Hyperconnected Urban Delivery with synergized public transportation options and containerization.

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Abstract: *This paper investigates a comprehensive exploration of a hyperconnected urban delivery system that synergizes public transportation options with containerization for efficient parcel logistics. The study focuses on optimizing the urban middle-mile segment of parcel delivery, emphasizing the integration of freight operations into existing public transport networks. This paper applies three means & ways concepts from the Hyperconnected City Logistic framework: open response planning, open resource deployment, and open capability enablement and adapts them. These three groups of decisions are interconnected, each influencing and complementing the others to enable the creation and efficient use of an urban logistics system using public transport and containerization.*

Keywords: *Physical Internet, Hyperconnected City Logistics, Freight transportation, Urban mobility, Public Transportation.*

Physical Internet (PI) Roadmap Fitness*: Select the most relevant area(s) for your paper according to the PI roadmaps adopted in Europe and Japan: ☐ PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories), ☐ Transportation Equipment, ☐ PI Networks, ☒ System of Logistics Networks, ☐ Vertical Supply Consolidation, ☐ Horizontal Supply Chain Alignment, ☐ Logistics/Commercial Data Platform, ☐ Access and Adoption, ☐ Governance.*

Targeted Delivery Mode-s*: ☒ Paper, ☐ Poster, ☐ Flash Video, ☒ In-Person presentation*

1 Introduction

1.1 Motivation

Since the COVID-19 crisis, the growth of Annual e-commerce sales in France has been significant: annual e-commerce sales have risen from €103.4 billion in 2019 to €146 billion in 2022, an increase of 41% (Fevad, 2023). This increase has led to a significant rise in the number of deliveries of different types and sizes in the city's various areas. In addition, the consumer desire for speed is constantly evolving, and same-day deliveries are more and more popular for the consumer, involving more resources, more saturation in city centers, and creating congestion and pollution by using more and more urban vehicles. Simultaneously, the increasing urban population density creates important passenger flows with their own operating network with dedicated resources (private like cars and public like buses and tramways) and infrastructures (roads, rails). Within urban areas, many public transport services are available, making it possible to reach pedestrian zones in the city centers that are inaccessible to freight vehicles. Often full during rush hour, public transport provides underutilized spare capacity during off-peak hours.

Despite similarities between freight network and people mobility within the same urban environment, the conventional practical framework imposes a separation in terms of flows, infrastructures, and resources. It is in this context of network separation that the physical Internet (PI) (Montreuil, 2011) is emerging, removing the separation between the two networks by connecting people, objects, stakeholders, and networks in a unified, open, interconnected system. When applied to urban environments and city logistics, PI emerges the concept of Hyperconnected City Logistics (HCL) (Crainic et al., 2016). HCL aims to create new urban logistics and transportation systems that are more efficient and sustainable. HCL framework gives several concepts, this study integrates the concept of integration and interconnection of passenger and freight movements. This concept establishes synergies between public transportation infrastructures dedicated to passenger mobility and freight networks characterized by hyperconnectivity and synchromodality (Labarthe et al., 2024).

Figure 1: TRAM-FRET Pilot, Bordeaux, France, 2015 (Source: Kedge)

Figure 2: KombiBus, Germany, since 2010 (Source: KombiBUS Gruppe)

Figures 1 and *2* illustrate projects combining one type of public transportation with freight. To facilitate movement within the public transport system, parcels are grouped together. Containerized parcels save space inside the public transportation and time to load/unload it.

In our work, we investigate combined systems, considering multimodal transportation, particularly public transportation modes, to transport part of goods in the context of HCL using parcel containerization.

1.2 Business Context

We consider the practice of consolidation and containerization. To unify the handling, loading, and unloading process at hubs for the parcels, they are grouped into containers when they are traveling in the same direction (Kaboudvand et al., 2021). Figure 3 illustrates the containerization and consolidations.

