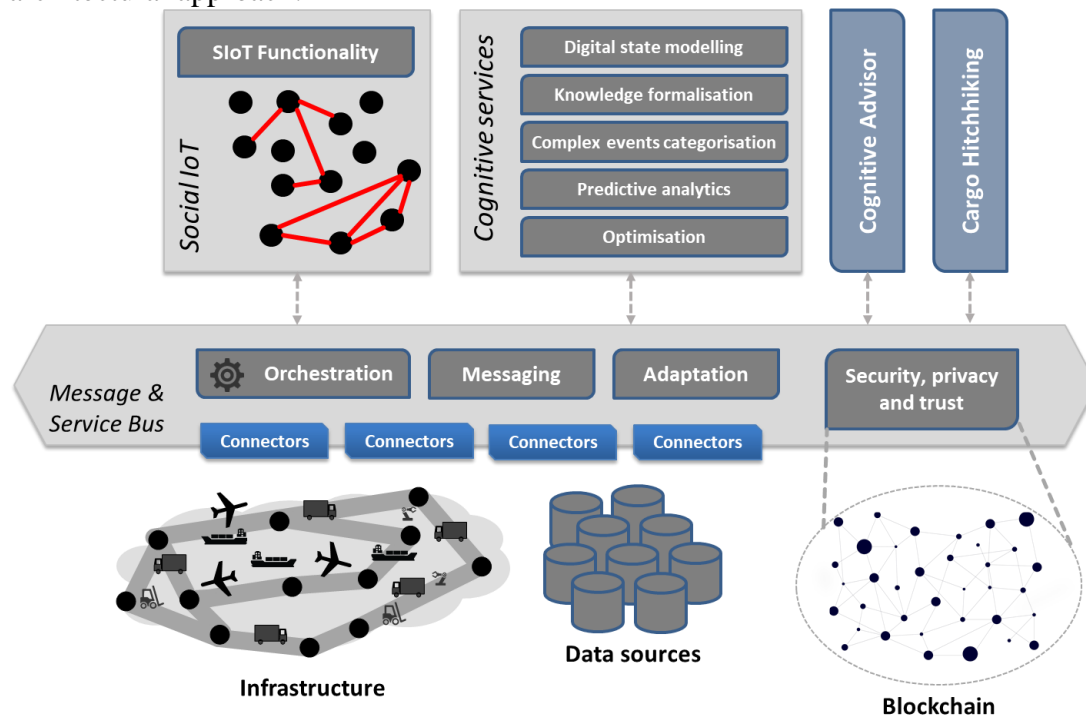
Figure 65: COG-LO Architecture

The physical entities that collectively carry out the actual logistics processes are denoted as the **Infrastructure**. These refer to a variety of concepts, including cargo (parcel, palette, container, etc.), transportation means (vehicles, trucks, trains, etc.), back-end ICT systems and services, as well as infrastructure components, like hubs, parking places, ports, and others. As it will be described below, all these entities have their digital correspondent, denoted as the Cognitive Logistic Object (CLO). The entities of the infrastructure are complemented by the **Data sources**, implying any source of data such as ERP, WMS, ITS, traffic information systems, along with operational and configuration data that are essential for the operation of COG-LO. Overall, the data records under consideration include internal enterprise data (e.g., ERP records, WMS reports, etc.); historical process files; streaming data (broadcasting/community/individual services, etc.); situational and contextual data at local and global level (e.g. traffic status, environmental conditions etc.).

As said above, each entity of the physical world is identified in COG-LO as a CLO. The CLOs reside in the **Social IoT** module of the architecture. This component provides information about CLOs social-like relationships and extends their functionalities by means of Virtual Instances (VI). VIs represent CLOs "digital twins" and are responsible of performing the processing, which cannot be executed locally on the device. The VIs appropriately abstract CLO capabilities, in a way that these, along with the CLO itself, are discoverable and manageable in the context of the COG-LO operation. The capabilities refer to semantically - defined behavioural characteristics of the object, and span from basic functionalities to more sophisticated tasks, including, among others, identification, sending and receiving information,

processing data, sensing, actuation, decision making, self-awareness - meaning the ability to know its state, being searchable, etc. At the digital sphere, a CLO is also able to peer with other CLOs, by establishing social relations based on common characteristics, interests or operational purposes, such as location proximity, participation in the same logistics process, etc. By augmenting CLOs with the social dimension, two major advantages can be achieved: (a) an overlay network can be built having the typical features of social networks, i.e., it is navigable and has a small diameter, (b) interactions are preferred between CLOs that are neighbours and more trustworthy. In order to achieve its goal and mission, the Social IoT module of COG-LO is conceptually organised on a constellation of CLOs - implemented as software agents that comprise the digital twins of the physical entities - and in a number of functions for managing the CLOs, such as the CLOs registry, the repository of friendship relations, functions for the establishment and management of relationships and navigation of the social graph, etc.

In order to provide for effective interaction, coordination and orchestration of COG-LO components and operations thereof, the architecture includes the **Message and Service Bus** (MSB), being a mediation middleware between the components of the COG-LO ecosystem. The MSB comprises a message-oriented system providing for both asynchronous and point-to-point message exchange between the system entities, circulation of events, and interaction between the CLOs. An important aspect here concerns the management of interaction channels for enabling the cooperation within *communities* of CLOs; this involves the dynamic establishment of message topics (queues), thus providing for the implementation of the *tweeting* CLOs functionality. Furthermore, the MSB provides for the integration of the infrastructure objects and data sources, by means of appropriate connectors; to this end, a fundamental duty of the MSB is the transformation of the Platform Independent Model (PIM) of the underlying components operational behaviour to the COG-LO Platform-Specific Model (PSM)[32]. The MSB incorporates also the functionality for the orchestration of COG-LO components and operations as regards the execution of workflows.

In addition, the MSB is the main COG-LO system entity for the enforcement of mechanisms for **data security, privacy and trust**. To this end, a variety of mechanisms will be incorporated in the MSB, including: (i) a policy-based access and usage framework for regulating the circulation and usage of information; since the MSB comprises the central interaction point, messaging will be subject to such control, in order to make sure that authorisation constraints are met as regards disclosure of data to system entities; (ii) appropriate software libraries for the enforcement of active *protection* means, such as cryptographic primitives, anonymization and pseudonymization mechanisms; (iii) a comprehensive framework for the establishment of trust, both subjective and objective, between the system entities; to this end, appropriate mechanisms for mutual identification and authentication will be put in place, providing for objective trustworthiness, whereas a distributed ledger will be leveraged for the effective management of corresponding certificates.

The main enabler towards cognitive behaviour in COG-LO will be a set of **Cognitive Services**, providing the necessary logical inference mechanisms for knowledge extraction and formalisation, learning and reasoning, as well as cognitive behaviour of the underlying entities, leveraging multiple analytics technologies. The COG-LO Cognitive Services, therefore, enable core services, including: events categorisation, infrastructure observability, critical constraints assessment and defining eligible CLOs for localised decision making on final activities execution level. The Cognitive Services will be coupled with exact optimisation algorithms and heuristics for enabling CLOs adaptation to operational changes from the external environment

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[32] PIM and PSM are commonly terms used terms in the Model-Driven Architecture literature and standardization — cf. e.g., The Object Management Group (OMG), Model Driven Architecture (MDA), MDA Guide rev. 2.0 OMG Document ormsc/2014-06-01, June 2014, https://www.omg.org/cgi-bin/doc?ormsc/14-06-01.pdf.

in near real-time. In particular, COG-LO couples analytics and optimisation for considering the effect of optimisation control measures to the performance of operations in an environment with continuous external variations.

Finally, the COG-LO architecture includes two tools notable the **Cognitive Advisor** (CA) and the **Cargo Hitchhiking**. The CA, comprising a functional front-end of the Cognitive Services, provides the logistics operator with visualised decision support for routing optimisation. The CA interacts with the MSB to visualise the formalisation, reasoning and cognitive outputs of the Cognitive Services. On the other hand, the Cargo Hitchhiking will reflect the tweeting CLOs functionality, enabling the creation of communities, along with messaging and coordination therein.

5 COG-LO pilots

COG-LO technology will be validated through 3 pilot cases:

Slovenia Post (PS) and Croatia Post (HP): Optimisation of collection, exchange and delivery of tracked cross-border shipments process between. The challenge is to improve the collaboration in terms of data sharing and optimized deliveries using different hubs and alternative routes where needed (currently only though one hub per country).

Hellenic Post (ELTA): ELTA will demonstrate two basic scenarios: a) load factor optimization in the major Greek backbone logistics route Athens-Thessaloniki through a picking shuttle van integration; b) optimal re-routing of courier resources for the handling of dynamic events (e.g. customers' ad-hoc pickup requests, random traffic events etc.) injected in the route plan during the day, aiming at the minimization of route cost and the fulfilment of agreed timeframe for pickup/delivery guaranteeing high service levels.

EKOL: EKOL, a leading EU Logistics Service Provider, will demonstrate how COG-LO can improve dynamic planning in cargo forwarding at the Port of Trieste. The main challenge is to achieve optimized timing and booking of cargo multimodal transportation by minimizing waiting times and use alternative flows in case of unexpected unavailability/delays.

6 Outlook: innovation potential and market benefits

This paper has described COG-LO, an innovative framework for cognitive and collaborative logistics. Having described the above approach, we can identify three innovation areas that the project tries to address:

Cognitive Behaviour: COG-LO builds on top of the knowledge gained from previous research projects (EURIDICE-FP7, iCargo-FP7). Those projects defined the intelligence framework together with relevant knowledge base and associated services. COG-LO, through the introduction of the CLO. In COG-LO, the CLO have also cognitive capabilities, which extends context awareness to local decision-making.

Ad-hoc CLO collaborative platform with by design security, privacy and trust. This platform will deploy the Social Networks of CLOs bundled with comprehensive access and usage control, information diffusion, and compliant workflows. Such mechanisms will be based on blockchain technology and allow for ad-hoc CLO communication, through the Tweeting CLOs tool.

New business models for logistics players as a result of the proposed technology. Ad-hoc collaborations, load factor optimization and new synergies will be demonstrated in three different scenarios: Cross-country interoperability, flexible intra- and inter- multi-model logistics operations. The consortium consists of three Post Operators, which faces many difficulties in adopting to the dynamics of the market. We will test new practices for ad-hoc delivery requests (shuttle bus in ELTA), new collaborative models with external players and assess the applicability on faster and same day deliveries.

Based on the above-proposed approach, COG-LO can offer the following benefits:

(a) *Better exception management*;

(b) "*Cargo Hitchhiking*", meaning that the cargo can identify combined transportation possibilities with vehicles transferring similar cargo to the same destination. Hence, higher load factors and lower CO_2 emissions will be achieved by engaging fewer vehicles.

(c) *"Tweeting Vehicles":* similar to the *Tweeting CLOs* concept, vehicles communicate each other, exchange <u>public</u> information on load status, cargo type & conditions, etc. to identify possibilities of merging deliveries.

(d) *Improved trust* through the usage of Smart contracts and blockchain.

(e) *Improved transportation planning*; logistics operators will be enabled to identify improved transportation alternatives and new opportunities for business collaborations in order to re-evaluate their transportation models.

(f) *Ease of access and stakeholders' engagement*; leveraging the COG-LO platform, a variety of stakeholders in the supply chain can join the COG-LO ecosystem at minimal cost. Along with the aforementioned, COG-LO will offer additional benefits, such as security, privacy, event and process management at small and large scale.

Acknowledgement

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RTPORT: the 5G-based Model-Driven real Time Module for General Cargo Management

Paolo Pagano [1], Alexandr Tardo [1], Domenico Lattuca [1], Anna Sessler [2], Rossella Cardone [2], Luca Stroppolo [3], Marzio Puleri[3], Teresa Pepe[3]

1. CNIT, Pisa, Italy
2. ERICSSON, Milan, Italy
3. ERICSSON Research, Pisa, Italy

Corresponding author: paolo.pagano@cnit.it alexandr.tardo@cnit.it
anna.sessler@ericsson.com rossella.cardone@ericsson.com luca.stroppolo@ericsson.com
marzio.puleri@ericsson.com teresa.pepe@ericsson.com

Abstract: Major maritime carriers are globally demanding improvements in the efficiency of port operations. Cargo carried by ships must be loaded and unloaded quickly with minimal stopover time in the port. This is driving the implementation of more efficient processes and the reorganization of technologies at the terminals: connected platforms, cloud-based services, service-oriented architectures (SOA), sensors and other IoT technologies (M2M), augmented/virtual reality (AR/VR), autonomous transportation, next generation mobile networks (5G) and blockchain-based technology. RTPORT, the 5G-based Model-Driven Real Time Module, will allow a better management of general cargo resulting in faster throughput compared to traditional human-driven communications. A full reorganized mobile network (5G), connecting smart sensors with cloud resources will be used in order decrease environmental impacts by optimizing trucks movements in the port area as well as improving workers' safety and enhance their skills with digital tools. The effectiveness of RTPORT will be evaluated in the Port of Livorno for EU Horizon 2020-funded Capacity with a Positive Environmental and Societal Footprint - Ports in the Future (COREALIS) project and it represents the starting point for the deployment of the Physical Internet.

Keywords: IoT, 5G, M2M, Automation, General Cargo, Physical Internet, Supply Chain, Augmented Reality, Sustainable Development, Virtual Reality, Container Terminal.

7. Introduction

The performance of the port and the quality of its services are closely linked to technological innovation applied to the processes involving the whole Port Community. The digitization, sensorization and telematization of the port, enable the Port Community to be a Smart Community. The emerging technological innovations in the ICT (Information Communication Technology), ITS (Intelligent Transport System), IoT (Internet of Things) and PI (Physical Internet) fields allow an overall redesign of the logistic chains, which become increasingly smart and compliant with the concept of Logistics 4.0. The new digital revolution, involving many national and international ports, implies a more innovative, faster, safer and more reliable way of conceiving information exchange. From the value-added services perspective, 5G-based technology is discussed for the fast and huge data transmission, distributed networks for the vehicular communications, photonic radars for the timely detection of data, cyber-security to ensure secure access and historicization of information and blockchain to allow the secure exchange of information and certifications on the origin of data. In this context, the

digitalization and integration, facilitated through the adoption of innovative information technology, have enabled a high degree of automation and streamlining in port procedures, especially in Container Terminals (CT). In fact, one of the most important roles of ICT is the ability to connect container terminals with other subjects in the port community, enabling a high level of interoperability and data sharing with the existing IT networks (i.e: Port Community Systems, Port Monitoring Systems, National Single Windows, Terminal Operating Systems, etc.). If for the case of containerized cargoes this proves to be absolutely true, since optimized tools are used (such as the Terminal Operating Systems), for the case of general cargo adequate solutions have not yet been found. The context of general cargo management, still suffers from a very low level of automation and digitization. Obviously this generates inefficiency that spreads over the entire supply chain and that in any case must be filled to guarantee the possibility of preparing the port environment for the deployment of Physical Internet (PI). This is the first requirement to enable the Physical Internet, an open and global logistic system founded on physical, digital and operational interconnectivity.

8. Problem Statement

The general cargo sector is an area that still suffers from the absence on the market of adequate management and monitoring solutions that can guarantee an acceptable level of automation and digitalization, effectively eliminating the operational inefficiency that derives from it. This problem finds its origins in the nature of the general cargo. Unlike the cargo transported in containers, the general cargoes are in fact characterized by irregular and non-standard geometries (i.e. pipes, components for industrial machinery, cars, etc.). The physical dimensions of the cargo constitute one of the main problems for terminal operators: often, this information is incorrect or even completely absent. This leads to many evaluation errors both during the loading phase of the ship and during storage and handling operations. In many situations the cargo taken from the crane according to the loading plan of the ship's captain is inadequate if compared to the space available in the hold of the ship. This means that it is necessary to put the cargo back on the apron, select another available cargo that meets the captain's requirements and load it onto the ship. It is clear that the unreliability of the information regarding the physical dimensions of the specific cargo, in this case produces inefficiency and waste in terms of time, actually slowing down the entire loading process of the ship. Another problem that arises is represented by the storage and handling of the cargo. Since the arrangement of the cargo in the storage area is performed without taking into account any storage optimization procedure (based only on the amount of available space), the movement of a given cargo leads to not always efficient maneuvers, with negative consequences in terms of time needed to find a certain cargo on the apron. To conclude this scenario, we must also consider the problem related to the forklift call. Currently, the control room operator executes manually the forklift call via radio communication systems. The terminal operator does not have a real-time visibility of the distribution of the vehicles on the apron and consequently runs the risk of making an inefficient call (choosing for example a forklift with a greater distance from the selected cargo). All these aspects highlight the fact that the management of the general cargo is still affected by a great inefficiency that affects the entire management and handling process, from the moment it arrives at the terminal to the moment it is loaded on the ship. In this context, RTPORT is proposed as a possible solution to the problems that have been presented, providing an automated and efficient system for monitoring and managing the cargoes on the apron.

9. RTPORT: Model-Driven Real Time Module

Digital transformation is having high impact in port handling and logistics providing new opportunities to enhance the productivity, efficiency, sustainability and port capacity. Although, in the last years there has been an acceleration in the automation and digitalization of ports; general cargo handling is still manual. The Model-Driven Real-Time Control module (RTPORT) fits this context in with the aim to optimize port operations thanks to disruptive technologies, including IoT, data analytics, and emerging 5G networks. RTPORT will allow better and faster handling of general cargo (e.g. storage optimization, yard-vehicles call optimization, loading/unloading phase optimization) if compared to traditional human-driven communication. It allows real time ports operation control by collecting data via yard vehicles and implanted sensors (including cameras) and taking operative decisions based on on-line analytic processing. A 5G mobile network, connecting smart sensors with cloud resources, will be used in order to allow the transfer of massive and high demanding bandwidth data. In the following, the general cargo logistic use case is described; moreover, an analysis of the use case using the structured analysis approach is reported.

a. General Cargo Logistics Use Case

The proposed use case focuses on the implementation of a system for the management of the general cargo analyzing both unloading (from the truck) and loading (to the ship) operations. More specifically, the general cargo logistics use case can be divided into three main phases (*Figure 1*):

- **Tracking and Storage** - this phase concerns all operations related to the handling of the goods from when they arrive in the port until they are placed in the yard;
- **Loading Operations** - this phase comprises of the selection of goods to be loaded on the ship and the transfer to the crane.
- **Yard Vehicle Call** - this phase concerns the forklift/stacker call during the general cargo handling operations.
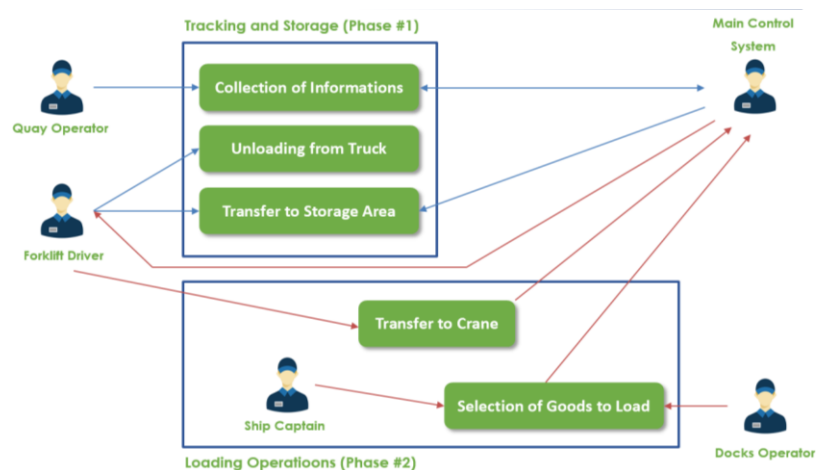

Figure 1: Functional Diagram

i. Tracking and Storage

The Tracking and Storage phase includes three operations:

- Collection of information;
- Unloading from truck;
- Transfer to the storage area.

