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March 2015

CIRRELT-2015-13

Document de travail également publié par la Faculté des sciences de l'administration de l'Université Laval, sous le numéro FSA-2015-003.

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Physical Internet Enabled Interconnected City Logistics

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Abstract. City Logistics and Physical Internet are two major concepts aiming to profoundly change freight transportation and logistics for increased economic, environmental and societal efficiency and sustainability. They share several basic ideas and are complementary, City Logistics providing the final and last segments of the Physical Internet logistics and transportation networks. We present the first study of the links and synergy between them, introducing the idea of *Interconnected City Logistics* systems and its nine fundamental concepts making up a rich framework for designing efficient and sustainable urban logistics and transportation systems. We conclude with a number of research and innovation challenges.

Keywords: City Logistics, Physical Internet, interconnected City Logistics, freight transportation, urban mobility, urban planning, efficiency, sustainability.

Acknowledgements. The authors thank the Discovery Grant and the Discovery Accelerator Supplements Programs of the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canada Research Chair in Business Engineering, the Strategic Clusters program of the Fonds de recherche du Québec – Nature et technologie (FRQNT), as well as Georgia Tech's Coca-Cola Chair in Material Handling and Distribution for supporting this research. While working on this project, the first author was Adjunct Professor with the Computer science and Operations Research Department, University of Montreal.

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INTRODUCTION

The transportation of goods into, within and out of cities constitutes both major enabling and disturbing factors for most economic and social activities at the core of urban life and prosperity (OECD, 2003). Since its inception, the main goal of *City Logistics* (*CL*) is to reduce the negative impact of freight-vehicle movements on city-living conditions, particularly in terms of congestion/mobility and environmental impact, while not penalizing its social and economic activities and fostering an efficient and sustainable transportation system (e.g., Taniguchi *et al.* 2003, 2013). More precisely, it aims to reduce and control the presence and motorization of freight vehicles operating within the city, improve the efficiency of freight movements and their environmental footprint, and reduce the number of empty vehicles getting in, through and out of the city (e.g., Benjelloun *et al*., 2010, Dablanc, 2007).

The *Physical Internet* (*PI,* π) is a new concept for freight transportation and logistics aiming to improve the economic, environmental and societal efficiency and sustainability of the way physical objects are moved, stored, realized, supplied and used all across the world (Montreuil, 2011; Physical Internet Initiative, 2012). Similarly to the Digital Internet, the movements of freight in the PI are independent of the actual operations of the transportation and terminal handling and storage infrastructure and services, and proceed in an openly consolidated way through a series of carrier services and relay facilities. The PI concept is gaining momentum in both research and applications, and has already shown significant potential gains in interurban transport and logistics (Ballot *et al.*, 2014; Sarraj *et al.*, 2014).

Cooperation, consolidation and a separation of the commercial transactions generating the demand and the way the actual transport and storage of the freight loads are performed are key concepts for both City Logistics and Physical Internet. The two are complementary, as City Logistics provides the final and last segments of the Physical Internet-enabled interconnected logistics and transportation networks. Yet, to the best of our knowledge, no study has explored the necessary links and synergy between these advanced freight transportation and logistics systems.

Our goal is to contribute toward bridging this gap by introducing the idea of *Interconnected City Logistics* systems and discussing its key concepts, potential benefits, and research and development challenges. The plan of the paper is as follows. Section 1 briefly recalls the main stakeholders and the general state of urban freight transport and logistics systems. The next two sections synthesize the main ideas of CL and PI, respectively. We introduce the Interconnected City Logistics and its key concepts in Section 4, and conclude with a number of major research and development challenges towards economically, environmentally and societally efficient and sustainable interconnected city logistics for people and freight.

1. LOGISTICS & TRANSPORTATION IN URBAN ENVIRONMENTS

Freight logistics results from the interactions and combined decisions of numerous stakeholders that, in a rather synthetic way, may be classified as providers, enablers and users of logistics services, as well as legislators. *Providers* include carriers, third-party logistics service providers (3PLs), public and private storage facilities, unimodal and multimodal terminals, etc. Examples of *enablers* are brokers and freight forwarders (these often include carriers acting as integrators). *Users* include shippers, retailers, distributors, manufacturers, etc., as well as institutions, offices and private citizens receiving and sending packages and letters. *Legislators* broadly include the municipal, provincial/state, national and international governments and agencies that make up the operating policies and rules, without forgetting the taxation legislation, governing the transportation and logistics systems.

City transportation systems are complex multimodal networks made up of five main types of entities. The first two are the entities being transported: *people* and *goods*. People have individual dynamic needs for transport, with varying degrees of urgency and subject to budget constraints. They can self-transport by walking, drive themselves to destination in a vehicle, or be transported using taxis, buses, etc. Goods also have needs for transport from origins to destinations specified by their owners or representatives. They come in various unit loads (e.g., boxes, pallets, containers) and have to transported on vehicles or conveying systems. *Infrastructures* on which vehicles move are the third type of entities. They can be public (e.g., streets, tunnels, bridges, subways, waterways and airways) or private (e.g., rail in North America). Fourth are mode-specific *vehicles* and *convoys* moving on particular routes according to particular schedules. Fifth are public and private *terminals* such as logistics terminals, distribution centers, truck terminals, rail yards, ports, and airports. They handle vehicles (e.g. sort and assemble into convoys), load, unload, transship, store and, eventually, sort and consolidate goods. People focused terminals similarly help people selecting vehicles and modes, waiting for boarding availability and switch from a vehicle/mode to another.

