An integrated two-layer network design model for an Interconnected Public and Freight Transportation System

Mellila Kechir[1,2], François Clautiaux[1], Olivier Labarthe[2], Walid Klibi[2]

[1] Université de Bordeaux, Institut de Mathématiques de Bordeaux, UMR CNRS 5251, Centre Inria de l'Université de Bordeaux, France

[2] The Centre of Excellence for Supply Chain Innovation and Transportation (CESIT), Kedge Business School, Bordeaux, France

Mots-clés : *Hyperconnected city logistics, Multi-Layer network design, Freight transportation, Urban mobility, Mixed-Integer Programming*

Managing efficient and effective city logistics is a raising challenge because of different issues and trends that are continuously impacting urban areas. For instance, the increasing urban population density is one of the key elements. Population growth created important passenger flows that have their own operating network with dedicated resources (private like cars and public like buses and tramways) and infrastructures (roads, rails). At the same time, the rise of e-commerce, especially during the COVID-19 crisis, led to an important increase in the number of deliveries of different natures and sizes to different areas of the city. These flows are taking over within the city and are co-existing with the passenger ones. However, they involve more resources, such as trucks and extra vehicles causing a saturation in the systems and creating issues like congestion, air and noise pollution, discomfort, etc. Even though both previous networks operate similarly in the same environment, the traditional practical and theoretical scheme imposes a separation between them in terms of flows, infrastructures, resources, etc (Crainic and Montreuil, 2016).

In practice, connecting people, objects, and networks in a unified, open, interconnected system involves two concepts: hyperconnectivity and synchromodality, which fall under the concept of *Physical Internet* (PI) proposed in (Montreuil, 2011) that defined it as *"transforming the way physical objects are handled, moved, stored, realized, supplied and used, aiming towards global logistics movements, shipping and sustainability"* . When applied to urban environments, PI emerges the concept of *Hyperconnected City Logistics* (HCL) that aims to design more efficient urban logistics and transportation systems. HCL relies on nine main concepts about interconnection synthesized in (Montreuil, 2011), including the concept of *integration and interconnection of passenger and freight movements in urban transit systems.* This latter establishes synergies between public transportation vehicles and infrastructures dedicated to people mobility and freight transportation operators and resources in order to move simultaneously people and freight in a secure and efficient way. In the literature and practice, long-haul freight transportation has witnessed the combination of people and freight flows using aircrafts, ferries, trains such as "Norwegian Hurtigruten carry freight" (Levin et al., 2012, "Hurtigruten Cruises Norwegian fjords & Northern Lights", n.d.). However, when it comes to short-haul transportation and specifically to last mile delivery in urban areas, very few studies are considering this option (Pimentel and Alvelos, 2018).

In our work, we focus on combined systems considering multi-modal transportation and particularly public transportation modes to transport a part of goods in the context of HCL. In a such environment, instead of managing the resources (vehicles and service scheduling), we make use of the PI concept to manage the parcels as entities of the problem. This vision to the problem, allows to consider parcels as flows and to move from the traditional separated routing, service scheduling and resource management decisions to connected consolidation and flow decisions in one model. In addition, we take into consideration the practice of consolidation and containerization and a hub-based network structure due to the nature of flow.

During last mile delivery, the important flow of small-sized parcels from multiple origins to multiple destinations makes hub-based networks suit better, as they are more likely to induce consolidation and economies of scale (Kaboudvand et al., 2021). When parcels are traveling in the same direction, they can be grouped into containers in order to facilitate their transportation, but also their handling, loading and unloading process at hubs. The containers are then loaded in transportation modes and moved jointly with passengers as independent units. The consolidation of parcels in containers helps to achieve significant reductions in transit times and the number of parcels touches which simplifies handling, loading and unloading processes at the hubs (Kaboudvand et al., 2021). The HCL setting opens accessibility to multiple mobility options such as tramway and bus as well as freight options such as urban vehicles and cargo bikes. The containers can then be transshipped from a mode to another and the parcels reloaded from a container to another.

In the literature, the decisions of consolidating parcels and managing their flows are in general treated by two different models and not integrated while in our case, they are combined. In the defined new operational setting, this makes the classical formulation less adequate and we aim to fill this research gap by investigating a new modeling approach of the problem as multi-layer network.

In this presentation, our contribution is threefold. First, we define precisely the problem with all the features described above. Second, we narrow the modeling gap in the literature by presenting an integrated two-layer network design model for the operational problem in the HCL environment including the different dimensions presented previously. Finally, we build a benchmark based on real data of the city of Bordeaux in France and demonstrate a real-world application to derive the economical and ecological benefits of the model for the city stakeholders.

References

Crainic, T. G., & Montreuil, B. (2016). Physical Internet Enabled Hyperconnected City Logistics. *Transportation Research Procedia*, *12*(June 2015), 383–398. https://doi.org/10.1016/j.trpro.2016.02.074

Hurtigruten cruises norwegian fjords & northern lights [[Online; accessed 2022-11-02]]. (n.d.). https://global.hurtigruten.com/

Kaboudvand, S., Montreuil, B., & Savelsbergh, M. (2021). Hyperconnected Megacity Parcel Logistic: Joint Parcel Routing and Containerized Consolidation. http://arxiv.org/abs/2103.02080

Levin, Y., Nediak, M., & Topaloglu, H. (2012). Cargo capacity management with allotments and spot market demand. *Operations Research*, *60*(2), 351–365. https://doi.org/10.1287/opre.1110.1023

Montreuil, B. (2011). Toward a physical internet: Meeting the global logistics sustainability grand challenge. *Logistics Research*, *3*, 71–87. https://doi.org/10.1007/s12159-011-0045-x

Pimentel, C., & Alvelos, F. (2018). Integrated urban freight logistics combining passenger and freight flows - Mathematical model proposal. *Transportation Research Procedia*, *30*, 80–89. https://doi.org/10.1016/j.trpro.2018.09.010