The collection of information refers to the goods acceptance procedure. Two actors are involved in this activity: the quay operator and the main control system. The latter is the software managing the sequence of general cargo operations. When a truck arrives, the quay operator checks all the goods that are going to be unloaded. For each object he has to get the information on the waybill and check if the size of the object is already reported, as shown within the procedure diagram in *Figure 2*. If not, he proceeds with the size acquisition using the measurement device based on the LIDAR technology. Once the size is available, the quay operator, using a dedicated application running on a tablet, writes down all data on a dedicated form and sends it to the main control system via the mobile network. Once the main control system receives the information about the incoming object from the quay operator, a record is created in the relational database, where the goods data is stored, inserting the waybill information and the size of the object.
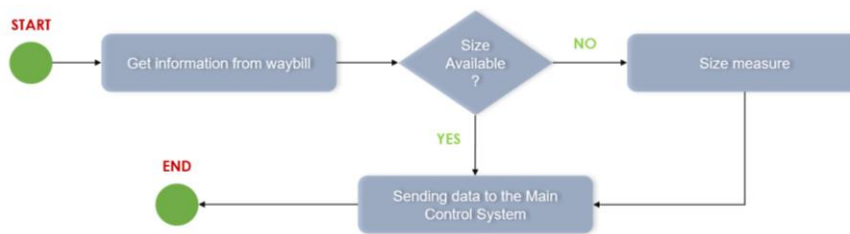
Figure 2: Procedure Diagram – Collection of Information

The unloading from the truck is a manual operation and precedes the size measurement, if required. The forklift or reach stacker picks the object out of the truck and stops waiting for the size measurement and/or the indication for the storage place.

The main control system after having created in the relational database the record associated with the incoming object, searches in its virtual map an optimal location in the storage area where to place the object according to a set of rules. When the location is identified, the object's record is updated in the relational database with the chosen location. The status of the object is changed to "in transit". Then it sends the forklift driver indications where to place the object (transfer to storage area phase). The location is shown on a virtual map on the driver's tablet. The application on the tablet, exploiting its GPS, will guide the driver to the location. When approaching the area, the driver can commute to the assisted positioning (*Figure 3*). By using the augmented reality (AR), he can see an image of the area captured by cameras mounted in the storage area. In the picture the position where the object has to be placed will be highlighted. Once the object is placed the driver has to send the main control system a message using the application, stating the completion of the operation. Then, the main control system updates the record of the object in the relational database, modifying its status as "placed in storage". In the meantime, the cameras in the storage area check the final position of the object and the main control system updates the object location in the database accordingly.
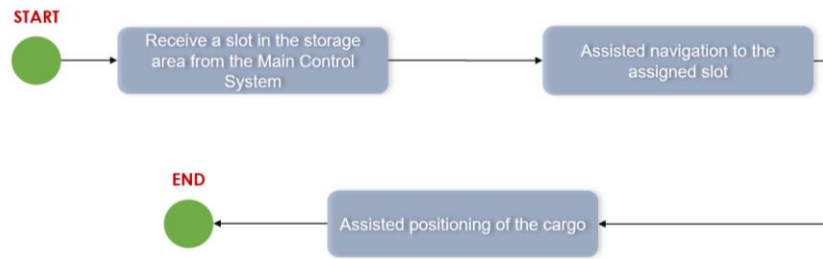
Figure 3: Procedure Diagram – Transfer to storage area

The storage area is equipped with cameras pointing to the stored goods. These cameras are used for stereoscopic vision of objects to detect their position. The same cameras are also used for getting the image stream to send to the driver to show him in augmented reality where to pick or place an object or which objects have to be moved and where, in order to accomplish the target. The object detection and localization functions in the main control system will provide the data description about each object. The main control system will then update the position and status of each object in the relational database.

### ii. Loading Operations

This phase includes the following operations:

- Selection of the cargo to load
- Transfer to crane

When goods have to be loaded onto the ship, there is a loading plan prepared by the captain. This plan can be changed runtime, if an object of different size or weight is needed (e.g. to balance the load on the ship). When an object has to be transferred from the storage area to the loading area in front of the crane, the docks operator, using an application, requests the next object to load from the main control system. The object can be identified in more than one way, depending on if it follows the loading plan or not. Once the main control system receives the request it searches for the proper object in the database (selection of the cargo to load phase).

When the main control system has selected the object to transfer, it chooses a free forklift and informs its driver about the object to be picked and where to place it (transfer to crane phase). The driver has an application on which he receives the data from the main control system (*Figure 4*). After having accepted the request from the main control system, he goes to the storage area where the object is located. The location to reach and the current position is shown on a virtual map on the driver's tablet. The application on the tablet, exploiting its GPS, will guide the driver to the location. When approaching the area, the driver can commute to the assisted positioning. By using AR, he could see an image of the area captured by cameras mounted in the storage area, that will highlight the position where the object to pick is located. If there are other objects to be moved to reach the target object, the main control system, through the driver's application, will give indication in AR about the objects to move and where to place them. Once the target object is picked, using the application, the driver has to send to the main control system a message stating the completion of the picking operation. When he discharges the object in front of the crane he sends a further acknowledgement to the main system to state the operation is completed. Then, the main control system updates the object record in the relational database, modifying its status as "transferred for loading".
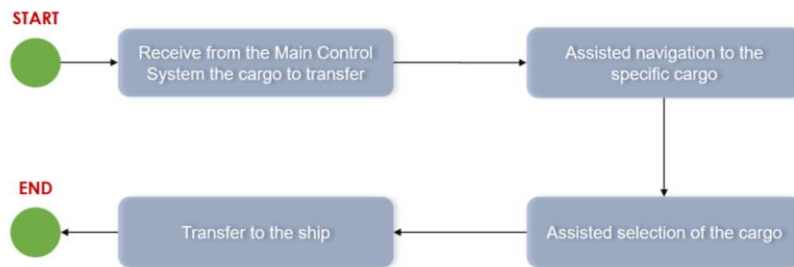
Figure 4: Procedure Diagram – Transfer to crane

iii. Yard Vehicle Call

This phase is based on the use of the 3D rendering module (called MonI.C.A.) of the Port Monitoring System used at the port of Livorno. The idea is to provide the possibility to the container terminal's operators both to trace and monitor the vehicles present on the general cargo area, involved in the operations of loading/unloading/handling of goods, and to monitor its status with the purpose to be able to move/call vehicles optimally, in relation to the disposition of the goods. The vehicles involved in the loading/unloading of the general cargo will be equipped with a tablet to perform the operations as described in the previous sections. The tablet is a built-in GPS tablet and will periodically send data about the position of the vehicle. These data represent the starting point for vehicle tracking and are transmitted, through a 5G network, to the machine-to-machine platform (OneM2M). Then these data are processed and consumed by the local Port Monitoring System. Through a graphical interface, the operator will be able to see (in real time) where each vehicle is located in relation to the general cargo's position that needs to be loaded, unloaded or moved. In this way it will be possible to make the most appropriate vehicle-call in relation to the disposition of the general cargo.

b. Structured Analysis of the Use Case

The proposed use case has been analyzed using the structured analysis approach, that helps in defining all data flows, data structures and processes required to comply with the required task. According to the structured analysis approach, a hierarchical set of data flow diagrams (DFDs) have been defined, describing data processing , the data flows and the data structures used in the system. In *Table 1* an explanatory list of the graphic elements used in the DFD diagrams is reported.

Table 1: DFD Legend

Graphic Element	Meaning
Green Box	Actor interacting with the system. It could be a machine or a human being.
Orange border rounded box	Process describing the transformation of the input data flows into output data.
Magenta Bar	File or database.
Arrow	Data flow describing the information exchanged between two processes.

The context diagram in *Figure 5* shows how the actors (green boxes) interact with the general cargo logistics control system (orange box). The arrows represent the dataflows exchanged among the actors and the system. The diagram includes two main sequence of actions, corresponding to the general cargo logistics main phases (Tracking, storage and Loading operations). Except for the camera, green boxes represent humans and interact with the system via a HMI (Human-Machine Interface) made, using a dedicated application running on a tablet/smartphone.
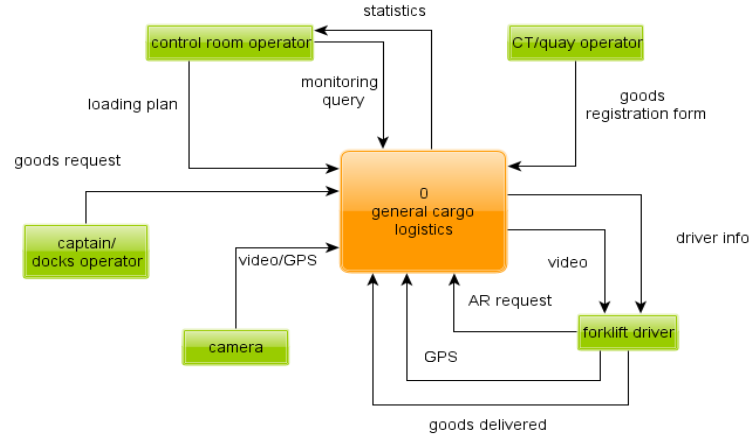
Figure 5: General cargo logistics context diagram

When a truck arrives, the quay operator registers the goods filling a goods registration form with all goods data, using a dedicated application running on a tablet. Then, the system (general cargo logistics) will register goods in a database. During the loading operation the control room operator provides the loading plan prepared according to the loading list provided by the captain in advance. However, this plan can be changed runtime, if an object of different size or weight is needed (e.g. to balance the load on the ship). In this case, the captain or the docks operator, using an application, can send a goods request specifying the next object to load. The control room operator, sending a monitoring query, can also visualize storage area statistics to monitor the yard's operations. When new goods arrive and when goods have to be transferred to the crane the system will identify the location where to place/pick goods and will send the forklift driver indications where the object has to be placed /is located (driver info).
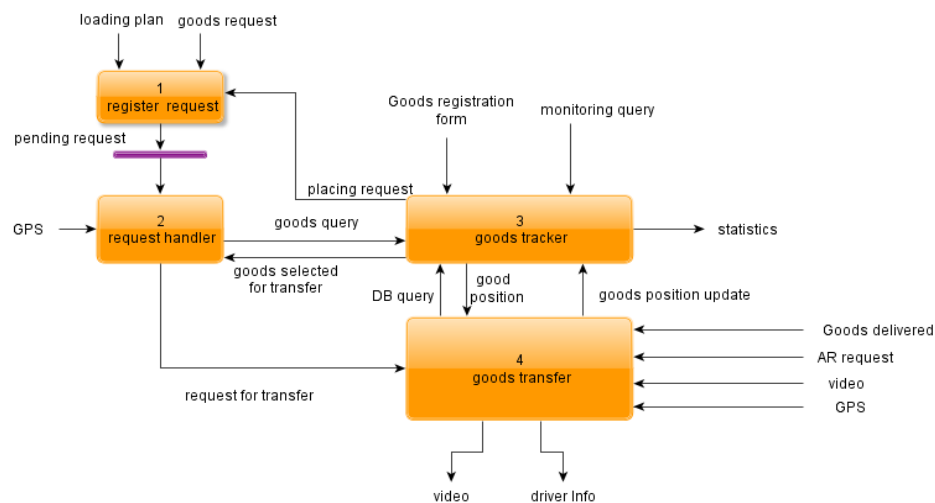
Figure 6: General cargo logistics context diagram

The application on the tablet, exploiting its GPS, will guide the driver to the location. When approaching the area, the driver could commute to the assisted positioning, sending an augmented reality request. By using AR, he could see an image of the area captured by cameras mounted in the storage area, that will highlight the position where the object must be placed/picked. The same cameras are also used for stereoscopic vision of objects to detect their final position. When the transfer is completed, a freight delivered message is sent and the object's status is updated. The "general cargo logistics" process is composed of a set of interacting sub-processes as shown in *Figure 6*. Moreover, it includes a file "pending requests" that queues the pending goods requests during the loading phase.

The processes involved are the following:

- **Process #1** - has the purpose of registering an incoming request for goods transfer into the requests file;
- **Process #2** - handles the next request to serve and the positioning of new accepted goods. During the loading operation, it sends a "goods query" to *Process #3* and, based on the goods selected for transfer, identifies the storage area to reach. Then, it chooses a free forklift and informs its driver about the object to be picked up and where to place it. For new accepted goods it chooses an optimal storage area and creates a request for transfer to send to *Process #4*;
- **Process #3** - manages the goods database;
- **Process #4** - guides the driver to the storage location. It is also able to provide assisted positioning by using AR.

c. Technical solutions

This paragraph reports the main technologies that will be used to implement the enhanced general cargo logistics use case.

i. Cargo size measurement

The size of general cargo goods is not a-priori well defined. The knowledge about their size is fundamental for loading operations and for optimizing storage. For this reason, a method based on laser range finders or laser distance measurement devices will be studied to create a volumetric model of the object consisting of the rectangular cuboid including it. A laser range finder is a laser sensor for area scanning. The light source of the sensor is an infrared laser with laser class 1 safety. The principle for the distance measurement is based on a calculation of the phase difference of the reflected beam, which makes it possible to obtain a stable measurement with minimum influence from object's color and reflectance. The laser range finder scans the environment along a plane, like a radar, computing the distance of an object from the emitter and getting a sliced view of the object on a specific plane. To get the complete model of an object several slices have to be combined obtaining a points cloud describing the object. The laser range finder has typically an opening of more than 90° on each side with respect to its front, scanning an area of more than 180° in total. A single scan lasts typically between 30 and 100 ms. Ten scans or less should be enough for the definition of the cuboid. The size computation should take around one second. In our case for the detection of the size of the goods a measurements system based on 3D LIDAR technology has been used. This device,

instead of using a single photodiode for reception, adopts a camera sensor, an array of receptors, to speed up acquisition.

Figure 7: 3D laser range scanner

The SICK Visionary-T 3D laser range finder shown in the *Figure 7* will be used. The sensor will be interfaced with a small portable computer or a tablet/smartphone on which the processing software will reside. The points cloud got by the sensor will be integrated and processed by the software displaying the cuboid size related to the scanned object. This software will allow the worker to introduce additional data, like the ID code of the measured object and other required data, and to transfer, via mobile network, all the information regarding the object to the logistics control system that will then store the data in its database.

ii. Cargo localization

Goods localization is required to optimize storage and allow a fast and optimized retrieval of the proper object to be loaded on the ship. General cargo is typically picked from a truck by a forklift or a reach stacker and placed in the storage area waiting for the ship's arrival. The area where goods are stocked is monitored by a set of cameras. A specific software will be able to identify each object and its position. When an object is picked from the truck, it is identified and registered by the main control system in its database. Then the forklift moves it to the storage area. As soon as the camera can detect the forklift, the object is tracked by the cameras and the location where it is placed is registered. In case an object is moved, the cameras recognize the object, track its movement and register the new position. To get a precise positioning stereoscopic vision will be used. This method should allow to achieve a high localization accuracy. Operating in outdoor environment, we must take care of lighting conditions that can change continuously due to the weather and the time of the day. For this reason, Wide Dynamic Range (WDR) cameras are adopted (*Figure*).

Figure 8: Example of WDR surveillance cameras

The HANWHA TECHWIN TNU-6320 camera is a candidate. Dynamic Range is the difference in light levels in an image, between the darkest and the brightest areas (*Figure 9*). On an overcast day, there will be a low dynamic range without areas of deep black and extreme bright spots. On a sunny day, instead, in an image with distinct shadows, there will be a greater difference between the brightest and darkest areas, and this is what it is called a wide dynamic range or WDR (also known as High Dynamic Range, or HDR).

Figure 9: Difference between a non WDR (left) and a WDR camera (right)

WDR mode is a technology that extends the camera's range, to cover a greater span between the bright and the dark areas in the image. There are several ways to increase the dynamic range, and many solutions are used in combination to achieve the best result. Several cameras will be placed in the storage area to cover it completely. Each point must be covered by two cameras at least to allow the application of stereo-vision to compute the position of the object. Apart from positioning, the camera will be also used for identification of goods. To achieve this, their images will be processed remotely to recognize and identify the monitored object. For the image processing and recognition open source image processing libraries will be used like OpenCV. For image recognition the possibility of applying technologies based on the analysis of an ensemble of preprocessed image patches using Approximate Nearest Neighbour and Bayes network techniques will be evaluated for identifying the seen object.

iii. Main Control System and its database

The main control system of the logistic application will make use of a relational database in which all the information related to each object will be stored (e.g. ID, destination, size, weight, location). This database will contain all the data needed to manage the object from its arrival to its departure. The same database will be used by the personnel, for instance, either to query the status of goods or to know what is stocked or to find a specific goods fitting some requirements for the loading onto the ship. MySQL is a candidate for this part of the system. An example of its usage can better explain how it will work and how it will be handled by the main control system. When an object arrives on a truck, it is registered with its data and a record is created in the database. When the object moves and reaches the storage area it is tracked by the camera system and its position is detected and added to the record. When the personnel on the ship asks for an object with certain characteristics to be loaded, via a specific application, the main control system identifies the object in the database that matches with the request and informs the harbor worker operating on the forklift which object to pick. The main control system and its database can be also used by the terminal employees to preplan the loading of the ship, optimizing both storage and loading operations. The main control system will be a program, written in python, running on a virtual machine in a local cloud installed in the terminal premises.

iv. Applications on devices

Some softwares and applications, needed for handling the logistics operations in an optimal way, will be developed. The applications will be developed for Android platform, that is one of the most used operating system for tablets and smartphones. The Android Studio development platform will be used for developing the code. This environment includes all the functionalities needed to develop and test the application both with an emulated and real device. Specifically, to provide the required level of automation and integration three applications will be developed. The first application will be used by the worker registering the entrance of a new

general cargo. This application will be connected to the tool for capturing the size of the goods. There are two main options: the measurement system is connected directly to the tablet or the measurement system is connected to the tablet via a miniPC. The application will collect the information about the size of the object managing the measurement process and showing the corresponding result to the worker. Then it will allow the creation of the information record about the arrived object sending it to the main control system for registration. A second application will be used by the worker on the forklift. It will provide information in virtual reality (VR) and/or AR to show where the object to be picked is placed in the area or where to place it. In case augmented reality will be used, the OpenCV library for Android could be adopted for the image processing. The application will make use of the GPS inside the tablet/smartphone for localizing the worker. This information could be integrated with more precise positional data provided by the environmental cameras, detecting the worker in the operation area. Then a VR map of the operational area will show the worker where he is, where the cargo he has to move is positioned and where it should be placed. The map will be updated by the remote main control system based on all the information gathered from the different sensors. The same application will provide additional information to the worker about his task and will be used by him to inform the main control system about the completion of the task. A third application could be provided to the stevedore on the ship. Using this application he will be able to send a request to get the next item in the loading plan or send information about the characteristics (size and weight) of an item that needs to loaded onto the ship not in accordance with the loading list. This request will be handled by the remote main control application in the cloud, that will look for an object satisfying the request, will start the search and transfer process, selecting a free forklift and sending the details of what to do to the worker on his application (the second application described previously) and, finally, will send a feedback to the stevedore on his application.

d. Use Case requirements

The real time handling of the goods, the continus exchange of massive information between sensors (i.e., cameras) and the control system and the use of AR poses tight requirements in terms of bandwidth and latency enabling the need of a 5G network on-site. *Table 2* details the main use case requirements.

Table 2: General 5G, Network and End Device requirements

Requirement	Value	Details
E2E Latency	<10ms (target 5ms)	time budget is < 100 ms for AR: target 50 ms to provide a smooth feedback to forklift driver; AR processing done in a local cloud close to the terminal area; 90% time budget must be reserved for AR processing.
Speed	>15Mbps/Camera	Cameras for AR and positioning check.
Reliability	More than 99%	-
Mobility	Yes (10mph)	Speed limit in harbor operational area.