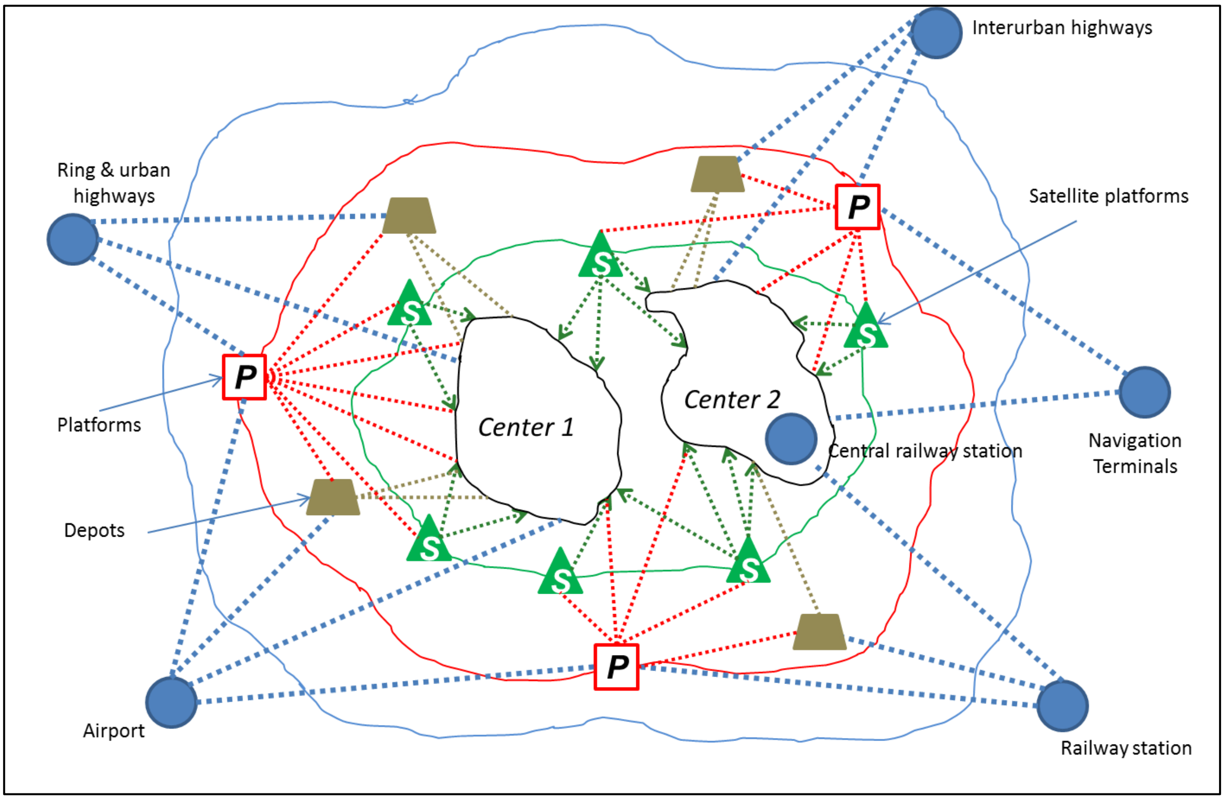

Figure 1. Schematic illustration of a large urban zone

Figure 1 (inspired by Sterle, 2009) attempts to illustrate the main components of such a network for a city with several (here, two) attraction poles, usually identified as “city center”, “downtown”, “central business district”, “old town”, “touristic area”, and so on and so forth. One thus finds a street network whose density varies according to the type of the city and the country encompassing it, as well as with the particular neighborhood considered. Its composition also varies, from large avenues to narrow streets and pedestrian areas. The road network complements this street network with several highways, some passing by the city and linking it with the rest of the country and the continent, some others circling and, sometimes, crisscrossing it. One or several airports are usually part of the system, as are rail systems for people and for freight. When the city is located along a river or by the sea, ports and maritime/river terminals are also part of the system. Other than the airports, ports, truck and bus terminals, and rail stations and yards, a variety of types of terminals are also part of the system, in particular intermodal platforms, distribution centers, warehouses and depots, to name but a few among the most important. Private (cars, bicycles) and public (buses) vehicles and service move people on the road network, sharing it with motor vehicles of various sizes and types carrying freight or on the move to service the "next" customer. Light rail, such as tramways, subways, and aerial trains, and regular rail services move people into, within and out of the city, sometimes sharing the infrastructure with freight convoys (particularly heavy when commuter trains are concerned). To simplify, we decompose urban logistics and transportation activities into two broad categories: *transportation* and *deployment*. The former is about moving the goods into, through and out of the city, while the latter refers to dynamically storing the goods in various facilities within or around the urban territory.

Freight logistics in cities is ubiquitous and takes many forms. It interferes with people transportation and the utilization of urban transportation infrastructures, particularly the road network and on-the-street parking. Yet, historically, city governments have mostly considered freight transportation and logistics to be outside the scope of their planning processes, except through regulations aimed at controlling 1) access of particular types of vehicles to particular zones of the city at specific times, and 2) utilization of public infrastructure, e.g., particular parking spaces for unloading and loading freight vehicles. This has resulted in the current state of affairs in most cities, where individual stakeholder decisions yield a huge number of movements of freight vehicles performing their individual tasks.

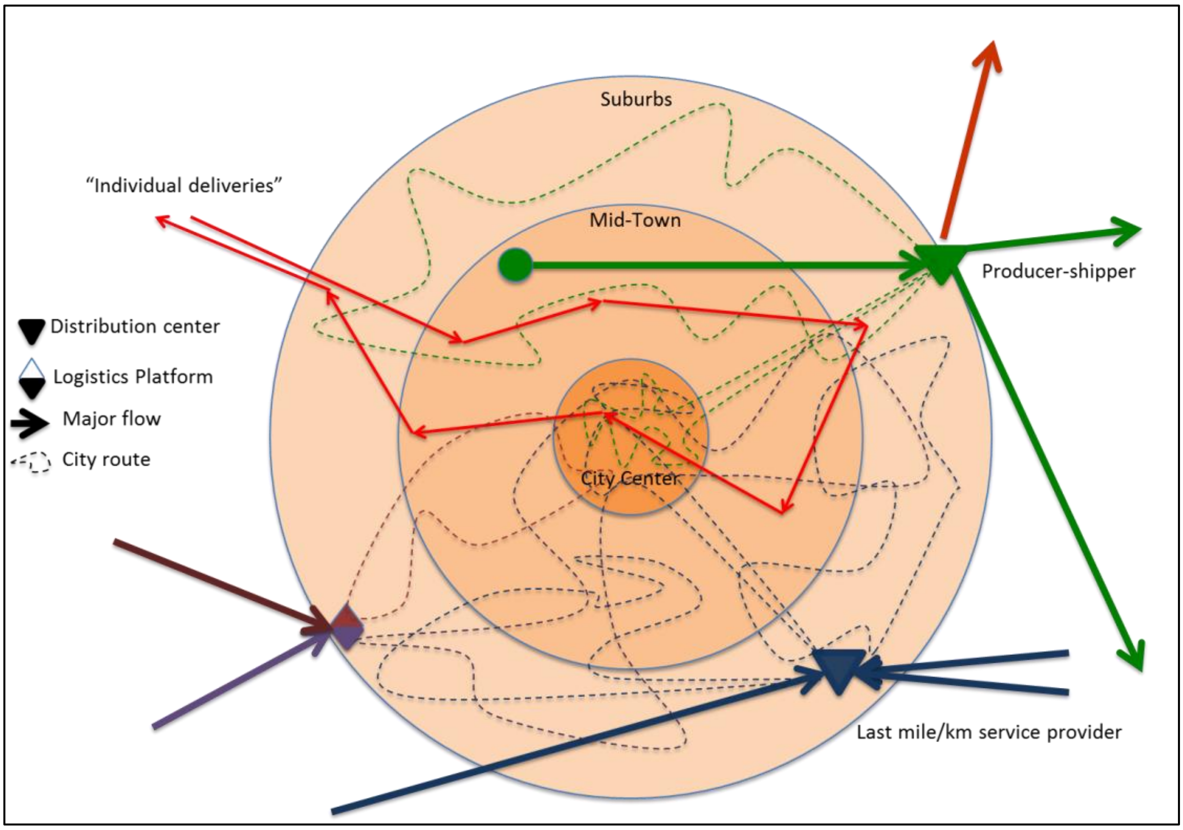

Figure 2. Illustration of individual transportation activities

To simplify the presentation, we hereafter use a schematic image of an abstract circular and concentric city depicted in three levels: suburb, midtown and city center (downtown). Figure 2 illustrates a number of transportation activities. It highlights that many systems, facilities, vehicles and routes overlap and intersect in current urban logistics and transportation systems, resulting in economic and operational inefficiencies, significant and continuously increasing greenhouse gas emissions (e.g., Environment Canada, 2013), as well as a degradation of the life conditions of the city citizens.

2. CITY LOGISTICS

The City Logistics concept has been introduced to address the challenge of the sustainable cohabitation and development of freight transportation and the city (Benjelloun & Crainic, 2008; Gonzalez-Feliu *et al.,* 2014; Taniguchi *et al.,* 2001). City Logistics proposes new organizational and business models for urban freight transportation to reduce its negative impacts, while continuing to support the social and economic development of the city. The fundamental idea is to consider urban freight transport stakeholders, material elements and activities not individually but rather as components of an integrated "logistics" system. The term "City Logistics" emphasizes the goals of (1) modifying the behavior of both the system as a whole and of the stakeholders individually, and (2) globally optimizing the consolidation of loads of different shippers and carriers within the same vehicles, the movements of these vehicles and loads, and the coordination of activities and resources.

