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# Shared Public Transport within a Physical Internet Framework: Review, Conceptualization and Expected Challenges under COVID-19 Pandemic

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## Abstract:

Traffic congestion, dominated by private mobility, reveals not only negative impacts on road safety and the environment, but also on community cohesion. With the global COVID-19/SARS-CoV-2/COVID-19 (COVID-19) epidemic, there is an urgent need for social isolation and the use of individual private transport as per the approved health guidelines. Urban transport, especially public transportation (PT), is amongst the primary sectors affected due to the COVID-19 pandemic. Thus, novel alternatives for competitive PT services still have to be provided to remain meeting the socio-economic and ecological PT challenges. In this respect, sharing PT vehicles carrying passengers (shared freight-PT) could exploit a significant residual capacity as absorptive capacity is actually reduced. However, such use is based on a large-scale mutualization. The idea of integrating freight in passenger transit networks could be efficient within a Physical Internet (PI or  $\pi$ ) framework for improving system monitoring, operational performance and, user comfort. This paper explores the major trends in the theory and practice of shared transport systems, in terms of passengers and freight, and suggests a PI conceptual framework to check if we could promote such logistics. In exploring the PI approach, a number of proposals appear providing answers and advance researches towards shared freight-PT.

**Keywords:** Integrative logistics; public transportation (PT), COVID-19 Physical Internet (PI,  $\pi$ ); shared transport.

## 1. Introduction

Urban areas involve growing sustainability and congestion problems with inefficient trips, long dwell time, and small shipments to private customers [1]. These problems take on many aspects, appear in many zones, and produced by several commuter and freight transportation systems. Thus, some other alternatives have been implemented to decrease the negative effects of private journeys including the use of PT. Actually, city dwellers could get a set of common vehicles using PT such as buses, trams, and trains that operate at regular times, on fixed paths, with affordable costs. Over time, researches have based on planners' previous knowledge and local communities' requirements to investigate PT travel behavior [7][9], operations of demand-responsive [6][8], and scheduling the fleet size that connects metropolitan and residential areas [4][5]. PT has played, subsequently, a major role in relieving traffic congestion; though, there are few studies that focus on PT applications, emergent technologies, and potential future policy scenarios [3].

The COVID-19 pandemic is, currently, developing rapidly, disrupting urban logistics and posing big challenges to PT. The actual epidemic has started to affect non-urban and urban mobility systems especially PT since the last quarter of 2019, in different cities around the world, and still affecting mobility services until the current moment of drafting this paper. Impacts are deep and new rules of mobility remain to be quickly introduced. Nevertheless, PT has undergone strict rules of operating in order not to spread the virus among numerous passengers occupying a restricted space. In this respect, PT absorptive capacity is reduced by an average of 50% as per the international health guidelines. Given the high correlation between human travel on PT and disease spread, passengers have been encouraged to switch to private cars. A set of investigations in China, Spain, India, and Colombia has revealed that PT users have decreased by 80-93% [10]. Moreover, urban transport of goods has been impacted regarding the global supply chains closure upstream of frontiers. City goods carriers are faced, thus, with the critical condition to deal with last-mile delivery due to the lack of skilled labor and subsequently merchandise shipping [11].

Based on the actual situation, a significant capacity of PT could remain unusable for long durations in the case of pandemics and disruptive events. With such facts, new alternatives could be investigated, such as integrative patterns for passengers and freight transportation across shared PT vehicles. The potential for shared mobility services and PT to support each other has been argued in different studies, however, the risk of new sharing strategies disrupting the PT continues to exist. Faced with the strict timetables, the awkward ticketing, and fixed stops, shared transportation treats their users as customers, picking them up and dropping them off close to their intended destinations, during a permitted period, with a view to making gains. When talking about freight, the aim would be to increase vehicle occupancy rates by globally driving gains for service users and transportation operators. This points to a challenging business model where policy-makers and mobility providers cooperate to integrate new shared modes into the existing PT infrastructure embracing the usual technological and benefits-driven advantages.

Shared transportation, in terms of passengers and freight, allows achieving the socio-economic and environmental aims of city logistics [20][49]. Under a systemic logic, flows of passengers and goods affect each other since they share at least one common

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logistics operators' interests and the traffic demand for both flows. Ensuring passenger PT within cities while maintaining a high quality of service is a challenge for service providers that prompts to prohibit shared patterns with freight transport. A second challenge lies in the manipulation of loads especially at the line's stops, embedded in suitable packaging for simple and quick handling. A third challenge concerns the fulfillment of the last-mile delivery by light vehicles when the final customer cannot pick up goods immediately during peak hours, which requires consolidation based last-mile journeys. However, henceforth it is worth considering the combined mobility improving transport planning, information systems, and decision-making supports to transport schemes with the actual request.

There is no one better approach to dealing with the idea of shared freight-PT, but there are certain features that can enhance its effectiveness, such as consolidation facilities, freight packing, real-time training, and tracking systems, etc. under a PI framework. This paper highlights the lack of recent researches on the combined transport and identifies the PI concept proposals that would address such integrative systems. According to the literature review (section 2), sharing PT's transportation systems is not an innovative concept. Nevertheless, the existing alternatives for future freight mobility might contribute, in the context of the COVID-19 pandemic, with a healthier, improved, and sustainable PT. One of the major challenges for transit operators is, ultimately, to rationalize different flows in order to reduce congestion, pollution, and energy consumption, all of which are necessary steps in sustainable development.