Broadband Connectivity	Yes	-
Network Slicing	Yes	-
Security	Yes	-
Capacity	400Mbps (UL) and 100Mbps (DL)	-
Coverage rea	15.000 square meters	-
Number of Devices	5-20	-
Density of Devices	1-3	-
Bitrate per Device	10-20 Mbps	-
Acceptable Jitter	5ms	-
Class Service (1-8)	2-3	-
Type of Device	Camera, PC, Tablet, Smartphone	-
IPv4/IPv6 Support	IPv4	-
Connection of Device	Wired/WiFi	-
Type of Connection	Ethernet/WLAN	-

e. 5G E2E Network Architecture

IoT devices (e.g. HDR cameras, LIDARs) installed in the area of the trial and supporting forklifts and operations are connected via 5G infrastructure to the local cloud running the application level. Local processing will be used to run the distributed applications needed for image processing and pattern and context recognition while AI processing will support workers' activities to guide drivers and workers with real time augmented reality info. In *Figure 10* the high-level solution of the 5G network infrastructure is reported.

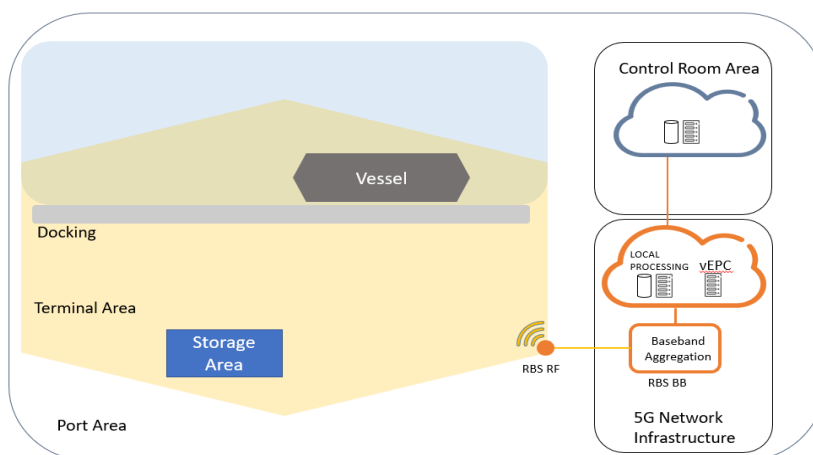*Figure 10: 5G Network high level solution*

The overall setup is based on 3GPP R15 Option 3.x architecture. In this option, the 5G NR (New Radio) for user plane coverage is supported by LTE radio access supporting both user plane and control plane. This architecture called NSA (Non Stand Alone) is a reasonable choice for an initial deployment of 5G network where the operator has already a 4G nationwide

coverage. Starting from the Radio Access Network section, the RBS RF function is installed at antenna site and will provide dedicated coverage in the test area identified in the Port and Terminal Area. As per NSA architecture the RBS RF will provide both NR and LTE radio coverage. The RAT BB function will be installed at a proper site where also the local Cloud Infrastructure will be hosted. The local cloud infrastructure installed in the same cabinet than the radio equipment will support Core as well as the application level. More specifically, this infrastructure will run all VNFs instances supporting the virtual Core (virtual 5G EPC, including vEPG and vMME and vHSS) to provide User Plane (UP) and Control Plane (CP) functions, in line with Distributed Cloud framework (equivalent 3GPP declination of the MEC paradigm). The UP function will be interconnected to local processing infrastructure through an application server with computing capabilities necessary for the use cases described in the previous paragraphs. The choice of a local 5G EPC co-located with the radio equipment and the NR radio interface is technically related to ensure latency and throughput requirements. More specifically, the local termination of the user plane allows the application to be as much close to the user application as possible, eliminating the transport section contribution to overall latency. In addition, the 5G NR radio interface is designed to reduce the radio access latency contribution in the end to end delay budget. High throughput levels in the radio access section are assured using wider spectrum portions dedicated to NR coverage in accordance to available LTE radio channelization. As a possible alternative implementation some or all functions governing the network control plane can be centralized in the MNO centralized Core Network, leaving locally just the functions dedicated to user plane handling. The result will not affect user plan latencies. Local user plane termination in addition to 3GPP radio cyphering of data and the intrinsic resilience coming for the adoption of MNO licensed spectrum on a dedicated local coverage together with a local termination of user plane (critical data remain on premises) provides additional benefits to reliability and security with respect to other unlicensed solution. From a general perspective, the proposed solution can be considered making part of Private Network solutions to be used in similar application to the one defined for the COREALIS Project in Livorno, where low latency and high throughput communications as well as security and resilience are required for advanced use cases (including enhanced logistics, industrial automation and automated guided vehicles).

f. Transferability Issues

The experimentation of the RTPORT module in a container terminal of the Port of Livorno (chosen as the test bed) aims to instantiate a pervasive 5G network and to demonstrate how the interconnection of IoT devices, through machine-to-machine standards (ie: OneM2M Standard Platform), is in line with the ITU IMT-2020 technical requirements regarding mMTC communications (massive Machine Type Communications) or, which is the same, mIoT (massive Internet of Things). Despite this, the functionality of the RTPORT module is closely related to the radio technology in use: the 5G allows to reach a high data rate, higher throughput, lower latencies, high service availability, very high user density and high energy efficiency, compared to fourth-generation technology such as 4G (LTE) and its evolution. If in some cases, such as Virtual Reality, these requirements are indispensable, for the others (i.e: Augmented Reality, vehicles tracking.) this does not appear to be true. In fact, the initial solution for prototyping the RTPORT module involves an overlap with the existing 4G technology with the possibility to switch when needed. This means that radio technologies of generations preceding the fifth can be used to provide similar services even if in a limited and not always optimized way (4G technology is not able to support, for example, a high number of connections per unit

area or even advanced features such as Network Slicing with a differentiated quality of service). In light of these aspects it is possible to state that the transferability of the RTPORT module (with its full functionalities) to other container terminals is closely linked to the availability of a fifth generation network even if it is not a necessary condition. It is clear that this also depends on the context in which each container terminal operates: for example, some terminals may not be interested in having a real-time assistance service during the cargo's handling phases, delivered via viewers and / or tablets with Virtual Reality. In this case a last generation, low latency and high availability network may not be strictly necessary, even if it would penalize the efficiency of operations. Another container terminal could have a very limited network of sensors (made up of a limited number of sensors) and a mMTC communication may not be strictly necessary. With all this, we simply mean that the RTPORT module is designed to work on fifth-generation mobile radio technology, which is why the problem of its transferability is closely linked to 5G coverage in the terminal area, but does not represent a limitation for the use of the module on 4G technology even if with significantly lower performance.

10. Societal Footprint

Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era, namely COREALIS, is an EU-funded Horizon 2020 project which aims at supporting digital transformation within international cargo ports. It proposes a strategic, innovative framework for the ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges thanks to the Internet of Things (IoT), data analytics, next generation traffic management and emerging 5G networks. When it comes to topics on ports, socio-economic development and competitiveness are inevitably tied to the minimization of the transit time of goods. 5G networks and digital technologies can shorten idle times for ships, while addressing workplace safety, environmental issues and sustainable development for the surrounding area. The Livorno Port Authority, the public authority in charge of managing port of Livorno, together with the non-profit R&D National, Inter-University Consortium for Telecommunications – CNIT – and Ericsson, a private company and one of the leading providers of Information and Communication Technology (ICT) to service providers, are developing together a technological experience on COREALIS to qualify the associated benefits from all perspectives including and caring about sustainability issues. The Port of Livorno is facing growing challenges mainly connected to a steady increase in the flow of goods and people in the medium and long term. This phenomenon inevitably demands for an improvement in the operational efficiency of the port. The deployment of an innovative solution combining 5G and Augmented Reality to optimize cargo operations in the port of Livorno will constitute a reference point far across Europe. The Sustainable Development Goals (SDGs), as depicted by the "UN Agenda 2030", combine all of the different aspects of sustainable development by harmonizing economic growth, social inclusion and environmental protection. As the fruitful result of one of the most innovative as challenging policy making and partnership initiative of our time, their immense value lies within the fact that they provide for a comprehensive framework to serve as a guidance towards sustainable development to public institutions, international organizations, non-profit and business sectors. Therefore, they prove to be an effective tool to the purpose of the Livorno Port Authority, as well as in terms of policy making and advising to many different types of public authorities interested in logistics integration and optimization, smart community and city models, inclusive and sustainable development. This collaboration within COREALIS framework is a proof point of partnership for sustainable development according to the UN SDG n. 17, since both private and public

stakeholders involved are committed to accelerate sustainable progress by means of 5G and digital technologies. The result of this cooperation will be a reference practice for the smart ports of the future and a guideline for decision makers of the ports. The UN SDG n. 9, which is related to "industry, innovation and infrastructure", proves to be the most directly impacted by COREALIS 5G technologies and related applications. In fact, the combination of 5G networks, Artificial Intelligence (AI) and IoT will improve the terminal operations efficiency, maximize the use of the infrastructure and decrease operational costs as well as those external costs related to congestion, waiting and idle times. Further, logistic movements will be managed in a safer and controlled condition for workers as well as transportations will be optimized with higher positive impacts on the environment. In a prospected view, 5G digital technology within the port of Livorno will prepare and enable the port to the next development steps. In addition, COREALIS aims at boosting economic development and innovation through the involvement and partnership with startups. Thanks to this innovation incubator approach within COREALIS, the port is going to be an innovation hub of the local urban space. 5G technologies and related applications allows higher standards of economic productivity and safer working conditions within port terminals, concerning health and safety aspects such as accidents' diminution, noise and environmental pollution reduction. The digital transformation of the ports, as the one occurring in Livorno, will determine a significant impact contributing to the development of a sustainable city (UN SDG 11).

11.　　Physical Internet Context

The Physical Internet requires a radical change of how supply chains are operated and managed. The main objective of this open global logistics system, is to create an efficient and sustainable supply chain to solve the environmental, social and economic problems. In order to achieve this, the transport and logistic systems need to evolve and to standardize procedures taking into the consideration the following requirements: 1) Interoperability between networks and IT applications for logistics, 2) Full visibility of the cargo through the supply chain (intelligent and standardized containers) and 3) Open logistics networks. With the reference to the scientific literature, the container terminal could be seen as the π-node, within the Physical Internet infrastructure, consisting of the main elements such as transporters (i.e. forklifts, trucks and ships) responsible for the transporting, conveying, handling, lifting of the cargo and the cargo in itself. Since the general cargo is characterized by not standard physical dimensions, it is not so simple to compare it with the concept of standard and smart container within the Physical Internet (so called π-container). Furthermore, it is not possible to apply a specific tag to the general cargo like for the case of containers, with the capacity to guarantee the traceability, identification, routing and other fundamental aspects for the implementation of the Physical Internet. This limitation must lead to exploring alternatives solutions. One of these could be to analyze the historical data regarding the general cargo (different types of cuboids acquired from the LIDAR system), identifying the most common types of cargo with the aim of being able to obtain a mapping according to the ratio of 1 to 1 between a specific cargo and its relative cuboid. At this point it could be possible to map the cuboid with a specific standard π -container's layout, extending the range of containers' types provided within the Physical Internet (0.12m, 0.24m, 0.36m, 0.48m, 0.6m, 1.2m, 2.4m, 3.6m, 4.8m, 12m and 18m) in order to include all cargoes that exceed the maximum standard dimensions. Of course this is a vary huge job that should be done in collaboration between all the container terminals around the world that manage the general cargo, collecting and processing all the acquired information. In this sense, the RTPORT module is representing the first needed step to explore and assess this possibility

on the field, providing at the same time a cloud platform that could be used in order to share this kind of information within all involved stakeholders. Moreover, RTPORT aims to reduce: the empty trips in container terminals, the total number of movements per general cargo unit, the vessel operation completion time, the unnecessary yard equipment movements and more. This produce a significant reduction in fuel consumption, as well as CO^2 emissions reduction. Since Physical Internet is based on the main objective to allow a more sustainable way to manage and transport cargoes, RTPORT certainly allows us to move in this direction.

12.   Conclusions

In this paper, a concrete implementation solution, based on the use of emerging technologies such as 5G, has been presented with the aim to address the problems that currently affect the general cargo management sector with the special attention to the Physical Internet. More specifically, it has been shown and discussed how the combined use of IoT sensors, innovative mobile radio technologies and process management/optimization software can provide an effective tool for managing cargoes on the apron, effectively eliminating operational inefficiency that derives from it. The implementation of the RTPORT module has been also addressed from the point of view of sustainable port development and the impact on the surrounding environment in line with the current United Nations 2030 Agenda, showing how it is possible to increase operational efficiency, increase the use of existing infrastructure and reduce operational costs. All these aspects have also been contextualized in the concept of the Physical Internet, showing how the processes of standardization, digitalization, integration and data sharing (enabled by the RTPORT module in the context of the management of the general cargo) are perfectly in line with those that are basic requirements of the Physical Internet.

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Paolo Pagano, Alexandr Tardo, Domenico Lattuca, Anna Sessler, Rossella Cardone, Luca Stroppolo, Marzio Puleri, Teresa Pepe

Key Capabilities to Thrive at the Nexus of Supply Chain Management and Digitalization

Patrick Brandtner[1]

1. Research Professor for SCM, Steyr, Austria

Corresponding author: patrick.brandtner@fh-steyr.at

Abstract: Supply Chain Management (SCM) is of crucial importance for organisational success. In the era of Digitalization, several implications and improvement potentials for SCM arise, which at the same time could lead to decreased competitiveness and could endanger long-term company success if ignored or neglected. From a practitioner's point of view, several key capabilities are becoming necessary at the nexus of SCM and Digitalization. This paper applies a mixed method approach of practitioner interviews and focus group workshops to elaborate these key capabilities. The main results of the paper indicate that the relevance of Digitalization for SCM is realized in practice. In the form of four key capability groups, a set of fourteen concrete capabilities is condensed: 1) creation of visibility and transparency, 2) advanced data exploitation, 3) strategic consideration of exogenous trends and 4) acceleration of technological transformation. The main contribution of this paper is an empirically grounded basis for future research projects focusing on Digitalization in SCM and an overview of the capabilities required at the nexus of SCM and Digitalization from practitioners' point of view.

Keywords: Supply Chain Management, Digitalization, Digital Transformation, Value Networks

1 Introduction

Digital Transformation is imperative for society, economy and politics. The ongoing process of digitalization and the technological developments driving it, equally affect individuals and organisations. From an organisational point of view, this change offers many potentials for improvement at different stages and in different areas, one of these being Supply Chain Management (SCM). Based on the definition provided by Mentzer et al (2001) Supply Chain Management is defined as the management approach concerned with systemically dealing with strategic coordination of traditional business functions and the tactics across these within an organisation and across partner organisations along the supply chain, with the aim of improving long-term performance not only of the individual organisation, but also of supply chain as a whole. Despite this rather elaborate definition of SCM, there are several issues with the notion of "chain". Especially against the background of the current, highly dynamic, increasingly networked and growingly complex, economic environment, the next evolutionary step in the area of digitalization seems necessary. Mentzer's et al. (2001) definition of SCM clearly states the holistic claim of not only focusing on individual companies and chains but also of integrally considering network structures as a whole. The creation of a system-wide total optimum is defined as the aim of SCM. Nonetheless, current Supply Chain Management practices are often conducted in the form of isolated, functional activity blocks and the focus on supply, production and distribution logistics still seems to be the common practice. The traditional view of Supply Chain Management in economic practice is still characterized by the chain-paradigm and the predominant focus on integrating customers, suppliers, partners and OEMs in more or less isolated, sequentially lined up blocks of activities. This approach to SCM has worked more or

less satisfactory in the past, but has increasingly led to problems and inefficiencies in current, increasingly complex economic environments (Strandhagen et al. 2017; Ponte et al. 2018). Significantly increased coordination effort and coordination intensity is just one effect of increased network complexity, which in turn results from higher environmental dynamics and network intricacy. A rising amount and variety of endogenous and exogenous logistics parameters as well as the heterogeneity of their interrelations lead to intricate systems, which e.g. manifest themselves in the form of highly individualized products and services or the growing importance of sustainability related issues. At the same time, higher environmental dynamics lead to shorter life cycles of nodes and edges in enterprise networks. Long proven network structures and relations are no longer stable and are subject to disruptive change and network dynamics (Wehberg, 2016). Traditional SCM approaches and capabilities won't be able to tackle these challenging developments (Kersten et al. 2017; Strandhagen et al. 2017). The shift from a traditional supply chain to a digital Supply- or Value Network-paradigm has already begun (Ponte et al. 2018) and the need for new approaches and the corresponding capabilites is recognized in industry and academia (Hearnshaw and Wilson, 2013; Lee and Vachon, 2016).

Despite the variety and plethora of Supply Chain Management (SCM) research, little attention has been given to actual challenges as well as to concrete key capabilities arising at the nexus of SCM and Digitalization from practitioners' point of view. Hence, the research question underlying this paper is as follows: what are the key capabilities required from an organizational point of view to harness the potential of digitalization in SCMs? Due to the limited availability of comparable, empirically grounded material focusing on practitioners' point of view, the main element of this paper is an empirical study following the methodology presented in section 2

2   Methodology

The research methodology of the paper comprises a set of practitioner interviews and focus-group workshops to collect research needs at the nexus of SCM and digitalization from practitioners' point of view. Focus groups are an acknowledged research technique and have long been applied in various research settings (Brandtner et al. 2015a). Focus group studies aim at analysing clearly defined areas or set of issues (i.e. the focus) by means of group discussions (Stewart et al. 2007, Brandtner et al. 2015b). The interaction between members of a focus group is a central element and source to collect information, which would be difficult or impossible to be elaborated in classic one-to-one expert interviews (Morgan, 2013). Encouraged by a moderator, a small group of people shares ideas and thoughts on open ended predefined questions. A typical focus group, as defined in literature consists of three to twelve participants, depending on the source of literature (Tracy, 2013, Krueger and Casey, 2009).

In the current paper, three focus group workshops where conducted. The first workshop included 2 groups of 12 participants, the second one 11 participants and the third one 10 participants. Each time, different organisations (in total more than 20) where included, ranging from retail, metal industry, automotive sector and IT-sector to logistic service providers, waste management, fast moving consumer goods and infrastructure providers. Hence, a wide range of different industries and service sectors could be included in the focus group study. A senior researcher respectively a professor was responsible for focus group moderation. Additionally, collaborative notes where taken by the moderator and the group using flipcharts and whiteboards. Besides that, a second observer took notes.

The aggregation of results was done based on the qualitative content analysis (QCA) approach proposed by Mayring (2000). The development of a structured coding scheme and the analytic

procedure of QCA further increased the validity of research results and allowed for a category definition as near to the documented focus group results as possible (Brandtner, 2017). The key capabilities were deduced tentatively, were step-by-step revised and where necessary reduced respectively combined. Additionally, the technique of peer debriefing was applied in the course of QCA, which also contributes to research validity (Thomas and Magilvy, 2011).