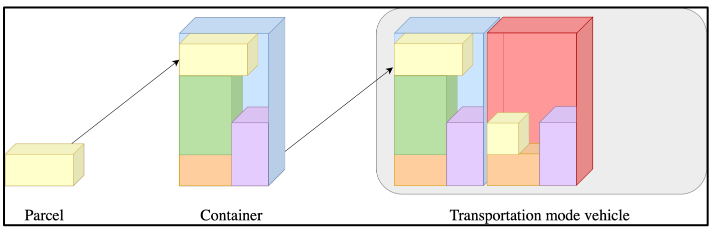

Figure 3: consolidation

In the urban context, demand is considered as a volume of parcels with an origin and a destination. Demand is available at a given time in an area and must reach its destination within a given time. To achieve this, we consider a Hyperconnected Urban Delivery System (HUDS) with three tiers: urban first-mile, urban middle-mile, and urban last-mile (*Figure 4)*. Our HUDS network is made of different logistic urban vehicles from the urban freight network and public transportation modes from the people mobility network.

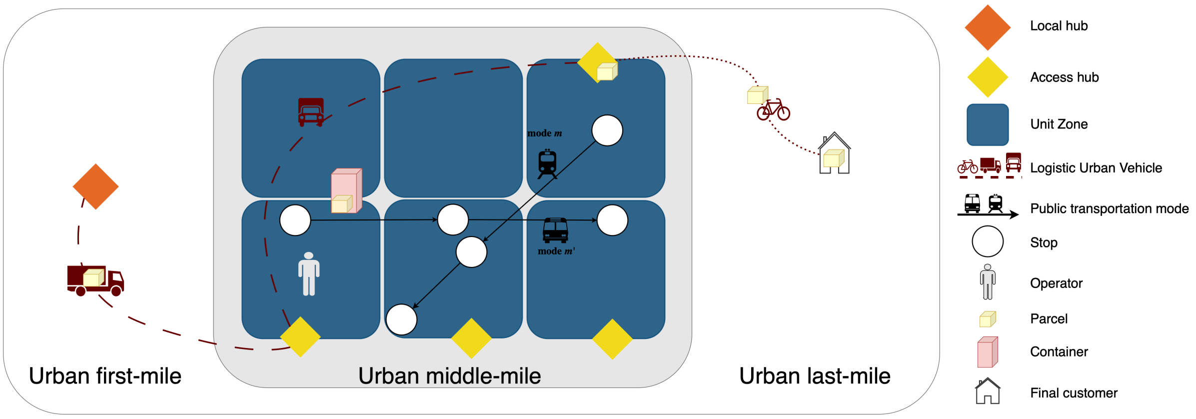

Figure 4: Hyperconnected Urban Delivery System description

The urban first-mile corresponds to the movement where an urban vehicle transports the parcel from a local hub to an access hub near the public transport network. Conversely, the urban last-mile corresponds to the last step, where the urban logistics vehicle delivers the parcel to its final customer. In this paper, we focus on the urban middle-mile. Assuming that demand is available at an access hub and must reach another access hub destination, we want to use our HUDS network at our disposal to demonstrate the efficiency of public transport in urban delivery. We, therefore, assume that at access hubs, urban logistics vehicles are perfectly synchronized with our urban middle-mile tiers to ensure that parcels are available on time. In cases where demand cannot reach the access hub destination by public transport within the required timeframe, we use an emergency urban logistics vehicle capable of reaching the destination directly. To move inside the public transport network, parcels are consolidated in containers to facilitate their transport. The urban area is divided into zones containing stops. Operators can be assigned to zones to authorize consolidated parcels evolving within the network. By consolidating transportation needs and using shared resources, the HUDS can achieve the same level of service with fewer resources, resulting in reduced gas emissions and pollution (Bektas et al. 2015). Additionally, managing the integration of various transportation public modes with urban freight networks opens additional business opportunities.

Recently, several studies have investigated urban parcel delivery systems with public transportation options. (Yang et al. 2024) propose a co-modality system, passenger-freight, in which passengers on the public transport network can carry parcels from the freight network, and these passengers are synchronized with the freight service. (Delle donne et al. 2023) propose the strategic integration of freight and passengers inside public transportation; however, transshipment operation isn't authorized in this study. In contrast, (Li et al. 2024) integrate freight transportation into the underground city logistics system, authorizing operations on train units. Regarding consolidation and containerization, (Kaboudvand et al. 2021) study containerized consolidation inside a Hyperconnected Parcel Logistics. The latter work doesn't consider public transportation services.