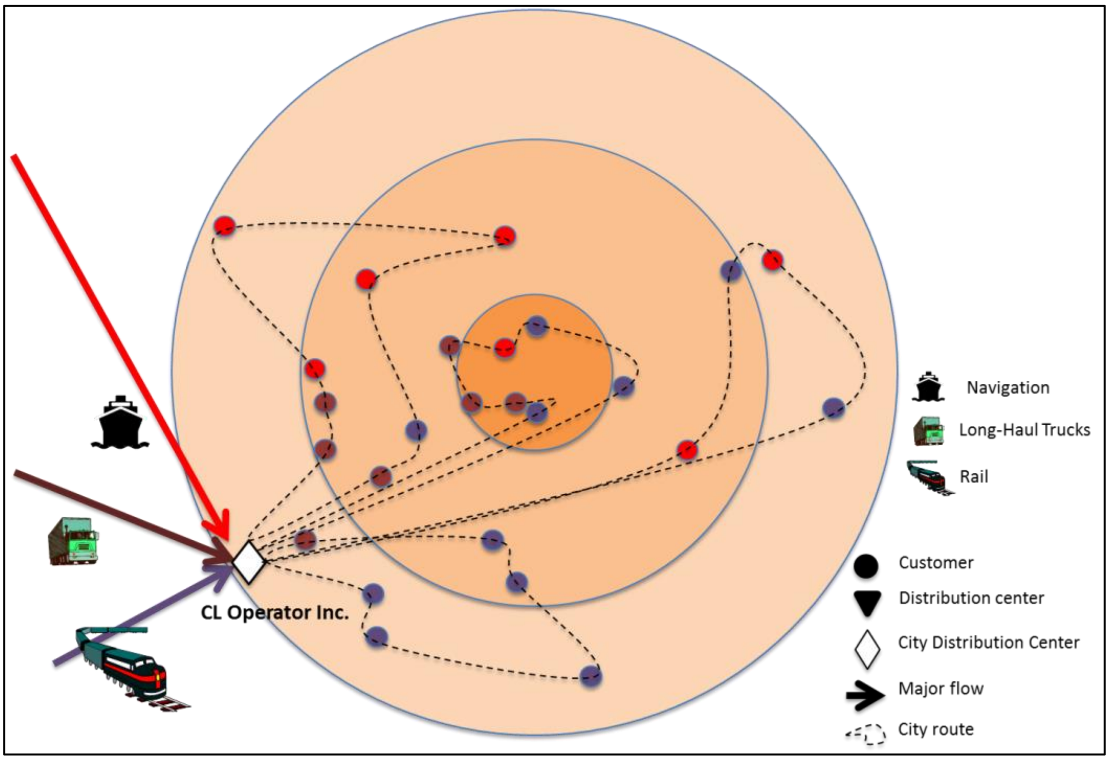

Figure 3. Single-tier, single CDC City Logistics

Several City Logistics concepts have been introduced and projects have been undertaken in recent years. As part of City Logistics, rules and regulations play an important role in the management of the transportation system by city authorities. While the restrictions on the number of vehicles allowed entering the city on any given day or time period, aimed to encourage carriers to work together within these limits, are generally no longer imposed, one observes the proliferation of city zones with access restrictions to vehicles, commercial and private, doted of particular permits. Even though a thorough investigation of their impact is yet to be done, such restrictions are modifying carrier behavior, as are legislations aimed to reduce CO_2 emissions (e.g., the European Union targets for commercial vehicles, European Commission, 2011, and the establishment of Low Emission Zones, Browne *et al.*, 2014).

To reduce congestion and emissions, one must reduce the number of vehicles moving within the city and use better those that do. Underground systems have been proposed to address the first objective, but these are extremely expensive when existing cities are considered. Focusing on managing the demand offers a more efficient approach, as demonstrated by the very successful off-hours project in New York City (Holguín-Veras *et al.*, 2011, 2014). Combining such approaches and supply-oriented concepts appears as one of the most promising current ideas.

The main concept on the supply side exploits the view of CL as an integrated logistics system, emphasizing the optimized consolidation of loads of various shippers and carriers within the same vehicles and the coordination of the resulting freight transportation activities. An associated core concept is the *City Distribution Centre* (*CDC*). CDCs are logistics facilities devoted to city distribution, offering crossdocking and consolidation functionalities for the most part. Short-term storage functionalities for inventories deployed for serving the city may also be offered. They are generally large in terms of load and vehicle handling capacity and are located on the outskirts of the city. Most CL initiatives to date have a single CDC serving small to medium size cities, as illustrated in Figure 3.

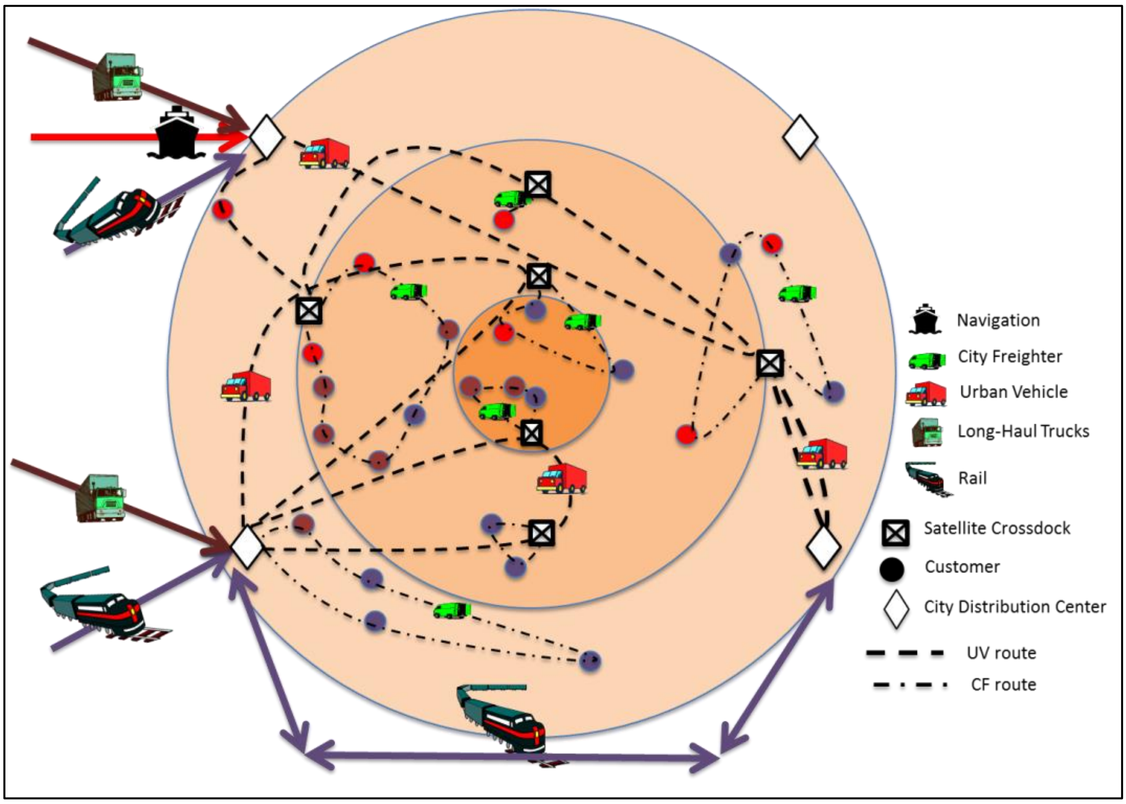

Figure 4. Two-tier City Logistics

A more advanced concept is the organization of activities in a two-tier City Logistics system (Crainic *et al.*, 2004, 2009, 2012; Gragnani *et al.*, 2004), illustrated in Figure 4. In two-tier City Logistics, loads arriving through the interurban logistics and transportation systems are first sorted and consolidated at CDCs (primary facilities) in the outer tier. The consolidated loads are then loaded into first-tier vehicles bringing them to smaller facilities, the *satellites*, located “close” to the City-Logistics controlled zone. Loads are then transferred to smaller second-tier vehicles, appropriate for city-center activities, delivering them to the final customers. The satellite characteristics include their location, the topology of their site and its connection to the street network, their physical organization, and the available space. These yield its capacity measured notably in the number of first and second-tier vehicles it can accommodate simultaneously. In most cases, satellites offer no or limited parking space, vehicles being allowed to be present at satellites only for a little longer than the time required by the crossdock transfer operations.

The interest for two-tier systems and their deployment by private firms such as express couriers and last-mile delivery companies as well as by groups of carriers and logistics service providers constitutes a significant trend (Huart, 2011; de Souza *et al.,* 2014). Also particularly noticeable is the constant increase in home delivery activities (Ducret and Delaître, 2013; Visser, 2014) due to the explosion of personal e-shopping and and the emergence of new two-tier services enabling to meet the induced delivery requirements. These new systems accelerate the trend toward modifying the fleets to become environment friendly by, e.g., changing the motorization of first-tier vehicles to electric or liquid gas, and relying on smaller vehicles such as electrical urban light trucks, scooters and bicycles for the second-tier operations. Although still embryonic, an emerging trend is to use private or public mass-transport modes, such as opening to freight transport interurban rail services, urban light rail and buses, or relying on people bringing loads to a “central” station or taking loads from that station to distribute in their neighborhood (Dizian *et al.,* 2014; Van Duin, 2014). As most people live outside the city center, a direct consequence of these phenomena is a much broader scope for City Logistics, now covering the entire city.