3 Results of focus groups and interviews

The final list of capabilities derived from the conducted focus groups and interviews is described in the following paragraphs. Each of these represents a potential starting point for adapting existing or developing new capabilities respectively for developing new solutions and deriving new research projects and endeavors:

- **Mapping and analysis of Supply Chain network structures**: This includes the capabilities and tools required to visualize network structures and partners, the relationships between these partners, central players and hubs or the deviations between actual and target states based on control charts.
- **Identification of criticalities in networks**: This includes the ability to evaluate supplier, customer or material criticality in comparison to other network parts or players, to analyse network elements in regard to their vulnerability to e.g. supply restrictions or to evaluate their susceptibility to environmental impacts.
- **Creating transparency in critical network paths**: This includes the identification of blind spots in critical network paths and the resulting need for additional data integration and its realization in the form of e.g. sensor based systems or the identification, development and provision of supporting data analysis methods and tools if existing data is not exploited sufficiently enough.
- **Creating near real-time transparency of physical flows**: This includes the skill-set enabling the identification of conceptual requirements for sensor based solutions applicable to close blind spots in critical network paths and their implementation in defined demonstrator settings, processes or transport infrastructures.
- **Identification of patterns in Supply Chain network and logistics data**: This includes e.g. the analytic know-how required for the identification and analysis of demand patterns, usage patterns, order patterns, transport patterns, storage patterns, damage patterns, seasonal patterns, system patterns, location patterns, service patterns, infrastructure patterns, supplier patterns, customer patterns, pattern-triggering events respectively general similarities & connections in data.
- **Unveiling actual drivers of complexity in SC networks**: Based on e.g. pattern analysis, this includes the capability to identify the actual drivers of network complexity resulting in e.g. out-of-stock situations or the need for express deliveries. It also subsumes e.g. the evaluation of network partner performance based on deeper insight, the identification of critical and non-critical players (customers, suppliers, service providers etc.) adding high levels of complexity, the provision of data based decision basis for deriving network adaption requirements or the quantitative basis for justifying decisions made in the context of e.g. supplier quality evaluation.
- **Analysis and evaluation of alternative reactions to network events based on data aggregation and analysis**: This includes the abilities required for e.g. the simulation of possible reactions to abruptly changed customer demands or seasonal variance, unforeseeable critical events as e.g. earthquakes or terrorist attacks and to possible future scenarios on a strategic network level. In order to enable this, complex

simulation-supporting network models have to be developed and possible measures have to be mapped in suitable optimization scenarios as input source for these models.

- **Enabling predictive actions for future network events**: This includes e.g. the analytical know-how for the prediction of customer demands, seasonal changes or of future bottlenecks in terms of e.g. out of stock or out of transport resources. These predicted future events can either be alleviated by means of e.g. adapting stock levels, transportation resources or changed quantity structures, or they can be reinforced in terms of desired future situations. Possible future events to reinforce could e.g. be the possibility to decrease stock levels or transport kilometers based on e.g. alternative sourcing, warehousing or routing strategies.

- **Evaluation and analysis of use-cases for applicant-distant future SC network technologies**: This includes the technological and SCM-knowledge required for the analysis of radical technologies (e.g. Blockchain or Deep Learning) in regard to their specific application fields in SC network structures, the quantitative evaluation of their impact on SCM key figures and the definition of the specific value added along and across internal and external network stages. Based on clearly defined and evaluated use cases, further decisions whether and at which stages a technology is applicable and reasonable can be made.

- **Strategic roadmapping of future SC network technology implementation**: This includes the strategic know-how for roadmapping the concrete next steps and projects required to create the organisational basis for implementing future network technologies in specific use case settings. Depending on the individual maturity of the respective organisation, this may also include the creation of interfaces at system levels, the adaption of specific process steps in accordance with aimed at improvements or the general organisational willingness to share data in distributed ledger systems.

- **Prototypical development and demonstration of future SC network technology use cases**: This includes the ability to develop and / or adapt new / existing technology-based solutions to specific use cases where implementation requirements from an organisational point of view are already given. The aim of these demonstrator-elements should be to prove the practical feasibility and the economic viability of these still applicant-distant technologies.

- **Identification and evaluation of trend-based implications on SC network structures**: This includes the capabilites required for 1) the identification of disruptive events (i.e. technological trends, socio-demographic trends (e.g. workforce shortage, ageing society, etc.), changing customer demands and service requirements (e.g. product-service bundling, order behavior, lot sizes etc.) or political and environmental trends (e.g. e-mobility, sustainability, etc.)) and 2) the evaluation of the specific impact of these trends in terms of their implications on SC network processes, value propositions, product-service combinations, future criticalities and structural network issues. The result of this should include e.g. quantitatively described scenarios of possible future events and trends with a long-term orientation and their potential, quantified impacts on Value Network design.

- **Definition of strategic scenarios as input for network simulation and optimization**: Based on the trends and disruptive events identified and evaluated in the form of quantitatively described scenarios, this capability block includes the preparation of optimization scenarios for simulation models of network structures. The goal should be to identify the actual, predicted implications of specific trends on complex network systems by taking into consideration critical paths and network key

players. The results of simulation could enable organisations to e.g. evaluate the relevance of certain partnerships (customers/suppliers/service providers), the profitability and reasonability of different e.g. hub locations or warehousing infrastructures or the impact of product-service bundles on strategic and tactical network levels.

- **Identification and conceptualization of potential network adaptions**: This includes the skills to identify strategic action fields based on the scenarios evaluated and tested. Possible results should include e.g. product-service bundling, strategic approaches to customer segmentation based on their network relevance, redesign of supplier network structures, the identification of possible joint-ventures respectively of mergers & acquisitions activities or the simulation-based identification and evaluation of possibilities for outsourcing and integrating third-party logistic service providers.

4 Development of key-capability categories

As explained in section 2, the analysis of results and the aggregation in key capability groups is done based on the QCA approach by Mayring (2000). Additionally, the technique of peer-debriefing (Thomas and Magilvy, 2011) is applied. The following figure provides an overview of the four main key capabilities groups 1) creation of visibility and transparency, 2) advanced data exploitation, 3) strategic consideration of exogenous trends and 4) acceleration of technological transformation and the respective capabilities as presented in section 3:

Creation of Visibility and Transparency	Advanced Data Exploitation	Strategic consideration of exogenous trends	Acceleration of Technological Transformation
• Mapping and analysis of Supply Chain Network structures • Identification of criticalities in networks • Creating transparency in critical network paths • Creating near real-time transparency of physical flows	• Identification of patterns in Supply Chain Networks and logistics data • Unveiling actual drivers of complexity in SC networks • Analysis and evaluation of alternative reactions to network events • Enabling predictive actions for future network events based on data aggregation and analysis	• Identification and evaluation of trend-based implications on SC network structures • Definition of strategic scenarios as input for network simulation and optimization • Identification and conceptualization of potential Value Network adaptions	• Evaluation and analysis of use-cases for applicant-distant future SC network technologies • Strategic Road mapping of future SC network technology implementation • Prototypical development and demonstration of future SC network technology use cases

Figure 1: Overview of key capability groups and respective capabilities

Subsequently, these four key capability groups are described in detail.

4.1 Creation of Visibility and Transparency

According to a recent, large-scale survey with over 600 SC professionals from 17 countries, only 6 % of companies have full visibility over their SC. 15% of participating organisations are limited to internal visibility on the production process only and for nearly two thirds of organisations (62%) visibility is limited to direct customers (ex production to customers) and to suppliers of their suppliers (from suppliers of suppliers to production). Creating SC visibility is one of the top three goals of SCM in 2017 and continues to increase in relevance (Geodis 2017). The focus group and expert interview participants agreed that visibility and

transparency provide the basis for well-informed and data-supported decisions on operative, tactical and strategic levels and is a crucial requirement for firstly data exploitation (in the course of e.g. near-real time route planning, warehouse-management or flexible order fulfilment). Furthermore, visibility and transparency is a prerequisite for better data exploitation (in the course of e.g. the recognition of demand patterns, transport patterns and seasonal fluctuations in a predictive manner or the evaluation and simulation based optimization of SC decisions).

Another finding in this key capability group is that especially smaller structures, as e.g. the Austrian economy (i.e. the country where the expert interviews and focus group workshops were conducted) with its limited resources and volumes (in comparison to other European and global companies), can benefit from increased transparency, visibility and provenance of physical and non-physical flow in SC networks. Being limited in terms of volumes and influence on a global scale, operational excellence (i.e. the efficient and effective usage of resources in network systems and lean SC processes and structures) and strategically aligned focus (i.e. a SC network design with customer focused value delivery and the alignment of general corporate and SC network strategy) are essential prerequisites for competing in future markets on a global scale. Although the implementation of visibility and transparency is a challenging task, the participating companies are aware of the importance of taking up these issues by creating data-based transparency, enabling monitorability of critical network paths and providing the basis for a higher degree of data exploitation in complex SC and logistics networks.

The following capabilities were subsumed under key capability group "creation of visibility and transparency":
- Mapping and analysis of Supply Chain Network structures
- Identification of criticalities in networks
- Creating transparency in critical network paths
- Creating near real-time transparency of physical flows

4.2 Advanced Data Exploitation

Based on the results of the conducted focus group workshops and expert interviews, it was found that not only the level of data utilization across SC stages and networks in current logistics and SCM activities is low, but also the resulting degree of data exploitation. While data utilization in our context is defined as the level of using existing information along SC stages, data exploitation is defined as the degree of generating additional findings and predictive statements and implications based on this data. The utilization of data can be increased through fostering monitorability and e.g. comparing planned and actual flows of goods, information or cash based on control charts. Data exploitation on the other hand requires more complex approaches and more "intelligent" solutions to identify and create additional value added by increased data analysis in the form of e.g. pattern recognition, big data analysis or simulation- and optimization approaches. In accordance with the results of the current paper and also according to other studies, focal technologies, i.e. predictive analytics, pattern recognition as well as simulation-optimization, will play a crucial role in future SCM and logistics (Kersten et al. 2017). The findings of the paper confirm the relevance of descriptive analytics to describe current states of SCs and flows in between them is still high (i.e. data utilization in our context). However, the results also indicate that an additional and even stronger relevance will be placed on additional data analysis (i.e. data exploitation) in

the form of predicting future states (predictive analysis) and of evaluating and simulating possible target states and the measures to reach these states (prescriptive analytics).

The following capabilities were subsumed under key capability group "advanced data exploitation":
- Identification of patterns in Supply Chain Network and logistics data
- Unveiling actual drivers of complexity in SC networks
- Analysis and evaluation of alternative reactions to network events based on data aggregation and analysis
- Enabling predictive actions for future network events

4.3   Strategic Consideration of Exogenous Trends

Besides critical events on operative and tactical level, criticalities and complexity drivers also occur on a strategic level, e.g. in the form of disruptive technologies, changed customer needs as e.g. product-service-requirements, political developments like increased taxes or changed laws, socio-demographic trend as changing workforce or in the form of general megatrends as e.g. e-mobility or same day delivery. Due to increased level of dynamics, short product and process life-cycles or rapidly changing customer demands and needs, most organizations are facing difficulties in systematically handling and managing uncertainty (Brandtner et al. 2014). In general, failures in process, services and product innovation are often due to inefficiencies and weaknesses of organizations to deal with and to contextualize uncertainty. The findings of the conducted focus group workshops and expert interviews confirm the need for new approaches to SCM specifically focusing on uncertainty reduction are needed. Similar to Corporate Foresight in the areas of innovation management and strategic planning (Brandtner et al. 2015b), a "Supply Chain Foresight framework" (processes, methods, tools and responsibilities) with the goal of enabling organisations to establish long-term network foresight capabilities is needed in future SCM. In this context, the results indicate that such a framework would have to include both bottom-up (e.g. operative or tactical, pattern-based events) and top-down starting points (e.g. exogenous trends on strategic level)..

The following capabilities were subsumed under key capability group "strategic consideration of exogenous trends":
- Identification and evaluation of trend-based implications on SC network structures
- Definition of strategic scenarios as input for network simulation and optimization
- Identification and conceptualization of potential network adaptions

4.4   Acceleration of Technological Transformation

Disruptive technologies as e.g. Blockchain (BC), autonomous vehicles, Artificial Intelligence (AI) or Deep Learning (DL) will comprehensively change SCM processes and will trigger a a variety of new capabilites and skills necessary in this context. However, despite the hype of e.g. BC and its potential for improving processes and enhancing new business models, a recent study showed that it is only known to few logistic experts and even fewer plan to implement or think about implementing it (Hackius, Petersen 2017). Same applies to e.g. DL, which is also considered a potential disruptive technology for SCM. As soon as such technologies have adequately matured, their impact will be enormous (Kersten et al. 2017). These challenges and uncertainties in regard to revealing and delineating the potential impacts of disruptive technologies on future SCM could also be confirmed by the results of the conducted focus group workshops and expert interviews. The derivation of concrete use-cases and quantified benefits of these still application-distant technologies and the taking of the first

steps to pave the way for their implementation are critical capabilities at the nexus of SCM and Digitalization.

The following capabilities were subsumed under key capability group "acceleration of technological transformation":

- Evaluation and analysis of use-cases for applicant-distant future SC network technologies
- Strategic roadmapping of future SC network technology implementation
- Prototypical development and demonstration of future SC network technology use cases

5 Conclusion

The findings of this paper indicate that proactively driving the digital transformation of existing Supply Chains into digitally supported networks of Supply Chains instead of just reacting passively to it is amongst the top priorities of Supply Chain Management experts and practitioners. The traditional view of Supply Chain Management with its predominant focus on integrating customers, suppliers, partners and Original Equipment Manufacturers (OEMs) in more or less sequentially lined up and detached Supply or Value Chains will have to shift towards a more future oriented, digital mindset with customer centric, demand driven and holistic networks of multiple Supply Chains in its core (i.e. digital Value Networks). To actually undertake this shift and to conduct the transition from managing traditional, sequentially-lined up and often opaque Supply Chains to digitally connected, transparent and intelligent Value Networks, certain key capabilities and skills are required in the organisations.

Based on the results of the conducted focus group workshops and expert interviews, 13 capabilities were derived and were further condensed to four main key capability groups. These key capabilities represent the main groups of skills that were found to be of relevance from practitioners' point of view at the nexus of SCM and Digitalization: 1) creation of visibility and transparency, 2) advanced data exploitation, 3) strategic consideration of exogenous trends and 4) acceleration of technological transformation. Furthermore, three main domains or areas were found to influence the future of Supply Chain Management: 1) hardware technologies (e.g. sensor systems, microelectronics etc.), 2) software solutions (e.g. Artifical Intelligence, Simulation and Optimization, Pattern Recognition, Blockchains & Distributed Ledgers, Prediction Algorithms, Deep Learning etc.) and most important 3) the Logistics and Supply Chain Management domain expertise to apply area 1 and 2 in Supply Chain Management respectively Value Network Management application fields. The combination of these areas will provide the basis to actually transform existing Supply Chains into digital Value Networks. We introduce the term "Value Network Management" as one possible approach to enable organisations to master future SC networks by combining logistics and SCM domain knowledge with state-of-the-art hardware and software solutions. The substantial contribution of the papers is the described set of key capability groups, which were aggregated based on practitioners' needs. These groups, the single capabilities and their descriptions represent the basis for deriving specific future research projects from a scientific and for developing a strategic project and skill development-roadmap from practitioners' point of view.

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Physical Internet: Overcoming barriers and learnings from other networks - 11th July 2019 13:30 – 15:00

Would the Physical Internet Deliver in Poor, Deprived Areas?

Would the Physical Internet Deliver in Poor, Deprived Areas?

Patricia Assen, Bart Louwerse and Nick Szirbik

university of groningen
faculty of economics and business

Introduction

People living in favelas are buying their food locally, from small family stores – called by researchers "nano-stores" (Fransoo et al, 2017). Most of the food sold by these nano-stores is prepackaged food, of low nutritional value, and very unhealthy if consumed exclusively.

There are a number of constraints and difficulties for the favela's population to buy fresh produce (dairy, fresh meat, eggs, green veg, and fruit), like:
- Need to leave favela and visit open markets;
- Limited offer of products ;
- Transportation by local small transporters with improvised vehicles from the DCs to the nano-stores;
- Lack of adequate (or any) public transport infrastructure to go outside the favelas to buy.

Paradoxal situation – favela inhabitants pay more for food than the rich neighbours:

Most of the current research is empirical and not normative → causes and punctual solutions.

We need a system design based on advanced concepts in logistics → exploring the problem, the context, the stakeholders, the requirements, functional, physical and operational architectures.

- Fransoo, J., Blanco, E.E., & Mejia Argueta, C. (2017). Reaching 50 million nanostores: retail distribution in emerging megacities, CSIPP, Cambridge.

PI micro-hubs and their use in favelas

The PI concept is not yet fully investigated from a problem-solving-via-a-system-design perspective, and there are still serious gaps in the overall vision for this concept – even more those related to food and especially fresh food shipments.

- Expected that all PICs reach the geographical point of use of the supplier and the consumer.
- This is impractical for favela nano-store shipments:
  - Smaller size;
  - Transportation;
  - Security;
  - Economics.

To be investigated: the design of a PI-oriented system that always uses PI micro-hubs as intermediate fresh food staging between the DCs and the nano-stores.

- Basis for a micro-hub concept:
  - Expand the PI architecture with the City Logistics Smart Rack (CLSR)
  - Nowadays: shipments are brought by suppliers to a Smart Rack, encapsulated and authorized transporters take to the consumers.
- Innovation proposed by Montreuil (et al, 2016), and expanded by Faugere (and Montreuil, 2017):
  - Combine the rack with PICs;
  - Issues with the weight carried (the containers have to be secure from break-in);
  - Special secure location for the containers (inside or outside the favela);
  - Encapsulation and decapsulation by an authorized intra favela transporter.
- Micro-hub concept (based on CSLR)

- Favela oriented
- Empty container
- Not carried to the final point of use
- Final consumer by from nano-stores

- Faugere, L., & Montreuil, B. (2017). Hyperconnected Pickup & Delivery Locker Networks, Proceedings of the 4th PI Conference, Graz, Austria.
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An operational scenario to deliver food via PI in favelas

This scenario assumes that some form of PI is already in existence, outside the last mile segment for this particular situation.

1. Information about demand is constantly gathered by the micro-hubs from various sources;
2. Perceived demand (product/quantity) - ordered by a favela micro-hub and delivered in a PI container (s);
3. Supplier packs and requests transfer from the envisaged PI global system;
4. PIC matched to the shipment - the PIC informs directly the supplier and micro-hub about the preliminary timing of the events;
5. PIC arrives at the supplier location (filled and sealed). Departing transport is pre-arranged;
6. PIC is transferred through the PI network, until it reaches the final DC before being sent to the micro-hub;
7. Transport for the PIC (consolidated if possible) is arranged to transfer it from the DC to the micro-hub;
8. Security for the transport towards the micro-hub is also arranged (necessary if the micro-hub is inside the favela);
9. The secured transport is effectuated from the DC to the micro-hub;
10. The micro-hub empties (decapsulates) the shipment, preparing the goods to be transferred to the FiTs (Favela-intra-Transporters);
11. The last mile is executed by the FiT (picks the goods from the micro-hubs and distributes them to the nano-stores;
12. After being emptied, the PIC can pursue its next task, and it is brought back in the PI flows by the departing transport from the micro-hub (and eventually nano-stores);
13. Some PICs, after emptied, may remain (sold by their owners - in the favelas, playing various roles (housing, storage, cold storage, power units, etc.)) - older PICs that are near retirement.

This scenario does not include the usage of the PIC as a temporary stocking unit, from where the micro hub can decapsulate only parts of the shipment, repeating the procedure until the container is emptied.

Assumption: the micro hub is a JIT (just in time) hub, where we want that the containers stay as shortly as possible (they are emptied as quickly as possible). If storage is required, PICs can be sold by the owners, and became (e.g. cold) storage points.

Conclusion

In Systems Engineering, there are two approaches to assess, test, and validate a complex novel system – like the envisaged PI. The PI claims to achieve global coverage and be affordable for everyone. A simple representation of the functioning envelope of the PI would be defined by two variables: coverage, and economic level of development. A cautious, but rather shielded approach to the current validation of the PI concepts is to start the system working in the areas of this functioning envelope where infrastructure exists and it well established and the economic performance is strong. As design researchers, we position ourselves differently, and we start to design the PI from the fringes of the functioning envelope, where the coverage/infrastructure is weak and the economics and safety/security are poor.