Our research contributes to the field of urban parcel logistics by integrating the Hyperconnected City Logistics framework into a hyperconnected urban network using public transportation infrastructure. Focused on the middle-mile segment of parcel delivery within urban areas, our study proposes a combined transportation system that merges passenger mobility with freight movements. A key aspect of our approach is the adoption of containerization practices, whereby parcels are consolidated within, allowing them to move inside the public transport network, changing lines an unlimited number of times with the support of the workforce.

This paper is organized as follows. In Section 2, our proposed approach is presented to answer the business context. Section 3 is dedicated to discussing and modeling our adaptation of three core concepts of the Hyperconnected City Logistic framework. Finally, the conclusion and perspectives are discussed.

2 Proposed approach

We are interested in the means & ways category of the Hyperconnected City Logistic framework (Crainic et al., 2023) enabling and leveraging logistic Hyperconnectivity. Our proposed approach focuses on an application of three of the fourteen core concepts of the HCL framework, *Figure 5*.

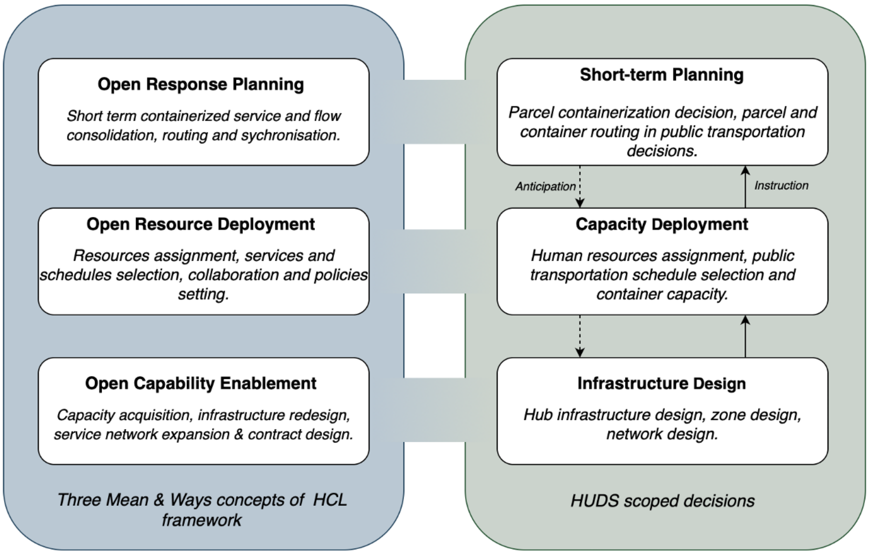

Figure 5: Scoped decisions adapted from (Crainic et al. 2023)

To create an effective Hyperconnected Urban Delivery System (HUDS), we consider three types of decisions adapted from the HCL framework: short-term planning, capacity deployment, and infrastructure design. Each decision is linked to the others, and together, they create a network that allows the joint optimization of these decisions.

The decision on *infrastructure design* is the one made upstream, as it takes place seasons or years before implementation. It corresponds to the “open capability enablement concept” for our HUDS. A service network design is established, focusing on the delivery network design, selecting the infrastructures (hub and transportation mode) to be utilized or created, and their role. Then comes the decision on *capacity deployment*, which is considered to take place weeks or months before. Capacity assignment of a hyperconnected network in parcel logistics is imperative to define because it delineates the boundary of feasible activity within a technological system. It is adapted from the “open resource deployment” consisting of allocated capacity as the human resources required to carry out consolidation operations, the public transportation frequency, and container characteristics. Finally, the decision on *short-term planning* is made shortly before execution, days or even hours in advance. This decision is adapted from the “open response planning” concept and consists of studying the flow of parcels and their consolidation into containers within various modes of public transportation.