3. PHYSICAL INTERNET

The metaphor of the (Digital) Internet that has transformed information and communication technology and industry, indeed the economy and society, is the inspiration of the *Physical Internet*, a redesign of the current global logistics system addressing its efficiency and sustainability challenges (Montreuil, 2011; Butner, 2010). Clearly, there are fundamental differences: physical objects travel much slower than data, each move and sojourn in the Physical Internet induces a cost, lost data packets in the Digital Internet can be transmitted again at negligible cost and delay, and so on. Yet the metaphor is powerful in shaping the Physical Internet as an open, global and multimodal logistics system founded on universal physical, digital and operational interconnectivity enabled through world standard encapsulation, protocols and interfaces (Montreuil *et al.,* 2013).

The Physical Internet transforms the fragmented freight transportation, logistics and distribution industries into an industry based on interconnected logistics. Goods are transported, handled and stored through a network of networks, indeed a Logistics Web. They are encapsulated in designed-for-logistics standard, modular, smart and reusable π-containers, from the size of small cases up to that of cargo containers. Figure 5 synthesizes the key characteristics of π-containers as described in Montreuil et al. 2015. These π-containers are routed across open logistics centers by exploiting their real-time identification, communication, state memory and reasoning capabilities. Handling systems, vehicles and carriers are designed or retrofit to seamlessly and efficiently deal with such π-containers.

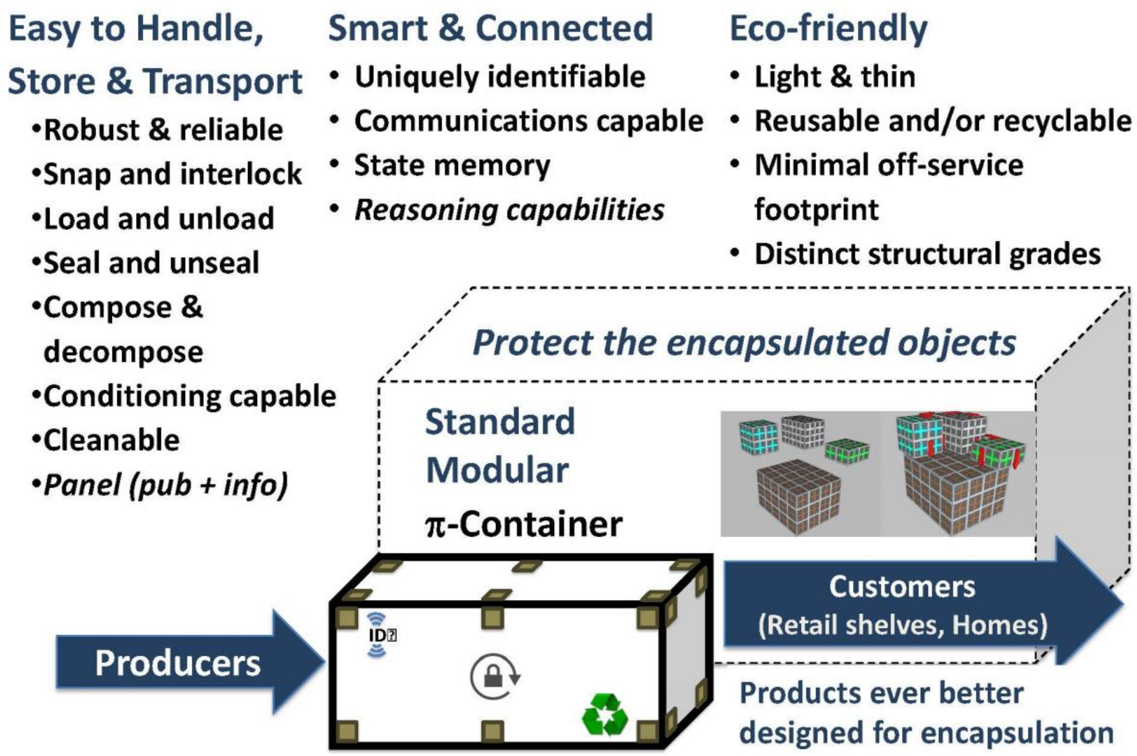

Figure 5. Key characteristics of Physical Internet containers (source: Montreuil *et al.*, 2015)

Freight transportation is now dominated by end-to-end transportation of full load and hub-and-spoke transportation of partial loads and parcels through networks dedicated to specific transportation businesses. The Logistics Web enables to shift toward much more distributed interconnected transportation, uncoupling origin-destination trips into multiple segments between open logistics centers, each segment dynamically dealt with through the most appropriate mode, means and business. Relative to distribution, it allows enterprises to deploy their stocks of products through a multitude of open warehouses and distribution centers, near their markets, enabling fast short-distance delivery to customers, instead of restricting them to exploit their sole or few dedicated centers. The same type of transformation towards global open interconnection is enabled for product realization (production, finishing, personalizing, etc.), supply and usage. The Physical Internet uses the same conceptual framework from the facility level to the worldwide level, as well as at the regional and city levels. It induces cultural, technological, business model, infrastructural and legislative innovation.

Figure 6 illustrates for a simple supply chain composed of two retailers and two manufacturers the impact of evolving toward Physical Internet enabled interconnected logistics. The upper part of Figure 6 shows in the baseline situation that each manufacturer and each retailer has its own dedicated distribution centers, and that each one individually optimizes its shipping transportation, with no synergy amongst them.