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The bumpy road to the adoption of the Physical Internet – Overcoming barriers from a stakeholder perspective

Tobias Meyer[1] and Evi Hartmann[2]
1. Friedrich-Alexander-University Erlangen-Nürnberg, Nürnberg, Germany
2. Friedrich-Alexander-University Erlangen-Nürnberg, Nürnberg, Germany
Corresponding author: tobias.t.meyer@fau.de

Abstract: The Physical Internet aims for a paradigm shift by eliminating the unsustainability issues in today's supply chain processes. The development of the concept in recent years has shown that the PI is still in its conceptualization phase. In order to increase the attention and adoption of the concept both, in literature and practice, empirical knowledge is needed concerning how and why affected stakeholders will adopt the concept. To address this gap, we gathered qualitative data through a single embedded case study approach. In total, we have integrated 14 stakeholders with verifiable expertise in the PI. The sample consists of logistics and transport service providers, shippers and includes companies selling or working on specific PI-products. Furthermore, we gathered empirical data from research institutes with specific knowledge or projects in the PI. This paper provides insights about the adoption of the PI and in particular about stakeholder intentions, organizational and technological readiness as well as barriers and drivers.

Keywords: Physical Internet, Case Study, Open networks, Drivers

1 Introduction

Driven by increasing global freight transportations and demanding stakeholder requirements, organizations are forced to rethink current value chain configurations and to design the handling and usage of physical objects economically, environmentally and in a socially sustainable manner. Today's logistics are responsible for approximately 7% of global greenhouse gas emissions, caused by fossil fuels burned for road, rail, air and sea transport (Stern, 2008). More than 20% of these transportations are caused by trucks running empty, resulting in significant inefficiencies of costs and emissions, which make logistics highly unsustainable (European Commission, 2014).

The Physical Internet (PI) aims to address these sustainability issues by combining and aggregating single logistics networks into one global logistics network, which integrates physical assets, such as hubs or containers, and human or organizational actors (Montreuil, 2011). The PI can be understood as a concept that defines the way, how physical goods or objects are moved, handled and delivered from the source to the destination. The PI thereby differs from the way today`s logistics processes work in three key aspects. First, physical goods are transported in standardized and modular PI-containers instead of in individual packaging. Second, PI participating companies share and use all existing production facilities, hubs and distribution centers for the realization, storage, and transshipment of goods. In the PI, this refers to the openness of the PI-nodes. Third, the routing of the PI-containers from source to destination is executed by the PI-movers in an intermodal way from one PI-node to the next with multiple load transfers in between. Simulations have shown considerable benefits from

these changes for individual companies and for the whole network in terms of supply chain visibility, security, agility and sustainability, while at the same time, cost reductions through increased capacity utilization and high customer service levels (Montreuil et al., 2012a; Fazili et al., 2016; Sarraj et al., 2013).

The idea of the PI is based on the digital internet, which brought a reconceptualization to the worldwide information web through its transparent interconnectivity between networks and nodes in an open network structure (Montreuil, 2011). By transforming the way information is routed through the digital internet to the way physical objects are routed through the PI, a system is created that focuses on the interconnectivity of universal physical, operational, digital and business elements (Montreuil et al., 2010). In such networks, resources like transportation assets, hubs, and containers are shared along the supply chain (Sarraj et al., 2013).

Within the PI, intermodal transportation can be applied more efficiently. While current transportations mainly follow point-to-point transits, the PI enables to split the transport at the PI-nodes to re-decide on the most time efficient, economic efficient and environmentally efficient way to route the products (Lin et al., 2013; Montreuil et al., 2015). This decentralized route planning allows consolidating shipments at each hub (Pach et al., 2014). Today, shipper and logistics service provider plan transport routes, delivery time and supporting services like track and trace in advance and agree upon them by contract. In the PI, the planning process is outsourced to the PI network, which in turn is responsible for allocating PI-containers to the respective transport mode on short notice (Montreuil et al., 2013; Meller et al., 2013; Ballot et al., 2013; Walha et al., 2016).

The PI received high interest from researchers and practitioners alike during recent years (Sternberg and Norrman, 2017). Previous research focused on the description of a perfectly implemented concept and its positive effects, without emphasizing practical, theoretically and empirically grounded experiences of the PI (Pan et al., 2017; Sternberg and Norrman, 2017; Treiblmaier et al., 2016). It leaves fundamental questions regarding how and why companies should change their current processes towards the way the PI concepts describes them unanswered. For this paper, we define this transformation process as the adoption of the PI by participating stakeholders.

Considering the various stakeholders who are affected by the PI and the necessary changes regarding supply chain processes and structures, questions arise as to why companies drive for the implementation of the Physical Internet and how the integration of the concept in current business models will occur. Empirically grounded answers for these questions have so far not been investigated (Sternberg and Norrman, 2017). Due to the novel nature of the concept and its practical relevance, we use an exploratory single embedded case study approach to build knowledge on stakeholder intentions and changing supply chain processes and structures. This approach allows us to gain insights from different stakeholder groups, who are all vital for the development of the PI.

Following the adoption model, as it is used by Sternberg and Norrman (2017) for the PI, we focus our research on the perceived benefits as well as organizational readiness of relevant stakeholders in regard to the PI. The application of this model on relevant stakeholders serves as the basis for our study. Stakeholders which are directly influenced by the PI in their supply chain or business model can be classified into three groups, which are providers (carriers, storage facilities), enablers (freight forwarders, who often include carriers acting as integrators), and shippers (user, manufacturer) of logistics services (Crainic and Montreuil, 2015). Within this study, we combine enablers and providers of logistics services into LSPs, as they often integrate forwarding as well as carrier and warehousing services into one business.

Furthermore, we distinguish between existing LSPs and companies that recently started to build up PI-products such as software or hardware solutions, which sometimes also have a second business within the provider or enabler environment. Since current efforts in developing an implementation roadmap to further support the adoption process are primarily conducted by researchers, we also integrate researchers into our study.

As a result, we emphasize companies' perceived benefits as well as their organizational and technological readiness. In addition, we contribute by working out barriers relating to new supply chain management and leadership structures in the PI. We found that shippers will have the highest interest for the realization of the PI and that they will force logistics service providers to adapt their business models accordingly. On the other hand, we depict a change of mindset within the organizational readiness of companies combined with unsolved issues regarding network responsibilities and leadership as main barriers for adoption.

The remainder of the text is structured as followed. First, we present our single embedded case study methodology. Subsequently, we describe detailed findings from our analysis regarding drivers, organizational and technological readiness as well as barriers for the adoption of the PI. The paper ends with a concluding discussion, implications as well as limitations and a further research agenda.

2 CASE STUDY METHOD

The lack of a clear roadmap for the adoption of the Physical Internet requires a broad and deep investigation of stakeholder intentions. Current studies focus on conceptual frameworks without emphasizing economical and practical needs for affected stakeholders to accelerate or hinder the adoption of the PI. The shows a high degree of uncertainty that requires multilateral examination. In line with this purpose, we, therefore, opted for an exploratory embedded single case study approach, as the situation being evaluated has no clear, single set of outcomes. The case study method can provide insights into the early phases of research and practical backgrounds while maintaining a holistic view of the phenomenon (Yin, 2014; Eisenhardt, 1989). Moreover, in particular for upcoming topics that lack practical penetration and grounded theory, case study research allows one to integrate and react spontaneously to upcoming themes and to explore key variables and their relationships (Yin, 2014).

5.1   2.1 Study design

In our study, the PI is the investigated phenomenon in the context of the logistics industry. We, therefore, collected information from various industries and academics as embedded units of the PI case. Since our purpose is to contribute to the adoption of the PI, the case itself is the main area of interest. To avoid biases we grounded our research on a clear methodology based on Gibbert et al. (2008) and Yin (2014) in regard to construct validity, internal validity, external validity and reliability throughout our study design, case selection, data gathering, and data analysis. Based on the conceptual framework, we first interviewed key informants from various stakeholder groups and integrated further units in a second step until we felt that we had collected sufficient data in each stakeholder group and that additional interviews would not reveal further information. This approach enabled comprehensive insights while increasing construct and internal validity to reach theoretical saturation (Eisenhardt, 1989; Strauss and Corbin, 1998). In total, 14 interviews were conducted with academic experts from universities and research organizations and with industry experts from logistics service providers, PI-product firms, consumer good and automotive companies, and intralogistics firms. The semi-structured interviews lasted 45-90 minutes and were all conducted via online conferences between January and March 2018 by the same two researchers. Each interview was recorded

and transcribed with consent before they were sent back to the interviewees to eliminate misunderstandings and give them the opportunity to further integrate thoughts (Yin, 2014). To further increase construct and internal validity, we analyzed multiple sources of evidence by triangulating interview data with secondary data from company presentations, company reports and trade publications to build up a case study database (Yin, 2014; Gibbert et al., 2008). However, secondary data did not reveal additional information, but confirmed interview data. The presented results are therefore based on the interviews.

5.2 2.2 Case selection

Grounded on the exploratory nature of our study, we applied the diverse case method (Seawright and Gerring, 2008) by integrating a high variance of stakeholders to gather exhaustive data along the relevant dimensions of the PI, as guided by the previously developed framework. That firstly includes the logistics and transportation category as the industry most affected by the PI through infrastructure changes and horizontal collaboration (*Alpha*). The interviewed companies in this section are providers of transportation, in-house logistics, and forwarding solutions. Second is the shipper industry, where we interviewed manufacturers from retail and the automotive industry (*Beta*). Third, are companies that had already started to invest in the PI with self-developing or producing PI products or software (*Gamma*). And fourth are independent researchers and organizations who actively work on the PI in terms of concept, product or business model innovations (*Delta*). The four selected dimensions represent a broad range of categories characterizing individual PI stakeholders and specific relationships between those stakeholders (Seawright and Gerring, 2008). Within the categories, we opted for homogeneity and chose units that are typical of each category. However, given the prerequisites regarding existing firm sizes within the categories, the units differ across the categories. In categories *Alpha, Beta,* and *Delta*, we focused on large firms and institutions, as they are particularly appropriate when a phenomenon is new (Koufteros et al., 2007), especially as they are more likely to have the resources and capabilities to invest in this new concept. In contrast, in category *Gamma*, start-ups and small companies have, until now, dominated, making them the focus units for this category. Due to the fact that these companies are often specialized in one single PI product or software, theoretical saturation occurred after a higher amount of cases, compared to the other categories. In each company, we purposively interviewed individuals in senior management levels with background knowledge of the observed topic demonstrated by previous publications or interviews. To ensure anonymity of the interviewees and companies, we used Greek letters as company names. Table 2 gives an overview of the interviewed cases and their characteristics.

We interviewed experts from seven different countries from Europe and Canada. This data allowed us to create a holistic picture of the PI concept, identifying drivers for adoption, but also barriers that need to be overcome.

Table 18: Overview of interviewed case units

Category	Unit	Industry	Company Size*	Country	Informants' job title	Integration of PI in processes	Member ALICE
Logistics / Transport Service Provider (Alpha)	A$_{Alpha}$	Forwarder / Carrier	Large	Germany	Business Consultant	Strategy; Pilot projects	No
	B$_{Alpha}$	Forwarder / Carrier	Large	Austria	Head of Innovation	Innovation	Yes

	C_{Alpha}	Intralogistics	Medium	Austria	Head of Product Mgmt.	Innovation; Pilot projects (urban hubs)	No
Shipper (Beta)	D_{Beta}	Automotive	Large	Germany	Managing Futurist	Strategy; Pilot projects (routing, transshipment)	Yes
	E_{Beta}	Consumer goods	Large	Belgium	Futurist and research fellow	Strategy; Pilot projects (intermodal transport, collaborative logistics arrangements)	Yes
PI-product companies (Gamma)	F_{Gamma}	Transport and Logistics Consultant	Small	Norway	CEO	Freight consolidation and collaboration system/software	Yes
	G_{Gamma}	Packaging	Medium	Belgium	Product Manager	Modular packaging; observations	Yes
	H_{Gamma}	Trailer	Small	Canada	CEO	Trailer prototype	No
	I_{Gamma}	Logistics Software	Small	Austria	Senior Consultant	Simulations	Yes
	J_{Gamma}	Logistics Software	Small	France	CEO	Warehouse matching platform, information bundling	No
	K_{Gamma}	Trailer	Small	Canada	CEO	Trailer prototype; Freight consolidation platform	No
Researcher (Delta)	L_{Delta}	Logistics / research institute	N/A	Germany	Department Head	Research; Observations	Yes
	M_{Delta}	Logistics / research institute	N/A	Germany	Strategic Researcher	Research; European pilot projects	Yes
	N_{Delta}	Logistics / research institute	N/A	Norway	Strategic Researcher	Research; European pilot projects	No

* Small companies: employees: 0-100, revenue: $0-$10 million
  Medium companies: employees: 100-1000 revenue: $10 million - $1 billion
  Large companies: employees: >1000, revenue: >$1 billion

3 ANALYSIS AND DISCUSSION

5.3 3.1 Description of interviewed units

All interviewees had previous knowledge or experience with the concept of the PI for over two years. Eight units are members of ALICE taking part in regular workshops or pilot projects. Six units had previously participated in one of the International Physical Internet Conferences. Although we addressed companies that are aware of the PI in particular, the study showed a broad awareness rising with key industry players, who already deal with the concept. All interviewees stated that the PI will affect global supply chain management processes during the next few years and they are confident that logistics will develop towards the PI. However, the level of adoption is still low, as research and pilot projects are the dominating level at which the companies integrate parts of the PI into their processes.

Within the interviewed logistics and transport service providers, the PI is mainly integrated into overarching departments, such as strategy or innovation, to search for business cases and possible application fields. Only one provider of intralogistics infrastructure and services started with a pilot project by building urban hubs to consolidate freight, before it is transported to customers in the city. The main activities of logistics and transport service providers focus on market observations, whereby special attention is paid to actions taken by shippers towards the PI, as company B_{Alpha} stated:

> We observe the whole topic of the PI, to determine what the shippers are doing in this direction [...].

They all report that the transport industry is highly cost driven and that the PI will only have a chance to be widely adopted if there is a positive cost-benefit relation. They state, that the claimed benefits of the concept need to be proven by pilot projects or simulations before broad adoption of the concept will take place within the logistics industry. The LSPs are convinced that logistics will develop towards the ideas connected to the PI but are careful with new concepts, especially when these concepts target their way of doing business. They, therefore, place themselves in a rather reactive position instead of leading the adoption process.

Interviews with shippers from two manufacturing industries showed that there are already pilot projects in place dealing with the routing and transshipment in the PI as well as with intermodal transport solutions and collaborative logistics arrangements. However, in both companies a deeper integration from the strategy department into operative processes has so far not been possible, as internal barriers hinder a faster adoption:

> It is difficult to persuade the management of the Physical Internet idea, as by 2050, when ALICE expects a complete implementation of the concept, only a few of the current managers will still be in the company.

Within the PI-product category, three companies (H_{Gamma}, $J_{Gamma,}$ and K_{Gamma}) solely work on products that are designed for the PI. The other three companies developed software or container solutions as a part of their daily business focus, such as consultants or software provider. These solutions deal with freight consolidation and cross-industry collaboration software (F_{Gamma}, I_{Gamma}) and modular packaging (G_{Gamma}). All PI-product companies had previous experiences in the logistics industry, where they identified several inefficiencies regarding capacity utilization in transport and warehousing. In order to eliminate the inefficiency, they either founded startups or implemented new products or software within their companies.

In the research category, we interviewed three logistics institutes. Two of these institutes work closely with ALICE in various pilot projects in order to test theoretical concepts in a practical environment. Their goal is to reach a consensus between industry partners and researchers.

Therefore, all researchers state that it is essential to implement parts of the concept in real-world environments in order to analyze the effects and benefits of the PI on relevant stakeholders. To support this approach, we asked all interviewees about the perceived benefits which drive them to adopt the PI.

5.4 3.2 Drivers for the adoption of the Physical Internet

The adoption of the PI is highly dependent on the perceived benefits each stakeholder earns from an implementation of the concept into their own supply chain processes. We found that large logistics service providers are already aware of the concept, but act reactively to the implementation efforts of shippers rather than proactively opting for pilot projects or business case developments themselves. In contrast, all interviewees consider shippers to be drivers for the PI, as they can expect the biggest benefits from the concept. From the customer view, shippers of products are responsible for fast and secure deliveries. Furthermore, it was stated that customers increasingly demand additional services, such as complete visibility of shipments through track and trace. In line with the claimed benefits of Montreuil et al. (2012a), Fazili et al. (2016) and Sarraj et al. (2013), our study confirms improved visibility, agility and security as well as lower costs and improved sustainability as advantages of PI processes, which would directly increase customer satisfaction. To meet increasing customer expectations, shippers continuously optimize and integrate additional services into their supply process. In order to do so, shippers have to forward customer wishes to the operators of logistics services. However, all interviewees of the category *Beta* declared that the adoption of such services by the operators entails long negotiations and new contracts while changing customer requirements are demanding a dynamic negotiation process. In contrast to this, the interviewees expect significant improvements through the PI, as its open structures allow shippers to have better access to different LSPs and their services. Subsequently, the interviewed shippers see the PI as a concept, which directly improves their supply chain processes, increases customer satisfaction and reduces efforts to access additional services from carriers and other providers of logistics services. Interviewee N_{Delta} even states:

> *The clients of logistics service providers are playing an important role because they are forcing them to change. The shippers are actually forcing the forwarders to change.*

However, also LSPs and in particular PI product companies outline benefits for their processes in the form of higher efficiencies and reduced costs.

As outlined before, the initial aim by implementing the PI is to solve the unsustainability issues in logistics. However, while shippers pointed out that their customers demand an improvement of the ecological and social sustainability in the transportation process, none of the interviewees stated that these sustainability components would be a reason for them to adopt. All reported benefits relate to an improvement in cost or revenue efficiency. The PI, therefore, has to have an economical short-term benefit for the stakeholders in order to convince them to adopt. This economic benefit can result from increased customer satisfaction or new business models generating additional value.

All interviewees reported that the PI attacks the business model of logistics service providers as it works today. Within an open and shared network, LSPs fear to lose customers, networks, and infrastructure as a competitive advantage, as it would allow other providers of logistics services to use the given infrastructure. Moreover, the global consolidation of shipments in the PI combined with a central allocation of those shipments to carriers and warehouses would take over the transport and storage planning process of LSPs, leaving only the physical handling of the products to generate revenues. However, the interviewees also pointed out that the physical

transport is more efficient in the PI, as empty running is reduced and resources are better utilized, which can be confirmed by the PI-product companies, whose solutions are already in use. Through convertible trailers company H_{Gamma} was able to reduce empty miles in their fleet from 40% to less than 5%. Moreover, F_{Gamma} invented a platform, which intelligently consolidates freight and reduces herewith the number of trucks along the main run of the transport. Through this process, they were able to increase the load factor of different LSPs from 45% to 90%.

Nevertheless, especially transport service providers (*Alpha*) point out that, in the future, transportation and product handling will not be the main source of income anymore. Instead, additional services will become increasingly important. In this context, the interviewees predict that, in the PI, the fight for customers will not be decided by the price, but rather by the services a company offers. The newly gained visibility allows companies to gather extensive data on the transportation process, which companies can use to offer additional services to their customers. The interviewed providers of logistics services unanimously see herein new business models that need to be adopted. One logistics service provider states that considering the PI as an attack on their business is too close-minded, as possible potentials are often unseen. They feel certain that the way revenues are generated today will change and that they need to adapt their business model respectively. For instance, they see new services in the analysis of loading data for trucks. The optimization of this data leads to more efficient packing of products within different transport modes. Moreover, the analysis of transport data combined with technological developments within the fields of big data and predictive analytics facilitates new service offerings for supply chain risk management. Thereby, hazards and disruptions in the network are anticipated at an early stage to allow for the reorganization of material flows in advance.