The outcome of each decision serves as the basis for the next, creating a loop where the results of one decision provide the input instructions for the next. The model of the previous decision acts as a simulation, guiding the formulation of subsequent decisions and enabling the model to be adapted. This process ensures that each decision contributes to the overall efficiency of the HUDS. To ensure that it is adapted to the specific needs and challenges of urban delivery, it is necessary for each decision to define the objectives, constraints, and information available. This is the subject of the next section.

3 Discussion and modeling

3.1 Short-term Planning

To implement the short-term planning model, it is imperative to initiate the decisions made at the two other levels: capacity deployment and infrastructure design. Infrastructure design provides the network structure with zone configurations, specifying the number of lines and stops used. The capacity deployment model provides instructions on operator allocation and determines the number of operations authorized in each zone. It sets limits on the number of containers per public transportation mode and establishes fixed transport frequencies.

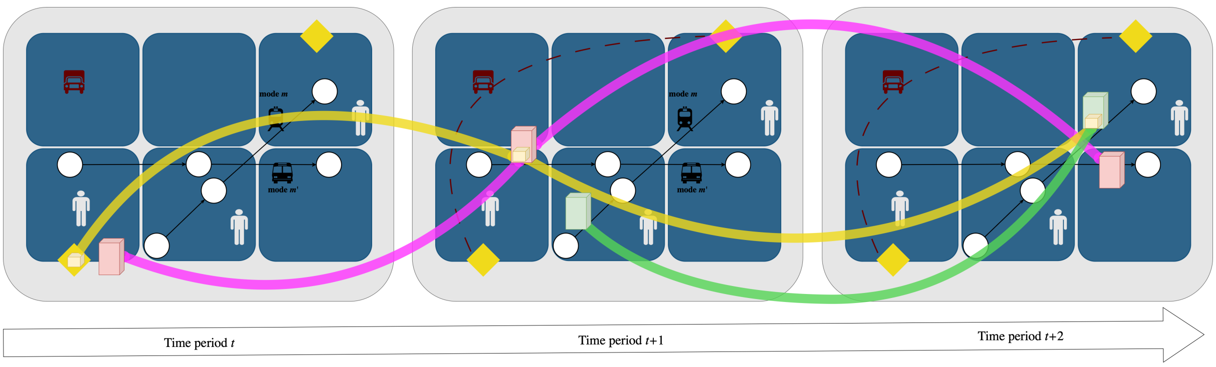

Figure 6: Parcel and container routes planning.

Figure 6 highlights route planning for parcels and containers during different periods. The objective of short-term planning is to assign each parcel a route composed of containers and transportation modes. In this model, decisions focus on planning routes of parcels and containers in our HUDS while ensuring efficient coordination between them to apply containerization.

Parcel routing and container consolidation represent interconnected decision problems (Kaboudvand et al., 2021). Parcels cannot travel independently and must be contained inside containers. Time constraints are important, as they dictate when parcels are available at their origin hub and when they must reach their destination hub. It is essential to consider these time intervals to ensure timely delivery within designated time frames. The last constraint to add is during specific freight operations, and careful consideration must be given to the time required between the various modes engaged in the process. If modes are not synchronized, a reasonable waiting period should be added in to ensure smooth operations.

3.2 Capacity deployment

To ensure efficient parcel and container movement, it is important to optimize the allocation of resources and capacity within the network. The aim is to allocate capacity while maximizing utilization and minimizing costs. For this purpose, we have information from the other decision level: infrastructure design. This includes instructions on the network's design, such as zone configurations and the number of lines and stops used. The short-term planning model, as it takes effect earlier, can be used to simulate the results found in the capacity deployment model. In our capacity deployment problem, we consider levels of demand that evolve throughout the day. For each demand, a time of availability at its source is known, as well as the time at which the demand must be at its destination.

The decisions associated with capacity deployment focus on human capacity allocation, PI-container characteristics, and public transport scheduling. These three decisions can be handled separately.

Human capacity allocation

To enable demand to evolve in the network and reach its destination with public transport, the quantity of workforce assigned to a unit zone at a time interval must be chosen. Operators can have short or long-term contracts, as already deployed in Bordeaux with (ELISE), which hires people on long-term contracts with disabilities or integration difficulties. Each operator's schedule must be known daily, so an operator can be either assigned inside a unique zone or deployed in several different zones at different times while ensuring that the travel time between the two zones is feasible. In the *Figure 6* example, the same operator is deployed in different zones at different times allowing different operations in each zone.