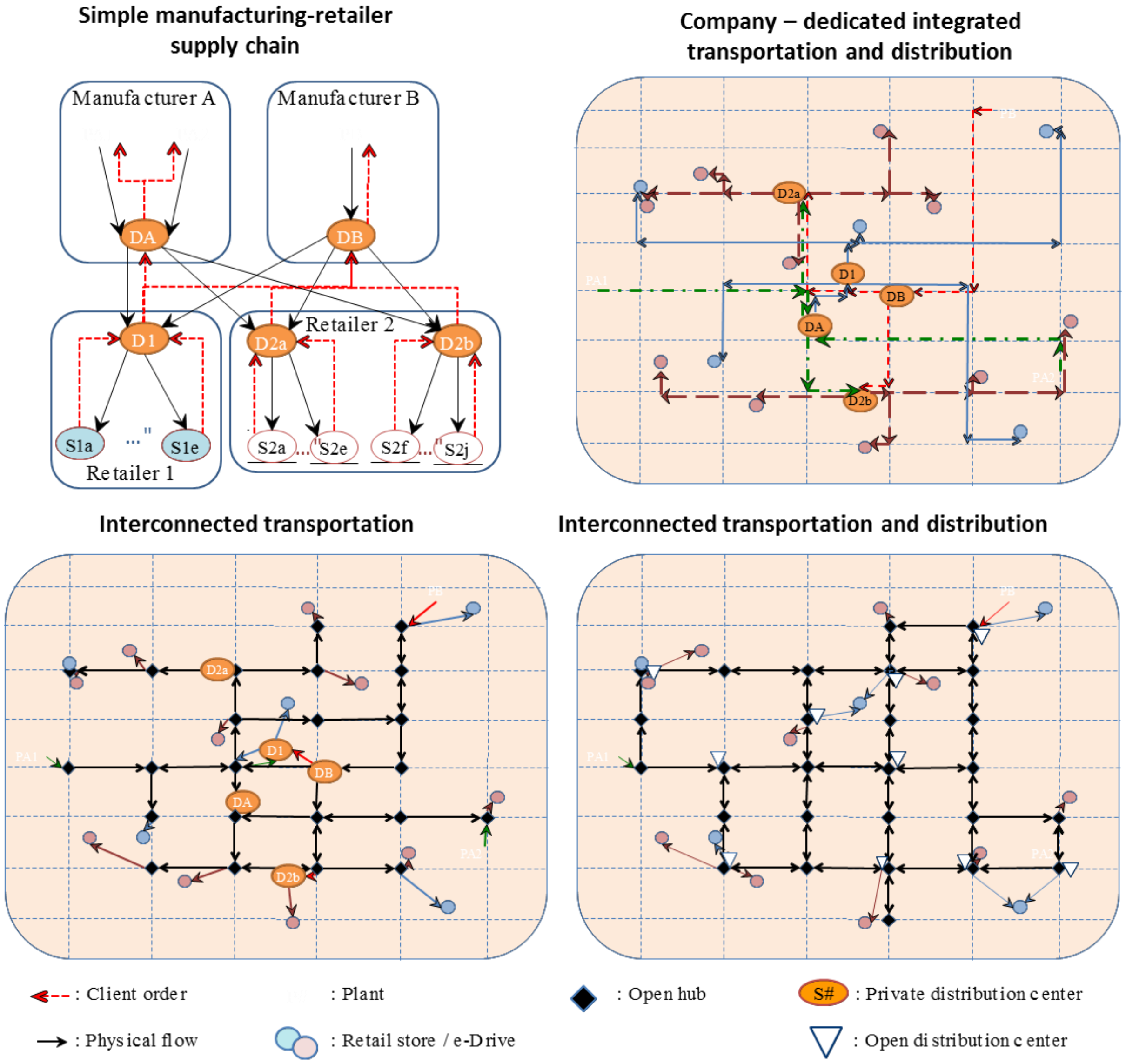

Figure 6. Contrasting company-dedicated integrated logistics and interconnected logistics for retail supply chains (Adapted from Hakimi *et al*., 2012)

Figure 6 provides two states of interconnected logistics. On the lower left side, only interconnected transportation is exploited. In the Physical Internet, there are numerous openly available hubs allowing to crossdock π-containers encapsulating goods, and there are numerous transporters available to move π-containers from hub to hub, irrespective of who is owning them. Instead of having each player end-to-end shipping its goods from their source to their destination, each one encapsulates them in sets of π-containers according to their specific destination, then just has the π-containers brought to the open hub nearest to their source. Then the interconnected transportation system gets it through the web of open hubs via multiple transporters, all the way to final destinations. In this case, it results in a 19% reduction of induced travel and a 29% reduction of consumed fuel at the price of a 15% longer average delivery time to store. The lower right side of Figure 6 exploits more of the potential of the Physical Internet, coupling interconnected transportation and interconnected distribution. The retailers and manufacturers do not anymore exploit their dedicated distribution centers. They rather rely on the availability of a web of open distribution centers for dynamically deploying the π-containers containing their goods nearby expected demands (Sohrabi et Montreuil, 2014). Compared to the baseline, this results in highly significant 79%

and 71% reductions of average and maximum delivery time to store, concurrently achieving also highly significant 42% and 44% reductions in induced travel and fuel consumption.

Recent studies have demonstrated the strong potential of the Physical Internet for economic, environmental and societal improvements in efficiency and sustainability. In the consumer goods industry, using the case of Carrefour, Casino and their top 106 suppliers, it has been shown by a France-Canada-Switzerland team (supported by the French PREDIT program) through a simulation-based experiment that shifting to Physical Internet enabled interconnected logistics may save on the order of 30% of total induced costs and reduce by 60% the greenhouse gas emissions while offering the same service level to consumers and getting truckers back home every day (Sarraj *et al*., 2014). Similarly a team from the CELDi research center (supported by the U.S. National Science Foundation) worked in collaboration with industry leaders such as CHEP, J.B. Hunt, Procter & Gamble, Tompkins International and WalMart, to show that if 25% of the US supply chain would adopt the Physical Internet, it would induce an annual profit boost of 100 billion $, a 32% reduction in greenhouse gas emissions (150+ Tg of CO2 annually), a reduction from 100% to 24% in annual driver turnover, and the US consumers would pay less for their goods (Meller *et al*., 2012).

INTERCONNECTED CITY LOGISTICS CONCEPTS

When applied to urban environments, the Physical Internet enables the emergence of what we term *Interconnected City Logistics (ICL)*, a rich conceptual framework for designing urban logistics and transportation systems that are significantly more efficient and sustainable. In this section, we identify the core concepts of ICL, as synthesized in Figure 7, and we illustrate a possible organization. Notice that several of these key concepts have a broader application to efficient logistics and transportation systems, and not only to urban freight transportation. This emphasizes the global view on logistics and transportation taken by the Physical Internet and the generalization of the City Logistics vision brought by the ICL.

Core Interconnected City Logistics Concepts		
Interconnect	Cities as Nodes of the World's Logistics Web	1
	Cities by Systems Standardization	2
	The Multi-Faceted Activities of City Logistics	3
	City Logistic Networks in an City Web Architecture	4
	The Multiplicity of Urban Logistics Center	5
	City Logistics Stakeholders into an Open System	6
	Goods Through Modular Logistics Containers	7
	People Mobility and Freight Logistics in the City	8
	City Logistics with Urban Planning	9

Figure 7. Synthesizing the core Interconnected City Logistics concepts

ICL concept 1: Interconnect Cities as Nodes of the World Logistics Web. The city and its ICL system are strongly interconnected with the rest of the world, being a node of larger regional, national and international logistics and transportation networks, overall shaping what we call the World Logistics Web. The interconnection with other cities and regions is a fundamental key to the city's logistics and transportation performance. One may think, to illustrate this interconnection, of the commercial traffic passing by and through the city, heavily using its road and intermodal infrastructure, or to the significant role that inbound and outbound flows have on the location and performance of intermodal facilities and open city-distribution centers making up the nodes of the city's ICL.

ICL concept 2: Interconnect Cities by Systems Standardization Whereas it is normal to consider one's city as being unique and to design a logistics system customized to its specific characteristics, it is however essential to aim for exploiting encapsulation, protocols and interfaces that are as standardized as possible among cities of the world. Indeed, most major users of the logistic system of a city are also treating with hundreds of other cities, and the same goes for the major transportation and logistics service providers. The last thing they want is to have each city setting its own standards, to have to learn and apply city-specific interfaces and protocols. This is true at the digital level (data, transactions, follow-up, etc.), physical level (packaging, facilities, vehicles, etc.), operational level (e.g., actual activities within facilities and the meeting of vehicles and facilities), as well as at the business model level (e.g., transactions and contracts). The drive for a comprehensive standardization will not be simple, as there are many cultural (in the broadest sense: political, social, business, etc.) differences between the cities and the countries of the world. Yet, quite a lot of standardization has already been achieved in container intermodal transportation, electronic data interchange, and Intelligent Transportation Systems, to name but a few. The specificity of the ICL for a particular city will then follow more from its location, topology, population, infrastructure and so on, rather than, for example, from basic logistics units such as the boxes freight is packed in.

ICL concept 3: Interconnect the Multi-Faceted Activities of City Logistics. As City Logistics emerged with the vision of treating the many freight transportation activities of the city as a system, for the most part it has focused on transportation only. Interconnected City Logistics goes beyond this somewhat limited perspective to a full-scope logistics-system perspective encompassing the way physical objects are moved, stored, realized, supplied and used. This goes beyond transportation, crossdocking, transshipment and handling activities, to include supply, value-adding, storage and deployment activities. As an example, the deployment of stocks, where to keep them, for how long, and how to supply the appropriate "customers", directly influences, and is influenced by, the transportation of the respective goods. Pooling the storage capabilities of the logistics facilities (e.g. CDCs) of participating stakeholders not only for keeping and distribution goods, but also to transship freight and route vehicles has a significant potential positive impact on the utilization of the freight vehicles, of all modes, their routing and scheduling and, thus, of the overall ICL.