Based on the various new services, the interviewees expect a distributed value creation in the PI with infrastructure providers, providers of physical tasks, such as for transportation and handling of products, and special service providers to enable visibility to use the generated data. All interviewees predict a transformation of their business model, rather than an elimination. However, even though the logistics service providers outline benefits by offering additional services, they so far only react to developments without actively testing or implementing new business models. The possible perceived benefits, which global LSPs can gain from a transformation of their physical business models to digital business models, currently stand in contrast to the fear of losing their competitive advantage in the form of their customers, their infrastructure and particularly their global transportation and warehouse network.

As most of the interviewees point out, it is important to distinguish between different LSP companies. While big providers of transportation services fear to open up their international networks, small LSPs can benefit from a shared infrastructure. These LSPs are often limited to local network structures, which is why shippers often prefer big LSPs in the allocation of shipments. An open network would allow small LSPs to reach distant customers, increasing their volume of transportations and making competition with big LSPs possible. Moreover, our study shows that LSPs profit the most from higher capacity utilization of their trucks, as small internal volumes often not allow for consolidating freight efficiently. The growing number of small LSPs in organizations like ALICE and as participants of the product provided by the PI product companies confirms the high motivation of these companies to be part of a shared and open network. Accordingly, most interviewees see them as the pioneers for horizontal collaboration and the adoption of the concept.

The adoption constraints of big LSPs and the benefits that drive small LSPs to implement a shared network indicates that the implementation of the PI will follow a hybrid concept, rather

than a global and complete implementation within a short time. Only one interviewee expects an implementation of everyone at the same time. The perceived benefits accelerate the adoption of horizontal collaboration and the development of shared networks between small LSPs, leading to a partial implementation of the PI. The developed network works as a new business model in itself, competing with the closed networks and business models of global LSPs. Within this business model innovation, additional value is created for customers through increased visibility and sustainability as well as lower costs.

5.5   3.3 Organizational and technological readiness

While perceived benefits motivate organizations to change their way of doing business, companies also have to be ready in terms of organizational and technological readiness to adopt an innovation. All interviewees stated that there are several barriers in the logistics industry hindering the adoption process. They reported that changes within their companies take time due to traditionally grown habits. The transformation of their businesses to the PI requires a broad cultural change, which reportedly scares employees as well as the management within the logistics companies. Most of these companies are still not involved in innovations to change the way they are doing business, as the CEO of company K_{Gamma} states:

> It is tough to change a traditional industry in which people are used to 100-year-old habits, where everybody runs around doing the same old thing because that is what worked yesterday, instead of looking in the future to come up with better ways of to do things.

A change of mindset to overcome traditionally grown habits in terms of collaborating with other companies is therefore needed as a first step to adopt the PI. The interviewed shippers and PI product companies in particular rate the change of mindset as the biggest barrier, which needs to be overcome before the adoption of the concept can occur.

In addition to organizational readiness, technological readiness is required for the adoption of an innovation. We asked all interviewees about technologies that are needed for the implementation of the PI in their business environment. All interviewees agree that new innovations are not required from a technological perspective. Information technologies, algorithms and warehouse technologies for the transshipment of containers are already in place. However, the interviewees also stated that the adoption penetration of these technologies has to expand throughout the industry. Several companies still need to adopt technological innovations in order to allow communication between production, warehouses and transport facilities. In this context, the interviewees rate the expansion of sensor technologies (RFID) in combination with the Internet of Things (IoT) as the most important enabling technology. Another technology which is seen as a fundamental component in the literature to make the PI possible are globally standardized and modular combinable containers. These containers were contentiously discussed in the interviews. While shippers rate the containers as a necessity to enable the secure handling and protection of their products, providers of logistics services and researchers think that standardized containers would make the implementation of the PI unnecessarily complicated. They argue that the containers themselves are not required to bundle shipments and to enable fast transshipment in hubs. Moreover, broad adoption and harmonization of the containers are costly and time intensive. Improvements in automated loading and transshipment of variable packages or even single products allow the adoption of the PI idea without the help of standardized containers. Accordingly, standardized containers would be advantageous to reveal the full potential of the concept, however, the majority of interviewees agreed that the PI can be successfully implemented without a global standardization of containers.

5.6   3.4 Barriers and changing supply chain processes

In today's supply chain processes, LSPs have a direct relationship with shippers, to whom they are offering their services. The PI changes this relationship between shipper and LSP, as the PI network coordinates the allocation of shipments and additional services to the provider of those services. LSPs and shippers, therefore, lose their direct relationship, which alters the way services are offered and the way value is created. The configuration of creating value for customers shifts from a direct value creation based on a contractual agreement to a distributed value creation within a network. This circumstance raises questions about the configuration of this value network, which includes the management of the PI, the way services are offered and rewarded as well as the contractual, liability and ownership conditions. To gain insights into the effects of a distributed value creation network on the logistics industry, we asked the interviewees to what extent their supply chain management processes change within the PI. This way, we were also able to analyze risks that occur along the adoption process, mainly within the management of the PI network.

LSPs, in particular, anticipate broad changes within their processes, as they expect to lose the planning process of transportation routes and shipment allocation to the PI network. Shippers and LSPs both describe the planning process of transportations as very time intensive, due to long negotiations regarding transport routes, prices, and additional services. The PI, on the other hand, requires fast and dynamic planning of transport routes as well as container or product allocation to the respective transport mode. Only this way, the PI can assure the efficient utilization of capacities within trucks, aiming for a reduction of the total amount of trucks on the road and increased sustainability. Transportations are therefore no longer planned on the basis of a contractual agreement, but rather are dependent on the efficiency that can be achieved through an optimal allocation of shipments. The process changes from static planning, where shippers book a fixed set of services from end to end, to dynamic planning, in which the PI network spontaneously decides the process. On the one hand, this requires trusted algorithms that plan the transport process within a short time after the shipments arrive in the hubs, as interviewee L_{Delta} states:

> *[…] the customer has to have confidence in the algorithms, that the products reach their destination within the expected time. The problem is that customers always have to worry that their shipments do not get the regard and priority which they expect or need.*

On the other hand, shippers no longer know who is handling or transporting their products. Therefore, shippers fear to lose a contact person who can be held responsible in case of disruptions and delays within the transport process or in case of product damages during handling. The interviewees are concerned about giving up control over their shipments and losing the ability to interfere in the transport process, as service providers change frequently. They describe the PI as a black box, even though they have complete visibility over their processes.

The PI will be responsible for allocating shipments to the service providers, which fundamentally alters the supplier-customer relationship as it works today. LSPs no longer offer their services directly to their customers (shippers). Instead, the value network changes, as all providers of logistics services, such as carriers or warehouse providers, offer their services to the PI or the manager of the network. Providers of logistics services will therefore only have a contractual relationship with the PI, which in turn decides who will be part of the network. Almost all interviewees state that there will eventually be one instance responsible for managing the PI. Currently, there is almost no literature on this topic and hardly any project or company has been dealing with the question of power and leadership within the PI. This

uncertainty unsettles the interviewed companies, especially the LSPs, as they fear giving up all the power to one organization. Out of 11 interviewees who talk about the leadership conditions within the PI, only F_{Gamma} and K_{Gamma} imagine that the leadership will be in control of a public or non-profit organization. All other interviewees are certain that one stakeholder or company will excel and manage the PI. The interviewees agree that the management of the PI will be in the form of a platform, similar to already existing digital freight matching platforms, which bring together shippers of products and carriers with free capacities. In the PI, one platform would be responsible for the allocation of shipments and could therefore directly influence which provider conducts which transport. The provider of the platform could become very powerful, leading to monopolistic conditions, as interviewee C_{Alpha} states:

> If the thought of the PI becomes reality [...], it has to be decided if people want one company managing the PI. One big company as the leader would create a huge monopoly. Smaller carriers would not have a chance anymore if they do not serve the platform.

The interviewees agree that a company with the ability to manage and develop such a platform will become the leader. Five interviewees independently name Amazon as a potential manager of the network. According to the interviewees, Amazon is currently not satisfied with their logistical contractors, conditions, and performance. Thus, they work and invest in logistical assets themselves. Combined with the IT knowledge from their main business (platforms) Amazon currently has the highest chance to take up that role, as F_{Gamma} states:

> If Amazon continues to grow without any competition, then they end up being the network.

Other interviewees argue that one of the big freight forwarders will eventually manage the network and explains that there are already companies who drive for this position. Those companies have a strong motivation for the fast adoption of the PI. However, as long as governance models of the PI stay uncertain, companies fear that the concept would become monopolistic, which stands in clear contrast to a shared and open concept based on horizontal collaboration, as it is presented in the PI. Therefore, a solution has to be found which fairly and trustfully allocates shipments and services to the respective providers. Only in this way could stakeholders be motivated to further drive for the adoption of the PI. Most interviewees see standard protocols that clearly define how shipments are allocated and how new providers can join the network as part of the solution to prevent the PI from becoming monopolistic. However, bundling of processes still requires a database or platform where incoming shipments are consolidated, processed and further routed.

Another barrier emerging from the changing value network in the PI deals with the rewarding of logistics services in such a network. So far, there is no clear description as to how different service providers are rewarded for their services. While interviewees confirm standard protocols as a prerequisite for solving this problem, they also state that there has to be a technological solution managing this process. Since service providers do not have a contract with shippers, the PI as a network needs to reward their services.

The unknown responsibility and leadership conditions within the PI network are rated as key barriers by all interviewees for the adoption of the PI. Moreover, next to the presented possibilities for stakeholders to create value through a change of their business models within the value network of the PI, a solution is needed to prevent monopolistic structures. The interviewees expect this to be changed through additional business models in combination with standard protocols. Four interviewees also see upcoming distributed ledger technologies, such as Blockchain, as a technological solution for several barriers within the PI. They anticipate

that Blockchain could enable trustful and secure data sharing between competing companies. Moreover, as Blockchain technology makes middlemen in certain processes unnecessary, the interviewees predict potentials for the decentralized allocation of transportations, which could eliminate the single leadership by a centralized platform.

In an innovation adoption context, questions about responsibilities and leadership need to be answered in order to drive stakeholders to further adopt the concept. In this regard, it is necessary to define stakeholder roles and establish business models or technological solutions dealing with trustful and fair conduction of processes.

4 CONTRIBUTION, IMPLICATIONS AND FURTHER RESEARCH

Based on an embedded single case study, we investigated the adoption process of the PI by relevant stakeholders from an innovation adoption perspective. We interviewed experts from logistics service providers, shippers, PI product companies and researchers to gain insights into the perceived benefits of stakeholder groups adopting the PI as well as current organizational readiness to implement the concept. Since current efforts in investigating the PI phenomenon are lacking in terms of empirically grounded research, our findings are valuable for both scholars and practitioners.

In the analysis of our case study, we outline several drivers regarding perceived benefits and new business models, which currently motivate relevant stakeholders to adopt the PI. On the other hand, we reveal fundamental barriers within the organizational readiness as well as concerning responsibility and leadership conditions.

From a managerial perspective, our study shows that adopting the PI is valuable for shippers, small logistics service providers, and PI product companies, as higher visibility and open network structures result in improved flexibility, higher capacity utilization and lower costs. Shippers can, therefore, better meet customer expectations while increasing the ability to easily access additional services from various service providers. Moreover, an open network allows smaller logistics service provider to reach customers globally while allowing the possibility of competing with the closed networks of large LSPs. Additionally, the identified change of mindset is a requirement for the adoption and therefore essential for stakeholders to pursue. Finally, large LSPs have to decide whether they transform their current business model in order to get involved in the adoption process and building herein new ways of creating value, or if they cut themselves off from the PI, risking the competition of an open network within a hybrid structure. These findings provide guidance for practitioners adopting the PI and reveal information about underlying conditions and prerequisites for open and shared networks.

However, as with every other empirical research, our study has some limitations. Although case study research is especially suited to provide insights into the early phases of research and practical backgrounds, while maintaining a holistic view on the phenomenon (Yin, 2014; Eisenhardt 1989), this approach is limited in terms of generalization. Therefore, although we chose the interviewees based on a systematic process, it is not possible to conclude that the findings are generalizable for all companies. It would be interesting to investigate small logistics service providers in particular to confirm some of the developed propositions and to gain deeper insights into their specific way of adoption.

Our study also reveals further research topics that can guide scholars for future investigations. First, the outlined barriers, in the form of responsibility and liability conditions need to be solved in order to expedite the adoption process. As stated by the interviewees, standard protocols and business model innovations are needed to define stakeholder roles and to deal with this issue. Second, it is advisable to clarify leadership conditions to prevent monopolistic

structures. It will be interesting to see if distributed ledger technologies could help to enable horizontal collaboration through a trustful exchange of information.

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Applying concepts of telecom networks to logistic networks – towards new business roles and - models for the Physical Internet

M. Djurica[1] and W. Hofman[,1,2]
1. TNO, The Hague, The Netherlands
2. Delft University of Technology, Delft, The Netherlands
Corresponding author: wout.hofman@tno.nl

Abstract: *Over the last couple of years, virtualization of telecom networks by separating software from hardware led to new business models. Since the Physical Internet is considered as the logistics equivalent of the Internet, it might be worthwhile to assess developments of the telecom sector and investigate its potential to supply and logistics. Future directions for innovative business models, - roles, and required functionality are explored and discussed. Data sharing is a prerequisite to realize these models with its supporting functionality.*

Keywords: *virtualization, Software Defined Networks, business innovation, Physical Internet*

1 Introduction

The Physical Internet (Montreuil, Meller, & Ballot, 2013) is about the creation of various layers in which modularized packages move from origin to destination (Ballot, Liesa, & Franklin, 2018). Routing protocols, data sharing, and pricing and procurement models are amongst others identified as research topics. These routing protocols can be implemented anywhere, e.g. in a node, a Logistics Service Provider, or even an intelligent asset.

These types of research questions have already been addressed in the telecom sector, where there is a need for standardization to increase market share and usability of smart devices. Various protocols for system-to-system have been developed and implemented, including the support of mobile and satellite communication. This sector evolves into virtualization of telecom networks meaning that communication networks are collection of physical links (cable, fiber, microwave links, ...), switches, and a number of processing functions implemented by software. SDN (Software Defined Network) and NFV (Network Function Virtualization) are game changers from a business perspective, implying for instance rapid deployment of communication networks on a shared infrastructure. Logistics can be constructed in a similar manner, consisting of assets that are service providers to construct their logistics network. These assets can be anything, ranging from warehouse, terminals, and cross-docking centers to trucks, vessels, and barges.

This paper analyses development of business in the context of the Physical Internet by comparison with the telecom sector. First of all, developments in the telecom sector are discussed, secondly, their analogy to logistics is presented and thirdly differences are assessed.

2 Telecom developments

Virtualization of telecom networks reflects the understanding that communication networks are a collection of physical links (cable, fiber, microwave links, ...), switches, and a number of

processing functions implemented by software. SDN (Software Defined Network[33]) and NFV (Network Function Virtualization[34]) are main developments and game changers from a business perspective. SDN has introduced functional separation of software and hardware and routing and switching functions of routers. NFV has introduced the idea that Network Functions, required to operate a communication network, can be implemented by software, that can run at any connected location offering sufficient processing, storage, and connectivity. Hardware like routers have their firmware, offering Application Programming Interfaces (APIs), that can be programmed by Network Functions like routing.

Using SDN/NFV as leading ideas, bodies like 3GPP (Third Generation Partnership Project[35]) are developing 5G, which will allow enormous flexibility to operators in operating their networks on a shared infrastructure and particular cloud providers offering computational and storage capabilities. Since the majority of network functions, if not all, is implemented by software, running on general purpose hardware (cloud / data center), an network service provider can easily create new instances of network functions in case of increased user demand or to cater with DOS (Denial Of Service) attacks. It includes having sufficient cloud resources, setting up virtual machine(s) and relevant network function software, and connecting these network function to corresponding network functions already in operation. The same holds for a situation where one network function might fail – new instance can be created and deployed rapidly.
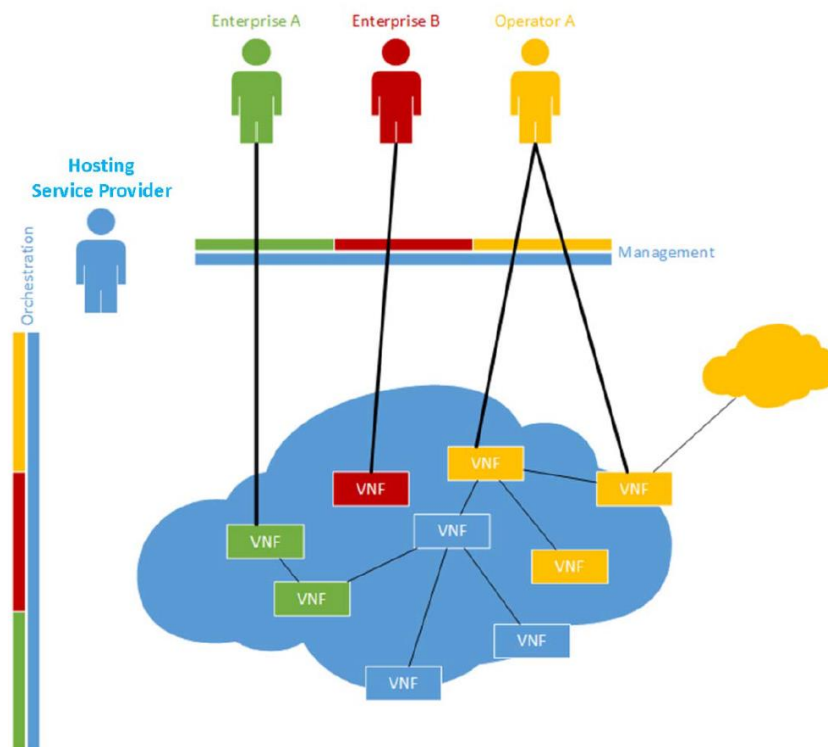
Figure 66: Multi-tenant network (source: ETSI[36])

By including automated tools for monitoring a network and matching the required network capacity with the demand for connectivity and data exchange to users, it is possible to construct a fully automated system that will manage such a network.

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[33] Example of OpenFlow can be found at https://www.opennetworking.org/

[34] https://www.etsi.org/technologies/nfv

[35] http://www.3gpp.org

[36] ETSI GS NFV 001 v1.1.1 (2013-10) Network Functions Virtualisation (NFV); Use Cases

These developments of virtualization led to the following business perspective:

- Multi-tenant telecom network provider, providing the hardware and communication links to service providers and enable them to exchange data. The hardware and communication links can integrate a variety of technology, e.g. mobile, fixed lines, and satellite networks. Network slicing is provided to offer a particular service to a network provider.
- Cloud providers offering storage and/or computational facilities.
- Software service providers developing and offering Network Functions and/or services like routing, firewalls, etc. These network functions operate in a cloud and integrate with hardware of telecom network providers via APIs.
- Service providers offering voice, data, video, and other types of network services to their users by orchestrating Network Functions that can operate in any cloud environment and manage and utilize underlying telecom networks of one or more multi-tenant telecom network providers.