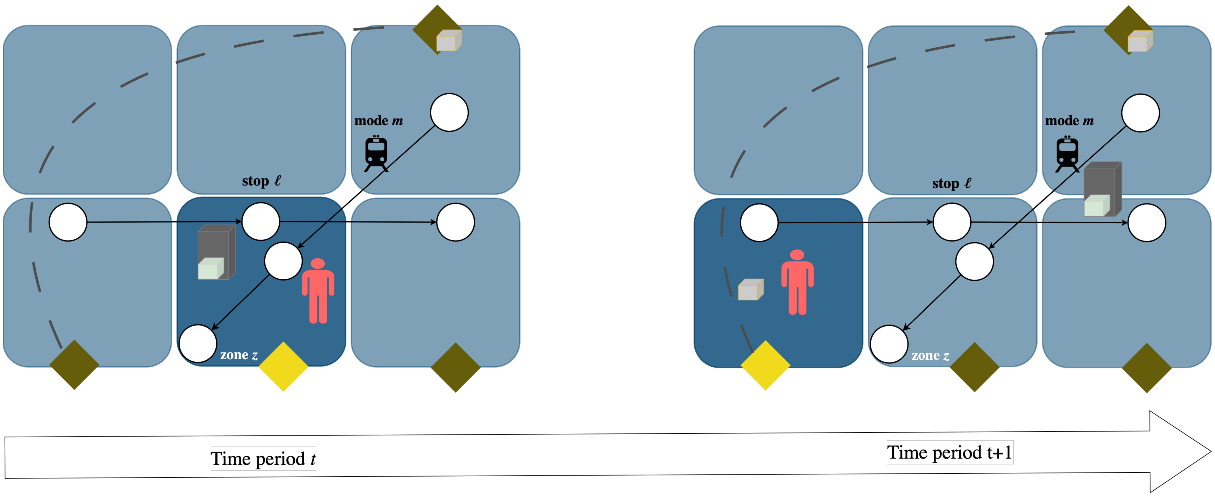

Figure 6: Time Capacity allocation

Time is an important factor to consider when allocating human resources. If an operator can be assigned to several different zones during his working day, it is important to specify the discretization of this day to have a decision by time interval. Flexibility in operators' working hours can be considered to meet fluctuations in demand throughout the day. This could involve flextime, rotating shifts, or overtime as required. The number of operators deployed in each zone also needs to be defined, as this will determine the network's capacity to handle parcels and containers.

PI-container characteristics

The quantity of containers, their origin and destinations, and their volume are decisions of the model as they fix the available capacity for parcels. The quantity of containers circulating inside the network should align with demand levels. The origin and destination zones of containers must be situated within areas with deployed workforce. Container volume plays a pivotal role in decision-making (Mohri et al. 2024) presents various containers of varying sizes and capacities, and it is possible to use different volumes and types of PI containers (Ben Mohamed et al. 2017). Moreover, container dimensions must be compatible with the height and width of public transport doors.

Public transport scheduling

As part of our HUDS, public transport scheduling plays a crucial role in capacity allocation. The availability and regularity of public transport determine the network's ability to transport passengers and goods efficiently. The public transport scheduling is a key decision. A high frequency allows more trips to be made in each time, reducing waiting times and improving the accessibility of the network for parcels. On the other hand, low frequency can lead to longer waiting times at stops, which can remove possible operations for operators and result in under-utilization of available capacity. It is also possible to consider variable frequencies (Ghilas et al. 2013).

3.3 Infrastructure design

Strategic infrastructure design and redesign are essential to integrate freight logistics into existing public transport systems inside a Hyperconnected City Logistics network. The decisions focus on optimizing line and stop selection, creating new infrastructure where necessary, and defining zones for efficient freight transportation. Constraints include considerations for passenger mobility, resource utilization, and network connectivity. The objective of infrastructure design is to create a network that is efficient, adaptable, and integrated with existing urban infrastructure. The results network will be inserted into the other two decision models to provide an efficient and complete HUDS. Two sets of decisions need to be made in this infrastructure design phase. The first concerns the design of the public transport network, and the second is the service and zones network design.