ICL concept 4: Interconnect City Logistic Networks in a City Web Architecture. The City Logistics system architectures currently implemented and studied are rather strict in terms of logistics organization, with either a single or two tiers of logistics facilities, and utilization of vehicle fleets mostly belonging to the road mode, generally focusing on a particular city zone or a group of carriers and logistics service providers. Interconnected City Logistics shifts to a distributed, multi-zone, multimodal, web-like architecture with open logistics hubs as focal interconnecting nodes of the City Logistics networks, and multimodal pathways acting as connecting links carrying the flow, defining a web of freight corridors, through an intricate interplay of urban policies and business decisions. Some of the corridors and associated service providers have planned schedules such as rail-based services. Others dynamically adjust their routes, modes and schedules to demand as it emerges through the logistics web

ICL concept 5: Interconnect the Multiplicity of Urban Logistics Centers. Most City Logistics initiatives consider exploiting a single or a few logistics facilities, for example emphasizing the implementation of a City Distribution Center. The idea of using the capacity of multiple facilities when available is at best embryonic. Interconnected City Logistics takes a broader perspective. Rather than limiting its scope to new city logistics centers, it emphasizes the interconnected utilization of the multitude of existing urban logistics facilities and usable spaces, including public and private distribution centers, platforms and warehouses, transportation facilities (e.g., hubs, vehicle depots, garages, end of public-transportation lines), public and private parking spaces and facilities, postal facilities, as well as sites such as abandoned rail lines that can be retrofit for city-logistics purposes.

ICL concept 6: Interconnect City Logistics Stakeholders into an Open System. Interconnected City Logistics is an open system engaging a multitude of diverse actors who, while aiming for their own goals, contribute to the overall performance of the system. In operational terms, the city logistics web requires numerous multi-modal logistics and transportation service providers to co-operate to ensure consolidation and synchronization. In business terms, it involves contractual arrangements between users and providers, notably in terms of pricing, service level, liability, insurance in a distributed risk, cost, revenue and profit context, leading the way to ever more interconnected business models. In public-service terms, it involves having the authorities interacting with the city logistics stakeholders to as to put in place and enforce the appropriate environment in terms of legislation, regulation and policy at the national and international levels as well as at the city and urban community levels.

ICL concept 7: Interconnect Goods through Modular Logistics Containers. Standardized large-scale cargo containers, offering safe and hands-offs handling for very large ranges of very different products, are ubiquitous for long-distance freight transportation. City Logistics literature and practice has put minimal emphasis on loading units for moving and storing goods in urban environments. As described earlier and illustrated in Figure 5, the Physical Internet suggests encapsulating goods in standardized, smart, ecofriendly, modular π-containers ranging from the size of small boxes to the size of cargo containers. The PI research and innovation community is actively engineering the first generation of such π-containers, with the understanding that, as the cargo containers, there are to be multiple generations of ever better π-containers. Interconnected City Logistics considers universal interconnectivity as crucial and relies on π-containers in order to insure a private protective space for goods in the public urban space, easing their fast, cheap, reliable and seamless flow into, across and out of the city and its facilities.

ICL concept 8: Interconnect People Mobility and Freight Logistics in the City. The Interconnected City Logistics system breaks away from the currently dominating and often legally enforced dichotomy between people mobility and freight transportation and logistics. It puts centerfold the concept of interconnecting people mobility and freight logistics that is embryonic in city-logistics literature and practice, such as proposing and pilot testing the transport of freight in a tramway. ICS fundamentally aims for the synergistic exploitation of public transportation vehicles and infrastructures, currently dedicated to people mobility, for secure, safe and efficient joint freight and people transport. Examples include exploiting regular rail lines with stations within the core of the city (the ubiquitous Central Station), subways, tramways, bus lines, etc.. Another vivid example is interconnected crowd-sourced delivery, allowing individuals such as commuters to deliver encapsulated goods of appropriate size from a hub nearby their departure point to a hub nearby their destination, using their car, motorcycle, bicycle, or even walking, making some money and contributing to reducing greenhouse gas emissions (Rougès and Montreuil, 2014).

ICL concept 9: Interconnect City Logistics with Urban Planning. Transportation and logistics activities are strongly interlaced with the other activities of the city Accounting for these interactions and relieving the negative impacts of the former on the latter is a prime objective of City Logistics in general and ICL in particular. Moreover, the urban layout and land-use policies have a huge impact on Interconnected City Logistics performance. These well-acknowledged facts point directly to the need for a comprehensive vision interconnecting freight and people transportation and logistics to the larger activity networks of the city, and for integrated planning and analysis methods and instruments embedded into comprehensive systemic urban planning platforms.

Figure 8 conceptually illustrates the essence of Interconnected City Logistics systems through a possible stylized instantiation. The ICL system is made up of as many components as there are different zones in the city. Here, the city is sketched using three concentric rings corresponding to its three levels: suburbs, midtown and city center (downtown).

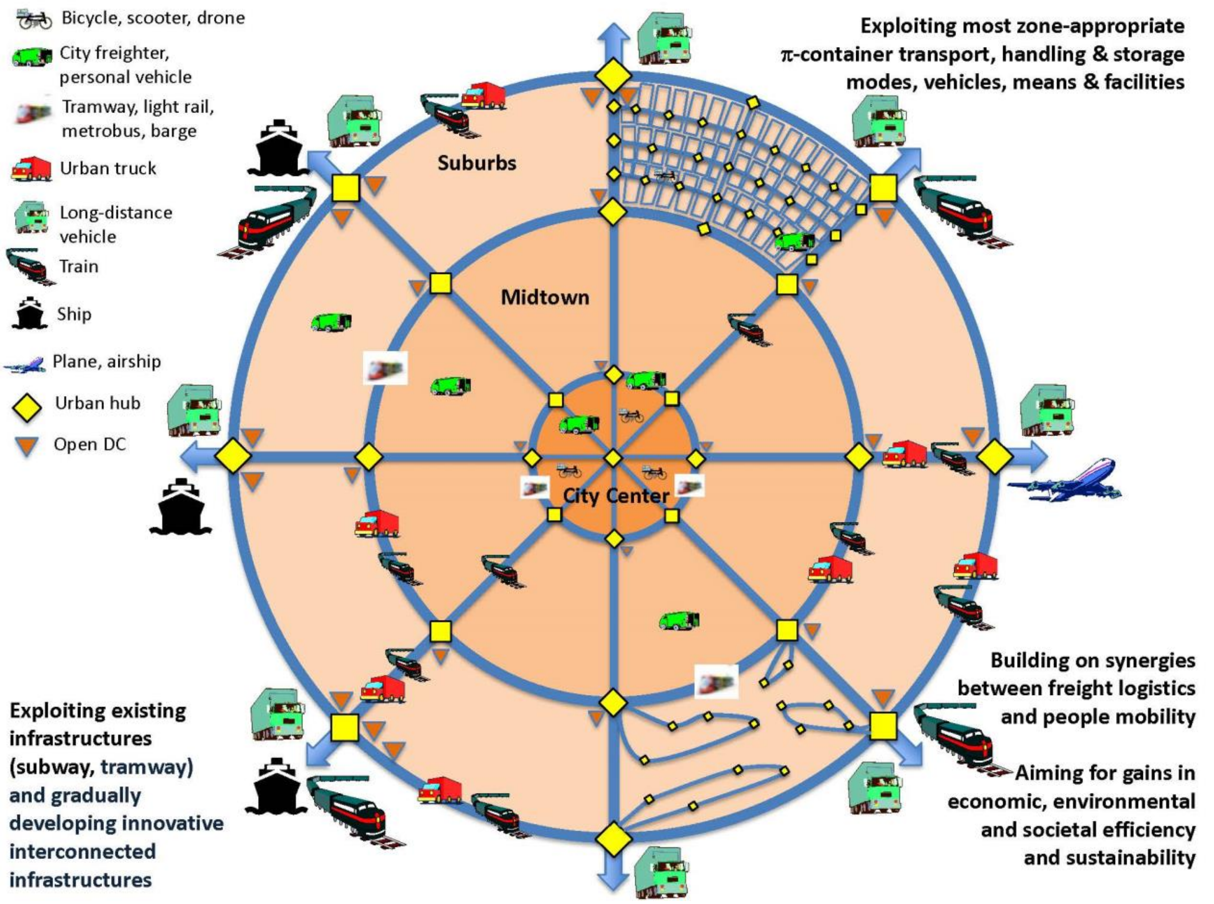

Figure 8. Illustrating Interconnected City Logistics instantiated in a concentric city

There is an outer ring with a set of urban multimodal gateway hubs that are located at strategic positions such as highway crossings, nearby airports and seaports, rail yards and so on. The urban gateway hubs openly receive, sort, transship, consolidate and ship both city inbound and outbound flows of goods encapsulated in π-containers. Nearby the outer ring and its gateway hubs are located sets of open peri-urban distribution centers (DCs) where, for example, businesses store their inbound goods in π-containers, buffering the city with sufficient inventory to deliver rapidly on demand their city customers.