Figure 67: ETSI NFV functional architecture
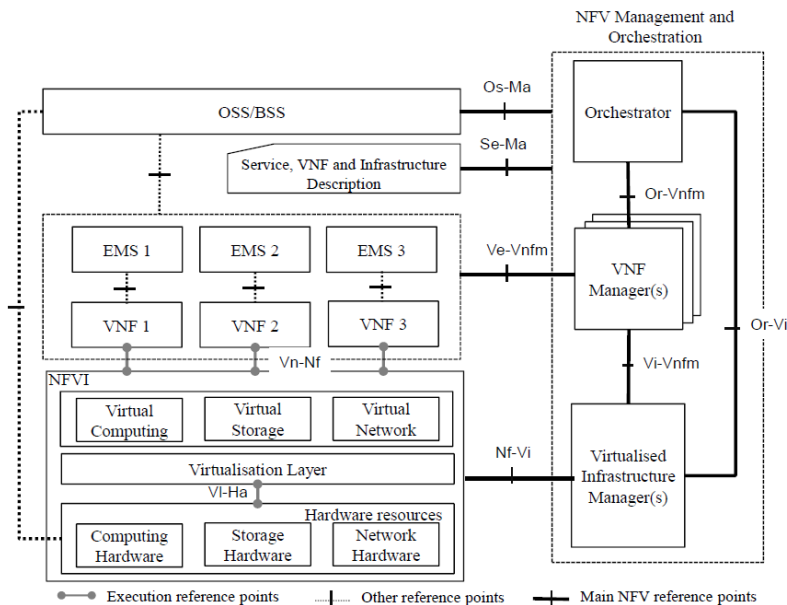
ETSI NFV has defined a functional architecture for virtualized network functions[37]. Main elements are a virtualized infrastructure (NFVI), VIM (Virtual Infrastructure Manager), virtualized network functions (VNF) and their manager, and an orchestrator, which is intermediary between requests of services for connectivity, functions and computing resources. An Operational Support System (OSS) is required for management of operational use of a virtual network. MANO (Management And Network Orchestration), consisting of VIM, VNF Manager, and orchestrator, is a main element in managing and assigning resources and thus providing the services of a service provider to their customers. Upon receiving request for communication (and network functionality), it will contact VNF manager and VIM in order to reserve resources (communication links, processing and storage in data center) to fulfil that request. MANO will also instruct VNF manager to set up relevant VNFs and place them in already prepared processing and storage (already arranged).

A Virtual Infrastructure Manager (VIM) is an element in the NFV architecture which is crucial to facilitate the business perspective. It manages infrastructure elements, and constantly aligns

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[37] https://www.etsi.org/deliver/etsi_gs/nfv/001_099/002/01.02.01_60/gs_nfv002v010201p.pdf

requirements of service providers with that of multi-tenant telecom network - and cloud providers to assure the proper service level to end-users of the network providers. Furthermore, standardization is of the uttermost importance to be able to operate required network functions using hardware APIs. So, VIM is aware of availability of resources and (foreseen) resource requirements. The assumption is that cloud providers will have sufficient resources for deployment of the VNFs.

SDN and NFV offer advantages for both a multi-tenant telecom network provider and service providers. Former ones can make optimal use of existing resources, while service providers can focus on their core business without dealing also with networking aspects of their business. It will allow the implementation of innovative (expensive) assets compliant with (inter)national regulations in the infrastructure, like 5G, that can be shared by different service providers improving their service offering.

3   Applying network virtualization to supply and logistics

This section applies the virtualization of network functionality to the supply and logistics sector in a straightforward manner, meaning there is no analysis of differences. Firstly, potential roles and business models are explored and secondly, required functionality is described. The next section discusses differences.

3.1   Roles and business models

We can draw a parallel between supply and logistic and telecom networks by making a distinction between physical assets ('hardware') and required functionality to deploy this hardware for meeting customer demands ('software'). Supply and logistics networks consist of assets functioning as resources with a particular capacity. Hubs with switching and (temporary) storage functions like terminals, warehouses, and cross-docking centers and physical infrastructure between these hubs can be compared with communication links, e.g. roads, inland waterways, and rail infrastructure. Since Physical Internet packages are physical, transportation assets like trucks and trains are required on these links, where the links are provided by public and/or private infrastructure managers.

Applying the concepts of SDN and NFV to supply and logistics, gives the following business perspective:

- Multi-tenant Asset Owners offer (network of) assets like hubs and transport means that can be utilized by many Logistics Service Providers. Hubs and transportation assets can be provided by different owners; the physical infrastructure used by the transportation assets is managed by private or public Infrastructure Managers or is not managed at all (e.g. oceans used by deep-sea vessels). Since all hubs and transportation assets will become autonomous, they need to have firmware with standardized APIs.
- Logistics Cloud Service Providers offer additional services like packing/repacking and stuffing/stripping (equivalent to computing services). They provide the so-called encapsulation layer (Ballot, Liesa, & Franklin, 2018).
- Software service providers developing all types of software-based services like dynamic chain planning, Estimated Time of Arrival (ETA) prediction, horizontal and/or vertical bundling, etc. These services can be compared with VNFs. Software service providers can have various business models like pay per use or monthly fee, depending on the functionality. Cloud computing services and virtualization of these services provides resilience and sufficient computational resources to operate these services.

- Logistics Service Providers (LSPs) offer customer-oriented services for logistics. They have to specify their competitive advantage by for instance differentiation or lower costs (Porter, 1985). Differentiation can be on specific types of cargo, like containers or liquid bulk like oil, specific products requiring additional handling, like fruit, flowers, and livestock, or a focus on a particular customer market like eCommerce shipments. Differentiation might require also a cost focus, in case the competition is strong. Large distribution or postal networks have for instance a differentiation on eCommerce shipments, but might also be integrated in those eCommerce service providers.

The current logistics market is not yet organized according these four business roles. Some LSPs combine all roles to offer their services in a multimodal network, i.e. they are Asset Owner of transportation assets for different modalities (vessels, trucks, barges, trains), Logistics Cloud Service Provider (they have their own container stuffing centers), Software Service Provider, and LSP, whereas others only operate as LSP without any assets. Before becoming a multi-tenant Asset Owner, these former LSPs rather invest in the use of assets of other Asset Owners to increase their market share. Under the assumption that IT investments are relative low compared to investments in physical assets, many stakeholders develop their own IT solutions or adapt COTS (Commercial Off The Shelve) software to manage customer goods flows. This has created legacy with a high Total Costs of Ownership. Furthermore, most of them compete on costs, some have a differentiation focus.

3.2 Required functionality for supply and logistics

Similar to network virtualization, the following functionality is required in supply and logistics:

- Physical functionality consists of:
  - Links like roads, railways, inland waterways, and air traffic control.
  - Storage is represented by warehouses, logistics terrains, and hubs (the latter only for temporary storage).
  - Handling of cargo in cross-docking centers, distribution centers, as well as terminals.
  - Loading and discharging cargo from transportation assets.
  - Monitoring the quality of the cargo.
  - Management of assets like maintenance, positioning, and cleaning. These management functions are applicable to transport means and packaging material like containers and modular packages.
- Virtual Network Functions are services like:
  - Compliance services to validate cargo flows with regulations;
  - Dynamic planning for routing of cargo and (positioning of capacity of) assets.
  - ETA (Estimated Time of Arrival), ETD (Estimated time of Departure) and turnaround time prediction.
  - Bundling services to combine cargo flows.
  - All types of information services that may affect cargo flows like weather forecast – and traffic information services.
  - Traffic flow optimization services for cargo flow optimization in the physical environment.
  - Payment, clearing, and settlement services.

  A number of these VNF services can be built upon data analytics, e.g. deep reinforcement learning (e.g. dynamic planning, ETA/ETD/turnaround time prediction, bundling services, and traffic flow optimization), whilst others require a machine-

processable representation (e.g. compliance rules, information services, and payment types of services). Developing data analytics based functionality requires training with large amounts of data.

- An Operational Support System (OSS) for monitoring and controlling cargo flows. It will need to show the actual status of cargo flows with special attention to exceptions (descriptive – , i.e. supply chain visibility, and diagnostic analytics). Examples of exceptions are (estimated) late arrival at the destination or arrival at another destination than the required one for cargo or a transport means. As VNF services control these exceptions, potentially goals of cargo flows need to be reformulated to meet customer demands.

A Registry is required for searching and finding the business services provided by stakeholders in the physical environment and the VNF for supply and logistics, similar to the one identified for the telecom environment.

Considering this layering, the Management And Network Orchestration functionality for supply and logistics will exist of:

- Virtualized Infrastructure Manager(s) that provide details of the Quality of Service (QoS) of a particular (subset of) the infrastructure, for instance road. The QoS will be affected by its predicted use and external factors like weather forecasts, but similar to retail, the QoS might also be calculated on past behavior.
- A Virtualized Network Function manager assuring the proper use of VNFs provided by external parties.
- An Orchestrator that creates a particular logistics network based on available assets, utilizing the various VNFs for supply and logistics. A specific focus will be given to creating a logistics network based on physical assets, since these will have to provide sufficient capacity to meet customer demands. The Orchestrator constantly monitors if demand and available capacity is matched, in coordination with the other management functions. This reservation can be at strategic -, e.g. quarterly based on predicted usage, or tactical level, monthly or weekly based on calculating the predicted time and costs required for the cargo flow using various business services provided by the physical environment.

The Orchestrator supports an LSP in creating it's logistics network based on physical assets and their available capacity. It can also imply that capacity can be shared between Orchestrators by one Orchestrator selling it's spare capacity to another. This type of orchestration can be compared with a Non Vessel Operating Common Carrier (NVOCC) that reserves capacity on vessels. New entrants like Flexport may also implement Orchestrator and OSS functionality.

These functions all require data as input to the various VNFs for supply and logistics. For instance, dynamic planning - and bundling algorithms provide the decision support that requires particular data. An open data sharing infrastructure is a prerequisite for functioning of the model. The following types of data are required for this type of decision support:

- Available business services and timetables spanning the network managed by an Orchestrator;
- (Short term) QoS of each of the legs and logistics activities of the network towards the final destination. This type of data needs to be provided by the Virtualized Infrastructure Manager.

- Details of short term availability of multi-tenant assets and a capability to reserve capacity of these assets for actual cargo flows. Availability of details of various cargo flows allows bundling of flows based on available capacity of assets and their services.

Decision support can consider aspects like costs, time, and carbon footprint. Mechanisms like slot management and dynamic pricing of slots can also be included to control flows.

4 Discussion

When drawing the parallel with telecom networks, the main difference of supply and logistics is the fact that cargo and assets are physical. Unlike information packages, cargo can get lost, cannot be resubmitted in case of loss, and assets have a limited capacity. Another difference is that information packages are only data, whereas cargo and transport means can have computational capabilities, i.e. they can be intelligent or (semi-)autonomous. Intelligent cargo implies that cargo can find its own way in the physical environment, via various hubs and with different transport means and – modalities. Finally, 'speed' is of another dimension in supply and logistics. Where seconds and minutes are of importance for telecom in transferring information packages, hours and days are considered in supply and logistics. These differences may lead to different implementations of VNFs, thus leading to other business models and – roles in supply and logistics compared with telecom.

We will discuss the parallel in more detail, both from a business and a functional perspective.

4.1 External drivers for change

The comparison between virtualization of telecom networks and supply and logistics networks clearly identifies current discussions within the logistics sector, namely should a logistics enterprise focus on becoming an LSP with or without physical assets.

Digitalization is the main driver of change supply and logistics, potentially towards these roles. Digitalization is at three levels: creation of autonomous assets (robotization), virtualization of IT functionality provided by new entrants acting as software service providers, and the introduction of eCommerce. Sustainability requirements formulated by authorities are an additional driver for change. These requirements may lead to new (inter)national and local regulations like city centers that are not accessible for some type of truck. These latter local regulations are already applicable.

There is an increase of robotization, covering aspects like loading/unloading cargo to transportation devices, fully automated terminals and warehouses, and creation of (semi-) autonomous transport means (trucks, barges, trains, vessels). These developments are bringing us a step closer to large scale fully automated logistic networks, operated by Multi-tenant Asset Owners. Extending this network with 'intelligent' π-containers, where these containers will have at least a sensor (IoT), but may also have (limited) computation power, even makes it possible to implement dynamic routing at package level. π-containers could have their goals programmed or refer to a so-called Digital Twin (Boschert & Rosen, 2016). Global operating shipping lines already invest in these types of networks by deploying fully automated terminals and investing in autonomous vessels.

The second driver for change is the development of innovative, software based services and multi-sided platforms. New entrants take the role of Software Service Provider by offer cargo bundling services (e.g. CargoStream), improve capacity utilization (e.g. TEUBooker), provide an overview of available services (e.g. Navigate), and implement an LSP as a multi-sided platform between customers and Asset Owners (e.g. Über4Freigth). These multi-sided

platforms have already established a position in passenger transport, they will apply the same rules to freight transport with the potential implication they decide on the margin and the service performance of asset owners. Other new entrants implement a fully automated LSP, e.g. Flexport, and may potentially have a (primitive version of a) Orchestrator to assure they have sufficient capacity to provide a competitive customer service.

Besides last mile distribution and city logistics that impose challenges, eCommerce has given new entrants in supply and logistics on a global level. These new entrants have evolved from web shops, virtual shopping malls, payment providers, and IT cloud service providers to major logistics players. These new entrants utilize logistics stakeholders, especially in their role as multi-tenant asset owners. They can act as LSPs with functionality presented before.

It is yet unsure how the market will evolve, it can however be expected that (semi-)autonomous, programmable assets with firmware will require more investments, whilst authorities will impose increased sustainability demands, evolving into Multi-tenant Asset Owners. Intelligent algorithms will also evolve in mature services provided by Software Service Providers, thus forcing LSPs to focus on orchestration with similar functions like MANO for telecom providers. This required functionality will be discussed hereafter.

4.2   Future business scenario's and strategies

Based on the parallel with the telecom network sector, the following scenarios are feasible:

1. The telecom model. Supply and logistics is going to be organized like the telecom sector. It implies that VNFs are developed by independent IT providers, can interface with various physical assets, and can be applied by many LSPs. In this scenario, a distinction between multi-tenant asset owners and LSPs exists – LSPs don't own assets. We can observe two variants within this context that can be used by LSPs to create their supply and logistics networks:
    a. Intelligent hub network (Ballot, Liesa, & Franklin, 2018). Hubs implement the VNFs and optimize capacity utilization across the various links. They have access to data to optimize cargo flows. Such a hub network neatly aligns with the concept of so-called TEN-T corridors[38].
    b. Intelligent asset network. The VNFs are implemented by the assets, they are 'intelligent'. Even OEMs could develop and implement the VNFs and act as multi-tenant asset owners or they can provide their assets with on-board VNFs.
2. Multi-sided platform model[39]. Independent IT service providers establish multi-sided platforms with VNFs. Multi-sided platforms can function as intermediates of transactions between customers and multi-tenant asset owners, only if dynamic adjustments can be made automatically by (potential complex) VNFs supported by an open data sharing infrastructure (Ondrus, Gannamaneni, & Lyytinen, 2015). The success of these platforms also depends on its installed base (Kung & Zhong, 2017).
3. Mixed scenario. This one reflects the current situation, where we have LSPs with or without assets, hub operators acting as multi-tenant asset owners, carriers providing multi-tenant assets, and new entrants providing multi-sided platform services.

The mixed scenario can evolve further by individual enterprises developing VNFs and becoming fully vertical integrated enterprises. These enterprises will be able to fully optimize their operation and prevent any spill-overs (Hagiu & Wright, 2015). Global operating LSPs like this already exist; yet others try to develop this model. It is our expectation that those that strive

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[38] https://ec.europa.eu/transport/themes/infrastructure_en
[39] See for instance: https://www.generixgroup.com/en/blog/platform-enabled-ecosystem-future-supply-chain

for vertical integration require development of innovative VNFs based on data analytics, require collaboration with others to develop such VNFs. These VNFs can only be developed based on access to large amounts of data (see before). Multi-sided platforms face the same challenge if they want to evolve beyond intermediation of transactions.

It is our view that innovation in supply and logistics depends on development of VNFs and additionally OSS and MANO functionality for supply and logistics. Development of innovative VNFs requires data sharing and collaboration amongst competing stakeholders. We expect competition will be on the combination of OSS and MANO functionality – those that can optimize their logistics networks and cargo flows by using VNFs and multi-tenant asset owners will provided the required customer service. It is not feasible to construct this type of functionality in intelligent assets, since it requires a complete overview of cargo flows in a logistics network (OSS) and strategic – and tactical coordination of required capacity (MANO functionality). Intelligent hubs will also not be able to provide this type of functionality, since they have a subnetwork view.

5 Conclusions

Although there are differences between the telecom – and the supply and logistics sector, mainly driven by the physical aspect of cargo flows, the SDN/NFV paradigm may provide insights on how supply and logistics business roles and - models can change. These changes are mainly driven by digitization leading to new entrants and autonomous assets and increased sustainability requirements. Data sharing is a prerequisite to achieve the required changes and create large scale, efficient logistics networks, the Physical Internet.

Applying these SDN/NFV paradigm to supply and logistics may lead to various scenarios. We have identified three basic scenarios, with two sub-scenarios. Independent of any scenario, collaboration is required for developing innovative VNFs (Virtual Network Function) for supply and logistics and constructing a data sharing infrastructure. Competition will be on basis of developing a Management and Network Orchestration environment to meet customer demands, together with an Operational Support System (OSS) for controlling cargo flows.

One of the potential ways forward is to collaborative develop VNFs and an open data sharing infrastructure. The Digital Container Shipping Alliance (dcsa.org) is an example of such a collaboration. However, it requires the development of an IT architecture identifying all components (VNFs, OSS, MANO), an open data sharing infrastructure, and distribution of intelligence to multi-tenant assets like π-containers, transport means, and hubs.

We have taken the telecom sector as an inspiration for potential changes in supply and logistics, towards realizing the Physical Internet. Other sectors like energy and industry may also be relevant to explore. Energy is for instance changing towards distributed production; industry is exploring the use of 3D printing and robotization, where these autonomous assets also share their (predicted) capacity. Mobility as a Service, MaaS, may also provide an inspiration to supply and logistics, by comparing passengers with 'travel companions' representing Digital Twins of intelligent assets.

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Is social capital relevant to the Physical Internet?

Rosario García García [1], Luis López-Molina, Vanessa Rodríguez Cornejo, Ángel Cervera Paz,
Víctor Pérez-Fernández and Miguel Ángel Montañez,
1. University of Cadiz, Cádiz, Spain
Corresponding author: rosario.garcia@uca.es - luis.lopez@uca.es

Abstract: Physical Internet is based on the physical mobility of logistic resources; therefore, we will try to move from an inefficient use of resources to a more efficient use of them. There is and will probably always be a temporal-spatial gap between providers and recipients. The logistics task is to plan and carry out the flow of goods in the supply chain in the most effective manner, which we can achieve by increasing the variables of Social Capital.

Just as the information can be transmitted over the net, through the Internet, we should be able to do the same with the goods that could be sent through a global logistics network. This requires close cooperation of the cooperators (integration of processes, exchange of resources). Through our work we will try to relate the dimensions of Social Capital, the relational, structural and cognitive dimension with the Physical Internet.

We attempte to analyse them from the point of view of Social Capital and analysing how this cooperation is between competitors, as Physical Internet demands to share those logistical networks, so that we would be talking about the External Social Capital (Bringing Capital), focusing on external relations to the enterprise.

As defined in ALICE (European Technology Platform) we will focus on finding the benefits of social capital as a variable that deals with coordination and collaboration between the parties interested in global supply networks.

Keywords: social capital, trust between competitors, supply chain, physical internet

1 Introduction

Our research seeks to find connections between the Physical Internet (PI) and attributes of organisational social capital, with a specific focus on levels of trust within networks. We chose trust as the focus due to it being one of the most relevant social capital attributes for the Physical Internet.