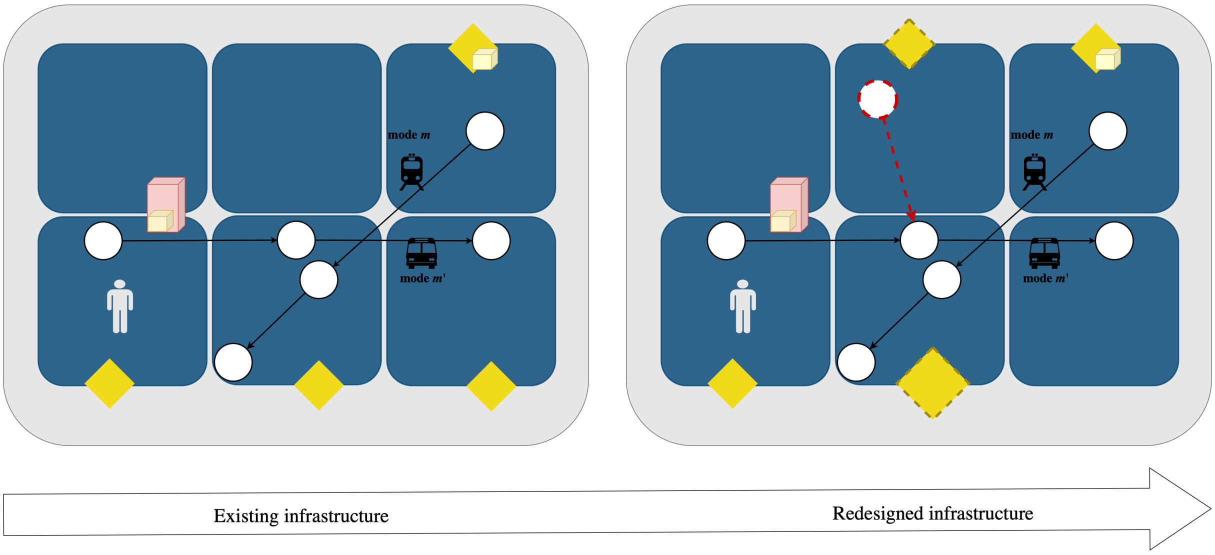

Figure 7: infrastructure redesign.

Figure 7 illustrates the difference between the existing and modified networks. The redesigned one contains a new stop with a new line, and one hub have been added and one expanded. This highlights the decisions to be made in the infrastructure design model.

Public network design

This model aims to strategically design public transport network by selecting bus routes and stops existing and potentially creating new stops or lines. To improve network connectivity, reduce delivery times, and optimize resource utilization for HUDS.

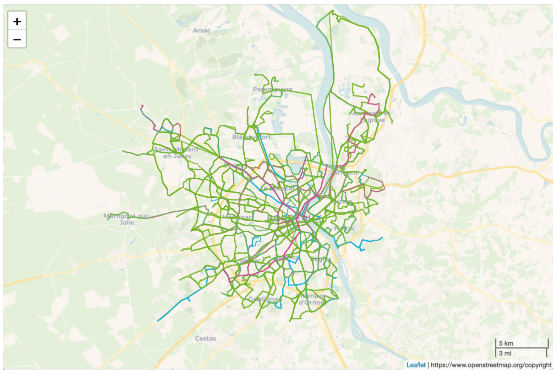

Figure 8: Lines public transportation Network, city of Bordeaux.

The decision to integrate either the entire existing public transport network or specific lines into our combined freight delivery and passenger system is pivotal for optimizing urban logistics. For instance, insights from (Diego Delle Donne et al. 2023) highlight the strategic significance of this decision by choosing the bus routes and stops to be used for delivery. The number of lines selected influences the total network's connectivity, as mentioned in *Figure 8* the entire network may be large, and not all lines will be used. *Figure 8* representing public transportation network of the city of Bordeaux is obtained by using OpenData website shared by Bordeaux public authorities (L'atelier Opendata). Opting for a subset of lines rather than the entire network for freight delivery integration can strike a tradeoff between passenger mobility and freight transportation efficiency. It's also essential to determine the number and location of stops to be used in the delivery network. Integrating into the network stops located in the main urban nodes can maximize their usefulness and facilitate efficiency. There are stops where several public transportation modes pass through. These stops are important because many operations can take place, and they contribute to the connectivity of the overall network.