The urban gateway hubs and the open peri-urban DCs are interconnected by a transportation ring facilitating multimodal flow along the outer circumference. Highways and rail, general or light, are generally making up the outer ring. There are also a midtown ring and a city-center fringe ring, similar in essence to the outer ring yet generally smaller as one goes more central. Along each ring, there are also sets of urban hubs and open DCs, expected to be smaller in inner rings.

The rings are interconnected by efficient radial flow corridors. Along the inner rings and radii, the transportation modes are increasingly involving smaller transport vehicles, buses, light rail and barges when canals are part of the city, as well as personal vehicles. Vehicles and carriers used in the more central areas, and in the residential areas in the suburbs and midtown zones, are generally smaller and ecofriendly, propelled using electricity, natural gas or active human effort.

Figure 8 illustrates that flows within zones of the city can be logistically structured in the interconnected way, illustrated here through the exploitation of small neighborhood hubs in a single suburb. Such neighborhood hubs, in their simplest essence, can take the shape of locker clusters where, for example, users can get access to their π-containers by unlocking them using coded signals from their mobile device (e.g., smartphones).

For visual clarity, we have drawn vehicle routes only in one suburb, and in limited quantity. Similarly, we have limited trains, light trains, subways and tramways to run along the symmetrical rings and radii. In practice, Interconnected City Logistics is to exploit existing such infrastructures that may be zigzagging through the city, and would gradually develop innovative interconnected infrastructures. Also, open DCs have been limited to locations near the urban hubs. In practice, ICL is to exploit any DC made open by its owner, respecting the Physical Internet interfaces and protocols, and designed to handle and store π-containers. Finally, it must be made clear that the proposed instantiation of ICL inherently builds on synergy between freight and people mobility, smartly interconnecting their usage of public infrastructures, public transport such as buses, as well as individual vehicles.

CONCLUSION

City Logistics and the Physical Internet are two major new concepts aiming to profoundly change the way freight transportation and logistics systems are defined, designed, planned, operated and managed for increased economic, environmental and societal efficiency and sustainability. Cooperation, consolidation and a separation of the commercial transactions generating the freight loads and the way they are actually moved and stored are key concepts for both City Logistics and Physical Internet. The concepts are complementary, as City Logistics provides the final and last segments of the Physical Internet-enabled interconnected logistics and transportation networks. To our best knowledge, this is the first study exploring the necessary links and synergy between these advanced transportation and logistics systems.

In this paper, we introduced the notion of *Interconnected City Logistics* bridging this gap, together with nine fundamental concepts offering a rich framework for designing efficient and sustainable urban logistics and transportation systems.

As with City Logistics and the Physical Internet, ICL is simultaneously a global concept, a desirable target for possible future city organizations, and a blueprint for innovation to address the many and multi-disciplinary research and development challenges of designing, engineering, justifying, planning, implementing, operating and managing such future organizations. We highlight some of those in the following paragraphs, along four concurrent axes: concept, assessment, solutions and validation.

Along the concept axis, we provided a first high-level contribution, not to be considered as the ultimate ending but rather as an exploratory beginning. Each core concept needs to be addressed in much further depth, as well as the interconnections between them.

Visions of interconnected city logistics should be developed for real cities of multiple sizes and types, holistically instantiating an ICL system, depicting and describing it so that it is vividly graspable by all stakeholders and can be analyzed, challenged, and further engineered. What has to be generic for cities worldwide and what has to be tailored for each city must be delineated.

From a business perspective, interconnected business models have to be developed for the various infrastructure and service providers as well as for the users. From a public governance perspective, sets of ICL-enabling city policies and regulations have to be conceived as well as the ICL-fostering financial and legal environment. Each of the key constituents of ICL systems has to be further designed and engineered.

Roadmaps toward the ubiquitous implementation and exploitation of interconnected city logistics have to be conceived and planned, both from a worldwide perspective encompassing all cities and from the perspective of individual cities in their quest towards ICL adoption. Such roadmaps include well-delineated phases, from simple, easy and fast to implement, success and confidence building phases, gradually evolving to subsequent more evolved phases building on the first phases. Scalability, complexity harnessing, risk management, adaptability and resilience should be at the core of the designs for each phase.

Along the *assessment* axis, the essence is to size the opportunity in terms of economic, environmental and societal efficiency and sustainability. This has to be achieved for individual cities of various sizes and types (culture, industrialization, etc.), for society overall encompassing all cities, and for specific single-city and multi-city stakeholders. Assessment studies are also needed to contrast alternative system architectures, protocols, operating models, strategies, policy designs, revenue models, and so on.

Assessment studies are to be achieved through analytics, optimization and simulation based experiments. Examples of such studies for the overall Physical Internet can be found in Meller *et al.* (2012), Sarraj *et al.* (2014) and Ballot *et al.* (2015). Numerous other operations research approaches can contribute to rigorous assessment, such as game theory and multi-level programming.

Along the *solutions* axis, the aim is to bridge the gap from current to required capabilities for enabling Interconnected City Logistics. Solutions have to be conceived for the multiple challenges aiming to overcome the numerous hurdles towards making it happen.

At the physical level, the requirements for city handling, storage and transport have to be embedded in the design and engineering of π-containers. Urban hubs and open distribution centers, from large peri-urban gateway hubs and DCs to small, distributed urban depots, have to be designed, engineered and prototyped. Urban vehicles and transport systems enabling smooth and efficient interconnected transportation have also to be designed, engineered and prototyped. Automation and robotization of appropriate city logistics activities should be investigated, taking advantage of the multi-faceted standardization inherent to ICL

At the operational level protocols and operating processes have to be elaborated enabling the smooth flow across the city of goods and people through an interconnected web of transportation and logistics service providers. How to insure the open consolidation and coordination necessary for lead times, reliability and costs to be improved sustainably? Dynamic, indeed quasi real-time, routing, scheduling, pricing and inventory deployment rules and algorithms have to be designed for the stochastic, fast-pace, multi-party, multimodal, distributed context of ICL. In essence, the dynamics of Interconnected City Logistics operations has to engineered and instrumented, within the City Logistics objectives of less vehicles in the city and less impact on the environment and congestion.

At the planning level, models and methods have to be developed for evaluating, designing and planning system architectures, services and operating-management policies.

Others have to be developed for supporting businesses and cities in designing their service offerings; in designing, sizing and locating their facilities, fleets and corridors, as well as for capacity and service planning subject to stochastic, day-to-day and seasonal variations of demand and resource availability. The planning models and methods must take into consideration the multi-objectives of ICL in terms of economic, environmental and societal efficiency and sustainability. At strategic and tactical levels, there should be integrated city planning methods encompassing considerations for interconnected city logistics of people and freight; a big challenge as the most advanced current systems for people transport address individual and public transport separately.

At the digital level, informational and decisional interconnectivity has to be enabled, including citywide real-time status and performance monitoring, visibility and traceability of π-containers, facilities, vehicles, infrastructures and services. Intelligent Transportation systems and Internet-of-Things technologies such as RFID and GPS, as well as their associated coding systems have to be harnessed and combined for comprehensive urban environments. Digital platforms and applications supporting ICL have to be engineered and realized, interconnecting all logistics service users and providers, enabling smart on-time decision making as well as more tactical and strategic planning. These should be accessible on smart devices by individuals on the fly for them to easily exploit or contribute to logistics services. The advances in intelligent transportation systems should be put to contribution.

Along the *evaluation* axis, there is a need for field-based or virtual pilot studies, case studies and living labs anchored in real cities of distinct sizes and types, in various cultural and political environments, where Interconnected City Logistics implementations are tested, allowing to evaluate the feasibility, performance and adoptability of ICL architectures, designs, policies, strategies, protocols, π-containers, facilities and platforms. First, the experiments are to be small scale, focused on a limited set of ICL constituents. Then, gradually larger-scale and more comprehensive experiments are to be performed.Overall, Interconnected City Logistics offers breakthrough potential in terms of efficiency and sustainability. This potential induces complexities and challenges in line with those of the Physical Internet in general and of City Logistics in particular. The introduction of Interconnected City Logistics goes way beyond the current state of City Logistics and opens a wealth of opportunities for research and innovation.