Our current aim is to integrate logistics systems so that they can cooperate in various areas of activity; greatly increasing levels of cooperation and integration. In this context, social capital allows us to increase cooperation among individuals; improve levels of trust; and look for shared codes and systems. Whilst there is always the opportunity to share this trust and these codes, a lack of trust in the other could prevent these physical mobility networks from being shared.

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2   Concept of social capital / Concept of the Physical Internet.

Social capital is an umbrella concept that is being increasingly used in multiple disciplines, including regional development, business, political science, economics, sociology and education (Adler and Kwon, 2002). Paldman (2000) went further and even suggested that social capital is becoming a "common concept for all social sciences", while Adler and Kwon (2002) state that the concept incorporates "researchers from heterogeneous theoretical perspectives", fostering dialogue from diverse disciplines. Its use in this discipline is also appropriate.

The term 'social capital' appears in the book "*Democracy in America*" (1835), by sociologist, Alexis de Tocqueville, where he suggests that social contacts based on the rules of reciprocity and trust made it possible for democracy to function better in America. However, it was not until 1916 that Judson Hanifan used it to describe the intangible assets found in people's daily lives: goodwill, companionship, sympathy and social relations between individuals and families that form a social unit. He explained the importance of a community's commitment to satisfying the social needs of individuals. Their study was based on two premises: (1) that social networks and rules of reciprocity can facilitate mutually beneficial cooperation; (2) that the community's major social, political and economic problems can be resolved by reinforcing solidarity among citizens. In the same way, all supply chain partners could use these same rules of reciprocity when sharing logistics networks. The PI concept should be a way of improving efficiency in supply chains in the future (http://www.etp-logistics.eu/?page_id=24, 15.05.2017).

The concept of the Physical Internet was mentioned for the first time by Benoit Montreuil from Laval University in Canada. The author presented a guide on practical uses for the PI as a result of years of study. In the draft on PI theory and practices, various milestones are proposed (http://www.etp-logistics.eu/?page_id=24, 15.05.2017) to ensure that by 2020 economic, environmental, social and security objectives are completely aligned. To achieve this, we can make use of the concept of social capital since it is based on relationships and their connections, with a focus on how it helps develop trust, cooperation and collective action within well functioning logistical networks.

The Physical Internet concept is interested in physically moving logistical resources in an attempt to move away from an inefficient use of resources and toward a more efficient use of them. There is and will probably always be a temporal and spatial gap between providers and recipients. The logistics task is to plan and manage the flow of goods in the supply chain as efficiently as possible. We can achieve this by increasing relational social capital and confidence levels.

Therefore, the Physical Internet will redefine:
• 	 The supply chain configuration
• 	 Business models
• 	 Value creation patterns

In logistics systems, there is currently an excessive amount of resources compared to that required, leading to a fall in profitability. This creates the need to implement a new logistics system management model.

Just as information can be transmitted over the Internet, we should be able to likewise send goods over a global logistics network, requiring close cooperation between those involved (integration of processes, exchange of resources). If global product flows were more efficient, operational costs could be reduced.

In literature on organisational social capital, there are four interconnected issues. With regard to the Physical Internet, we are interested in two of them:

• Trends and changes in the environment of organisations occur at a fast pace and it is not possible to continue in the same way with the same knowledge.
• Organisations undertake changes and redirect management.

Through our work, we will try to relate the relational, structural and cognitive dimensions of social capital to the Physical Internet. The relational dimension of social capital is characterised by high levels of trust, shared norms, perceived obligations and the feeling of mutual identification. Its conceptualisation is very similar to that used by Granovetter (1973), which assumes strong unions between individuals characterised by trust, reciprocity and emotional intensity.

These are the very same attributes we should seek to encourage in companies when developing a systematic solution. The aim is to increase efficiency in process performance and logistics development in addition to simultaneously attaining economic, social and environmental balance [Montreuil et al., 2012]. Physical Internet seeks to guarantee: stability; the mobility of a physical object across the world; and the ability to collect, store, sell and use it. [http://www.modulushca.eu, 15.05.2017] If we develop social capital attributes, all of this could be achieved in a more efficient way.

Trust is an attribute of the relational dimension of social capital and this characteristic in a relationship can lead to joint efforts. Furthermore, the fact that someone is worthy of trust means that they are more likely to receive support from others to achieve their objectives, which would not happen if that trust did not exist. In this sense, there is a direct relationship between trust and cooperation: trust paves the way for cooperation and cooperation cultivates trust (Nahapiet and Ghoshal, 1998). Accordingly, Melé (2003, a, b) indicates that generating trust and promoting cooperation are two elements that are closely related to the relational dimension. We will focus on tackling two of the five areas highlighted by the strategy (http://www.etp-logistics.eu/.15.05.2017).

Firstly, we will focus on the Information Systems for Interconnected Logistics before secondly addressing the Global Coordination and Collaboration Networks. We will analyse them from the point of view of social capital and explore what cooperation between competitors looks like in the context of the Physical Internet which requires that competitors share logistical networks. This moves us into the realm of external social capital which focuses on relationships outside of the company.

As defined in ALICE, (European Technology Platform) (http://www.etp-logistics.eu/?page_id=89) we will focus on finding the benefits of social capital for coordination and collaboration between the parties involved in global supply networks. Coordination and collaboration refer respectively to vertical and horizontal synergies throughout and along different supply chains. In this context, coordinating supply networks equates to a dynamic synchronisation and update of logistics and transport plans for all modes and actors (manufacturers, retailers, logistics service providers, operators, terminal operators, etc.). The Supply Network Collaboration is concerned with maximising the use of resources, such as vehicle capacity and infrastructure, by matching the demand of multiple shippers with the transport and logistics services available in different modes and with different service

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providers. Both coordination and collaboration can yield significant gains in terms of efficiency and sustainability and represent a major step towards the Physical Internet, leading the transition from individually managed supply chains to open supply networks. Therefore, strengthening social capital will generate synergies that will help achieve the ALICE planned objectives.
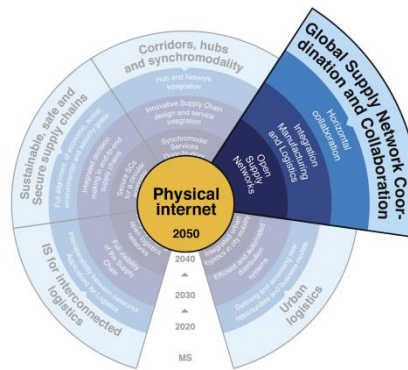

Figure 1: Road Map ALICE – Global Supply Network Coordination and Collaboration

Therefore, our intention can be as defined in ALICE: (http://www.etp-logistics.eu/?page_id=89) "define research and innovation paths that need to be addressed to achieve real-time re(configurable) supply chains in (global) supply chain networks with available and affordable ICT solutions for all types of companies and participants" but using the variables of social capital as a means to generate a Physical Internet based on an open global logistics system based on physical, digital and operative interconnection, enabled through the encapsulation of products, standard interfaces and protocols. The goal of the Physical Internet vision is to move, store, produce, supply and use physical objects around the world in a way that is economically, environmentally and socially efficient and sustainable.
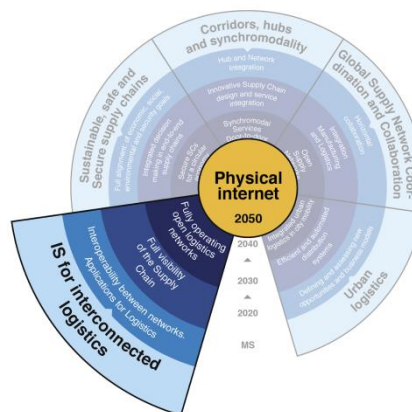

Figure 2: Road Map ALICE – IS for interconnected logistics

From this perspective, trust, reciprocity and cooperation will form the basis of social capital relationships and social structures, which are foundational for facilitating the sharing of logistical networks:

•   Trust: attitude based on the behaviour expected from another person, taking into account the principle of reciprocity. This attitude is expressed in repeated and reinforced behaviours.
•   Reciprocity: logic of exchanging objects, help and favours, which makes us see that our collaborator is willing to start or maintain a social relationship.
•   Cooperation: aimed at achieving shared objectives, looking for a system that increases efficiency through logistical development.

When we discuss the relationship between social capital and the Physical Internet, we argue that companies that have greater social networks find more opportunities to establish logistical networks and better conditions to take advantage of these new opportunities. We therefore aim to highlight the importance of social capital and its attributes in the Physical Internet as a way of guaranteeing the physical mobility of objects.
The Physical Internet has two areas of interest (Roman Domanski et all, 2017):
•   One is focused on the technical-technological sequence and the problems of unifying and integrating logistics units in the supply chain and the infrastructure required to facilitate the flow of these units.
•   The other focuses on the organisational flow - developing the concept of managing the flow of logistics units, based on the possibility of sharing resources and skills with other participants in the supply chain as a way of guaranteeing the physical mobility of objects.

3   Dimensions of social capital.

We are going to use the classification that Adler and Kwon (2002) used and we are going to divide it into structural, relational and cognitive dimensions. We will explain each one further.

3.1   Structural dimension

This dimension attempts to encompass all the relationships that a company has and the social interactions that occur, focusing on the properties of the social system and the network of relationships as a whole (Nahapiet and Ghoshal, 1998).
Social links are the channels through which information and resources flow. A person or group can have access to others' resources through social interactions (Bolino, Turnley, Bloodgood, 2002). In this way, discovering a company's contacts and where they stand in a social structure of interactions will provide the company with a series of advantages or benefits. The organisation can use its contacts or links to obtain jobs, obtain information or access specific resources and look for information systems to interconnect logistics (Roman Domanski et al., 2018).
The structural dimension of social capital includes:

- The examination of how individuals are connected within the logistical networks of an organisation.
- Description of the connection patterns among the employees of the logistics networks of an organisation.
- Examination of the utility of these connections between the organisations involved in these logistics networks.

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3.2   Relational dimension

The relational dimension of social capital describes the type of personal relationships that individuals have developed with others through interactions (Granovetter, 1992). According to Nahapiet and Ghoshal (1998), the relational dimension of social capital is characterised by high levels of trust, shared norms, perceived obligations and the feeling of mutual identification. Its conceptualisation is very similar to that used by Granovetter (1972, 1973) which assumes strong unions between individuals characterised by trust, reciprocity and emotional intensity.

The relational term is used to refer to the advantages generated by connections, with the following factors being key:

- Trust and honesty (Fukuyama, 1995, Putnam, 1993)
- Norms and sanctions (Coleman, 1990; Putnam, 1995)
- Obligations and expectations (Burt, 1992; Coleman, 1990; Granovetter, 1985)
- Identity and identification (Hakansson & Snehota, 1995; Merton, 1968)
- Other complex incentives that derive mainly from the company's history and reputation (Gulati et al, 2000).

Therefore, the relational dimension tries to indicate the extent to which economic actions are affected by the quality of relationships between companies (Ghoshal and Barlett, 1994). Confidence among organisations refers to how safe the company feels that a partner is not going to exploit the weaknesses of others. In other words, having the expectation that a business partner will not act opportunistically (Barney and Hansen, 1994). Confidence is the result of repeated interactions with other companies, which demonstrate in the accumulated experience that they will respond quid pro quo to an act of generosity, feeding a bond that links the acceptance of risk with a feeling of affectivity or extended identity (Tsai and Ghoshal,1998).

Trust is an attribute of a relationship, which can lead to joint efforts. There is a direct relationship between trust and cooperation: trust paves the way for cooperation and cooperation builds trust (Nahapiet and Ghoshal, 1998). So, global supply networks are facilitated by coordination and collaboration (Roman Domanski, 2018). Although expectations of trust reside within individuals, it is legitimate to think of interorganisational trust within economic organisations (Zucker, 1986, Gulati, 1995 a, 1995b).

All partners in the supply chain (manufacturers, transport service providers, retailers) will be able to carry out their independent operations through a common logistics network. This logistics network should be based on mutual trust and on the existence of shared standards. The ability to adapt to the needs of changes that may occur at any given time is a natural feature of the supply chain [Hajdul, Nowak, 2014]. In the future, the concept of the Physical Internet should be a way of improving the efficiency of activity in supply chains.

Interorganisational trust implies the presence of considerable interdependence, and a high level of task coordination among companies that have previously maintained relationships, providing them with important knowledge on the other's rules, routines and procedures (Gulati et al., 2000). In this way, we can improve efficiency in supply chains with the Physical Internet (R. Domanski, 2018). Trust has proved to be a precedent for cooperation (Tsai and Ghoshal, 1998). When two units begin to trust one another, (manufacturers, suppliers of transport services,

retailers) they may be able to function independently using shared logistical networks (R. Domanski, 2018).

Trust facilitates the exchange of resources and increases communication (Putnam, 1993, Misztal, 1996, Jones and George, 1998, Tsai and Ghoshal, 1998) in a way that facilitates stability, global mobility and the creation of distribution networks: objectives of the Physical Internet (R Domanski, 2018).

The consensus in the literature is that trust can contribute significantly to the long-term stability of an organisation (Heide and John, 1990), and Lee and Billington (1992) expand on this argument by suggesting that effective coordination of the supply chain is built on a foundation of trust and commitment.

The implementation of such a holistic view of the supply chain requires a degree of trust between all players, hence the link with partnership/relationship initiatives (Mason-Jones and Towill, 1997; Nesheim, 2001).

3.3   Cognitive dimension

The cognitive dimension of social capital refers to the resources that provide representations, interpretations, and systems of shared meanings (Cicouriel, 1973). These resources also have great importance and consideration in intellectual capital, including shared codes and languages (Arrow, 1974, Cicouriel, 1973, Monteverde, 1995). Not considering these resources as another dimension of social capital risks making the whole concept of little use, since without it, the value provided by relationships would be scarce or non-existent (Adler Kwon, 2002). In this way, the cognitive dimension refers to the degree to which network contacts possess valuable resources (Nahapiet and Ghoshal, 1998, Uphoff, 1999, Uphoff and Wijayaratna, 2000, Puttnam, Krishna and Uphoff 2009).

We could conclude that structural, relational and cognitive heterogeneity constitute the three dimensions of social capital and that these three dimensions specifically influence the PI since social capital is considered a resource that generates competitive advantage to companies (Tsai and Ghoshal, 1998). Therefore, while the structural dimension describes the mere fact that there are relationships between companies and channels through which information flows are created; the relational dimension would be in charge of describing if those relationships are effective or not; and if, as they intensify, trust is generated or not. The last dimension of social capital focuses on whether these connections have a cognitive component or not.

As discussed by Ballot et al. (2012), researchers who have studied distribution networks and supply chains focus mainly on the supplier-customer relationship and coordination at each level beginning with the raw material and ending with the finished product in the hand of the user. We think it is justifiable to use the three variables of social capital as repeated and intense social interactions ("the structural dimension") create an intimate atmosphere of trust and mutual commitment ("the relational dimension") which in turn induces the development of common codes ("the cognitive dimension") and the necessary language to share distribution logistics networks. In the search for the best solutions in terms of inventory and customer service, the researchers emphasised the benefits and risks shared from collaborating in decision-making and planning. This is the reason why Montreuil proposed the Physical Internet as the means to break classic paradigms.

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4   Structure of the paper

Our proposal is to conduct a study of the variables of social capital and examine how these would have an influence on the PI. We will take a qualitative approach.

We propose to use the indicators of social capital used in the Integrated Questionnaire for the Measurement of Social Capital - Group of Experts in Social Capital - B.M (2002)

- Indicators of cognitive social capital:
    - Norms, beliefs and values that indicate a sense of belonging and that tend to facilitate exchanges and reduce transaction costs and commercial information without contracts.
    - Orientation towards the collective management of resources
- Indicators of relational social capital: Types and degrees of confidence:
    - Trust linked to the establishment of interpersonal relationships of friendship and social networks
    - Extended confidence in companies (based on shared expectations, norms and values).
    - Trust in government institutions (their official rules and procedures)
- Indicators of structural social capital: Types and degrees of collective action:
    - Characteristics of formal and informal organisations and networks.
    - Mode of operation of interest groups
    - Participation in decision-making
    - Heterogeneity of interest groups
    - Extension of connections with other groups
    - Results of the case

We will collect the data from companies based in Cádiz using:
- In-depth interviews with companies around Cádiz
- Structured interviews with logistics providers in the Cádiz area.

5   Conclusion

The variables of social capital that we have studied affect the Physical Internet, therefore we are going to carry out a detailed study of how they affect it and to what extent.

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Transport System Modularization - 11th July 2019 13:30 – 15:00

Decision support tool for containerization problems

Decision support tool for containerization problems

Clusters 2.0

Introduction

- Examining an optimal configuration for **the containerization level** of the sourced products using a new modular dimensioned container concept named **NMLU (New Modular Load Units)**.

- Addressing the business case of a supply network with a set of plants, a cross-docking distribution center and a set of store zones with various demand levels.

- Comparing the transportation and handling costs at each level of the supply network for the two following cases: (1) **The current packaging scenario** and (2) **the NMLU packaging scenario**

- Developing **a decision support tool** to address the NMLU's impact on supply chain performance in terms of the handling and transportation costs.

Motivation

As-Is packaging

Context

Capacities' exploitation
- Products' quantities are not optimized compared to containers capacities
- Containers' handling and transportation cost is high
- Loading and unloading time is high

Operational costs
The way containers are designed and supplied is not economically sustainable for the company

GOAL

Improve the design, handling, and transportation of containers from the supply sources to the stores in terms of economic and ecological performance

NMLU packaging scenario

VISION
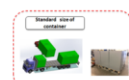
Packaging using NMLU
Optimize sequentially for each product:
1. The sizes of boxes (tier 2) to synchronize with the demand level
2. The choice of the best size of containers (tier 4) to handle

- ✓ Encapsulate goods in modular dimensioned container to increase efficiency,
- ✓ Minimize the operational costs
- ✓ Optimize the size of handled containers

Methodology

- ➢ Given the structure of a supply chain network

Example of supply chain structure

The company can compare the As-Is and NMLU scenarios regarding:

1. The transportation costs
2. The handling costs

NMLU-Decision Support Tool

Main frame of NMLU's tool

Frame 1
Users select:
- The product to be shipped
- The features of the product
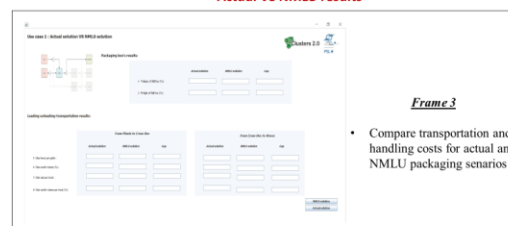- The supply chain structure

The trip planning

Frame 2
Users select for each level:
- The handling options
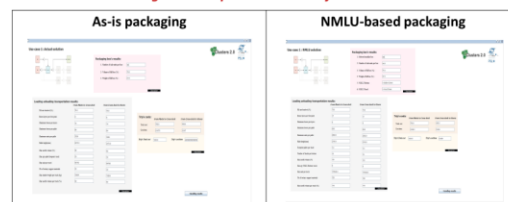- The transportation options

Actual VS NMLU results

Frame 3
- Compare transportation and handling costs for actual and NMLU packaging scenarios

Handling and transportation results for each scenario

As-is packaging | **NMLU-based packaging**

Conclusions

- ✓ A packaging problem considering the positioning of boxes at particular containers is studied
- ✓ A decision support tool addressing the NMLU's impact on supply chain performance is developed
- ✓ A significant diminution of the unused containers' volume was observed when we compared the as-is and NMLU packaging scenarios

[i] House of Commons, Transport Committee, Operation Stack, First Report of Session 2016–17 – Dover and the Channel Tunnel

[ii] Source: Kent County Council (OPP 021), Kent County Council (OPP 055)

[iii] Highways England Webtris Data – Roadside cameras

[iv] Source: Website of Charlie Elphick MP for Dover, 2017