Additionally, it is worth considering the possibility of creating new stops (dedicated to freight or serving both freight and passengers) or public transport lines at strategic locations. This approach can bring improvements to both networks simultaneously by enhancing connectivity, reducing delivery times, and optimizing resource utilization. By placing new lines or stops, cities can address specific freight delivery needs while also improving overall public transportation accessibility and efficiency.

Service network design and Zone configuration.

The objective of this model is to optimize the zone and service by strategically dividing space and creating or modifying hubs.

A zone corresponds to a division of space comprising one or more stops, and some zones may contain hubs. Inside zones, when manpower is assigned, we can carry out the various operations. In the context of Hyperconnected Urban Delivery with synergized public transportation options and containerization, the creation of zones is a crucial aspect for ensuring efficient and effective freight transportation. One approach to defining these zones involves leveraging classical clustering methods, which group stop stations based on geographical proximity, demand patterns, or other relevant factors. However, more sophisticated zone design methodologies exist, such as those discussed in the literature by (Huang et al. 2018) in their article on designing logistics systems for home delivery in densely populated urban areas, offer additional insights and considerations. These advanced techniques go beyond simple proximity-based clustering and consider indivisible micro-cells in the city merged into blocks, including geographical barriers.

To improve the design of zones within the delivery network, it's essential to consider the internal structure of these zones, including the installation of hubs or lockers. Strategic placement of these facilities can significantly impact the overall network design and cost performance (Janjevic et al. 2019). It is imperative to consider not only the location of infrastructures such as hubs or lockers but also their size and type of storage. The right placement of infrastructures in a zone can improve the fluidity of delivery operations by reducing waiting times and travel distances. In addition, the size of the infrastructure must be adapted to the volume of parcels handled. Finally, the choice of storage type - whether secure lockers, warehouses, or other solutions - depends on the specific characteristics of the zone. These characteristics must not deteriorate the passenger mobility network already deployed and must not affect passengers' appreciation of the network. By incorporating these considerations into the design of the delivery zone, it is possible to create a network that is more efficient and adaptable to the changing needs of the urban area.

Conclusion

Our study presents a comprehensive framework for enhancing urban parcel delivery systems by integrating three key decisions from the Hyperconnected City Logistic Framework: open response planning, open resource deployment, and open capability enablement. Through the adaptation of these decisions into short-term planning, capacity deployment, and infrastructure design, we have developed an integrated approach aimed at optimizing the efficiency of urban logistics using public transportation. These three decisions - short-term planning, capacity deployment, and infrastructure design – are interconnected, each influencing and complementing the others to create an efficient HUDS.

The first decision of our approach concerns the optimization of parcel and container routing, which directly addresses the concept of open response planning. By planning the movement of parcels and containers within the urban delivery network, we aim to minimize delivery times and maximize resource utilization. This involves coordinating the routes of parcels and containers considering containerization. Capacity deployment inspired by Open Resource Deployment is the second decision of our framework focuses on the efficient allocation of human resources and container characteristics. By assigning a workforce, optimizing container volume, and line scheduling, we enhanced overall efficiency and performance. Once Capacity deployment is fixed, the short-term planning can be used as a simulation to validate the solution’s feasibility. The redesign or selection of public network infrastructure and zone design emerged as key factors in optimizing system efficiency, aligning with the Open Capability Enablement concept. This third decision consists of selecting optimal lines and stops within the public transport network, as well as strategically placing hubs and lockers in delivery zones. Together, these interconnected decisions offer a solution to the challenges of urban parcel delivery using public transportation with containerization.

Further research avenues include calculating the economic and ecological benefit for the city stakeholders of using the HUDS. To test the model and develop it, a case study for the city of Bordeaux, France, can be built using data available in open data.

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