ACKNOWLEDGEMENTS

The authors thank the Discovery Grant and the Discovery Accelerator Supplements Programs of the Natural Science and Engineering Research Council of Canada, the Canada Research Chair in Business Engineering, the Strategic Clusters program of the *Fonds québécois de la recherche sur la nature et les technologies*, as well as Georgia Tech's Coca-Cola Chair in Material Handling and Distribution for supporting this research. While working on this project, the first author was Adjunct Professor with the Computer science and Operations Research Department, University of Montreal.

References

Ballot, É, Montreuil,B., Meller, R.D. (2014), *The Physical Internet: The Network of Logistics Networks*, La Documentation Française, Paris, France, 205 p.

Benjelloun, A, Crainic, T.G. (2008), Trends, Challenges, and Perspectives in City Logistics, In *Transportation and Land Use Interaction*, Proceedings TRANSLU'08, 269-284, Politecnica Press, Bucharest, Romania.

Benjelloun, A, Crainic, T.G., Bigras, Y. (2010), Toward a Taxonomy of City Logistics Projects, *Procedia - Social and Behavioral Sciences*, 2(3), 6217-6228.

Browne, M., Rizet, C., Allen, J. (2014), A Comparative Assessment of the Light Goods Vehicle Fleet and the Scope to Reduce its CO_2 Emissions in the UK and France, *Procedia Social and Behavioral Sciences*, 125, 334-344.

Butner, K. (2010), The smarter supply chain of the future, *Strategy & Leadership*, 38(1), 22-31.

Crainic T.G., Errico, F., Rei, W., and Ricciardi, N. (2012), Integrating c2e and c2c Traffic into City Logistics Planning. *Procedia - Social and Behavioral Sciences*, 39, 195-204.

Crainic T.G., Ricciardi, N. Storchi, G. (2004), Advanced Freight Transportation Systems for Congested Urban Areas, *Transportation Research Part C: Emerging Technologies*, 12(2), 119-137.

Crainic T.G., Ricciardi, N. Storchi, G. (2009), Models for Evaluating and Planning City Logistics Transportation Systems, *Transportation Science*, 43(4), 432-454.

Dablanc, L. (2007): Goods transport in large European cities: Difficult to organize, difficult to modernize, *Transportation Research Part A: Policy and Practice*, 41(3), 280-285.

De Souza, R. Goh, M., Lau, H.-C., Ng, W.-S., Tan, P.-S., Collaborative Urban Logistics – Synchronizing the Last Mile, A Singapore Research Perspective, *Procedia Social and Behavioral Sciences*, 125, 422-431.

Diziain, D., Taniguchi, E., Dablanc, L. (2014), Urban Logistics by Rail and Waterways in France and Japan, *Procedia Social and Behavioral Sciences*, 125, 159-170.

Ducret, R., Delaître, L. (2013), Parcel delivery and urban logistics - changes in urban courier, express and parcel services: the French case, 13thWorld Conference on Transport Research, July 15-18, 2013 - Rio de Janeiro, Brazil, https://halshs.archives-ouvertes.fr/halshs-00853932, Accessed December 30 2014.

Environment Canada (2013), *Canada's Emissions Trends*, Environment Canada.

European Commission (2011). *Regulation (EU) No 510/2011 - Setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light-duty vehicles*. Brussels: European Council.

Gonzalez-Feliu, J., Semet, F., Routhier, J.-L. (Eds), (2014), *Sustainable Urban Logistics: Concepts, Methods and Information Systems*, Springer.

Gragnani, S., Valenti, G., Valentini, M.P. (2004), City Logistics in Italy: A National Project, In E. Taniguchi and R.G. Thompson (Eds.), *Logistics Systems for Sustainable Cities*, 279-293. Elsevier.

Hakimi D., B. Montreuil & E. Ballot (2012), Simulating a Physical Internet Enabled Logistics Web: the Case of Mass Distribution in France, *ISERC 2012 Proceedings*, 2012/-5/19-23.

Holguín-Veras, J., Wang, C., Browne, M., Hodge, S.D. and Wojtowicz, J. (2014), The New York City Off-Hour Delivery Project: Lessons for City Logistics, *Procedia Social and Behavioral Sciences*, 125, 36-48.

Holguín-Veras, J., Ozbay, K., Kornhauser, A., Brom, M.A., Iyer, S., Yushimito, W.F., Ukkusuri, S., Allen, B. and Silas, M.A. (2011), Overall impacts of off-hour delivery programs in the New York City metropolitan area, *Transportation Research Record*, 2238, 68-76.

Huart, A. (2011), *Optimization of multi-modal transportation chains in city logistics / Optimisation de ressources en logistique urbaine*, Ph.D. Thesis, Université de Valenciennes et du Hainaut-Cambrésis, France.

Meller, R.D., Ellis, K.P., Loftis, B. (2012), *From Horizontal Collaboration to the Physical Internet: Quantifying the Effects on Sustainability and Profits When Shifting to Interconnected Logistics Systems.* Final Research Report of the CELDi Physical Internet Project, Phase I, http://faculty.ineg.uark.edu/rmeller/web/CELDi-PI/Final%20Report%20for%20Phase%20I.pdf, Accessed 30 December 2014.

Montreuil, B. (2011), Towards a Physical Internet: Meeting the Global Logistics Sustainability Grand Challenge, *Logistics Research*, 3(2-3), 71-87.

Montreuil B. (2012). *Physical Internet Manifesto: Globally Transforming the way physical objects are handled, moved, stored, realized, supplied and used*, version 1.11, www.physicalinternetinitiative.org

Montreuil, B., E. Ballot, W. Tremblay (2015), Structural Modular Design of Physical Internet Containers, *Progress in Material Handling Research vol. 13*, MHI, USA, to appear.

Montreuil, B., Meller, R.D., Ballot, E. (2013), Physical Internet Foundations, In *Service Orientation in Holonic and Multi Agent Manufacturing and Robotics*, T. Borangiu, A. Thomas and D. Trentesaux (Eds), Springer, 151-166.

Physical Internet Initiative (2012), www.physicalinternetinitiative.org. Accessed 2014/12/29.

OECD (2003), *Delivering the Goods: 21st Century Challenges to Urban Goods Transport*, Technical report, Organisation for Economic Co-operation and Development, OECD Publishing, http://www.oecdbookshop.org

Rougès J.-F. & B. Montreuil (2014), Crowdsourcing delivery: New interconnected business models to reinvent delivery, *1st Physical Internet Conference IPIC 2014*, Québec, Canada.

Sarraj, R., Ballot, É, Pan, S., Hakimi, D. and Montreuil, B. (2014), Interconnected logistics networks and protocols: simulation-based efficiency assessment, *International Journal of Production Research*, 52(11), 3185-3208.

Sohrabi H. & B. Montreuil (2014), Towards an interconnected distribution planning framework, *1st Physical Internet Conference IPIC 2014*, Québec City, Canada, 14p.

Sterle, C. (2009), *Location-Routing Models and Methods for Freight Distribution and Infomobility in City Logitics*, Ph.D. Thesis, Ingegneria Informatica ed Automatica, Università degli Studi di Napoli "Federico II".

Taniguchi, E., Thompson, R.G., Yamada, T. (2003), Predicting the effects of city logistics schemes, *Transport Reviews*, 23(4), 489-515.

Taniguchi, E., Thompson, R.G., Yamada, T. (2013), Recent trends and innovation in modelling city logistics, *Procedia Social and Behavioral Sciences*, 125, 4-14.

Taniguchi, E., Thompson, R.G., Yamada, T. and Van Duin, J.H.R. (2001), *City Logistics: Network Modelling and Intelligent Transport Systems*, Pergamon.

Van Duin, J.H.R. (2014). City logistics through the canals? A simulation study on freight waterborne transport in the inner-city of Amsterdam. *International Journal of Urban Sciences*, 18(2), 186-200.

Visser, J., Nemoto, T. and Browne, M. (2014). Home delivery and the impacts on urban freight transport: A review. *Procedia Social and Behavioral Sciences*, 125, 15-27.