## 2. Trends and actualities

Many research papers [15][16][17] have proven that the propagation of COVID-19 occurs through droplets exhaled from contaminated persons, touching non-sterile surfaces, and the presence of numerous persons in closed spaces. In this respect, the World Health Organization (WHO) recommends staying at least one meter away from other people to reduce the risk of infection by the virus [18][19]. There is a set of studies that have linked the dissemination of COVID-19 to the use of PT systems [13][86][87][89][90]. In order to prevent the spread of the COVID-19 pandemic, government authorities have advised city residents to avoid PT systems as far as possible.

Several guidelines have been taken for deterring the use of PT and keep it operating safely. Thus, PT still hit significantly for protecting commuters against COVID-19. In this lockdown, PT operators have decided to run less than normal capacity. Beyond the limited number of passengers for enabling physical distancing, PT has been influenced by the stoppages in business, schools, and regular individual movements. With such constraints, the impacts on PT are expected to increase enormously the number of taxi and private car users [12]. The adopted measurements during the pandemic arise the tendency to reduce demand and competitiveness ability of the PT patterns.

### 2.1. Impact of COVID-19 on PT

#### 2.1.1. Urban PT

In spite of the potential weakening of incomes, France and United States (US) authorities have opted to take immediate decisions of the PT closure [21][23]. In China, it has been decided to enforce public health measures such as social distancing, facemasks in buses, trains, ferries, etc. [25][104]. The United Kingdom (UK) government has given broad guidelines to PT users in order to respect social-distancing for encouraging safe use with a limited number of passengers in cars and stations [22]. Furthermore, in the Netherlands, traveling with PT has been the most affected with a great decrease in journeys because of asking people to stay home or search for other transport alternatives when it is absolutely necessary [24].

Such regulatory instructions have led to a reduction of 65% in the number of trips across France, which has proven to be particularly effective in reducing work-related short-distance mobility, especially at peak times [92]. Due to the night-time and lockdown bans, ridership reductions have dropped by ranges of 80%–90% in major cities in China, the US, and Iran, and as much as 70% for some PT operators in the UK. In Singapore, mass rapid transit has reduced traffic due to the COVID-19 pandemic by 80% [111]. Sales of short period tickets dropped to almost zero in Sweden [109]. UK's restrictions on PT have led to a 95% decrease in underground journeys in London [103]. In Australia, there has been an annual reduction in PT commuter's travel time by \$5.58 billion (Greater Sydney Metropolitan Area), representing a 54.02% reduction in the Pre-COVID-19 total time costs [116]. The New York City subway has been deemed to be a major PT system for the spread of COVID-19 in New York in early 2020 [113].

In order to reduce the negative impact on urban PT, several interventions have been made. Dutch authorities, for example, has allocated €1.5 billion for recompensing the Dutch railways and urban PT operators in Amsterdam, the Hague, and Rotterdam [114]. The US has funded PT in rural and urban areas by \$25 billion [118]. Swedish government provided SEK 3 billion to recover the nationwide revenue losses caused by the reduction in ticket sales [115]. The peak shortage is expected to reach 25% during evening hours if physical distancing is imposed [117]. A growing body of literature has claimed that the economic shock of PT closures and restrictions on internal movement, though temporary, would not be readily recovered in both the short and long terms [116][119][120][121][122].

#### 2.1.2. Non-urban PT

One of the main recent researches has indicated that public health and non-urban PT systems have been mutually affected when faced with contagious viruses [100]. In this respect, it has been reported that frequencies of high-speed rail services in Wuhan city have impacted directly the number of affected people in destination sites [13]. The research findings have shown that the increase in the number of confirmed cases is mainly associated with person movements through air flights and high-speed rail facilities. In



Because

restructured to recover their efficient involvement in responding to the demand for urban mobility given the physical distancing and capacity restriction. With the mitigation procedures, if users switch from PT to private cars, adverse impacts might affect PT's competitiveness, air quality road congestion, and safety.

Streamlining urban mobility and reducing congestion are issues for which research has provided many solutions: implementation of urban distribution centers [41], optimization of vehicle routing [27], the synchronized last-mile concept [42], etc. One of the biggest challenges for city stakeholders is that PT should continue to be at one of the main components of mobility. Deploying shared freight-PT (Figure 1) in terms of passengers and goods without deteriorating the quality of service, delays, and frequencies of the passenger system is a solution worth be considered. The contribution of this paper is very relevant in prompting stakeholders to implement and assess the impact of exploiting the residual capacity of passenger PT for carrying urban goods. To this end, we propose a new design to allow physical distance (Figure 2), even if it reduces capacity and avoid crowding on PT. This representation is based on the main principles of the PI approach and aims to explore the function of the universal interconnection of service users and providers. The objective is to take up the challenge of more sustainable urban logistics by pushing the sharing of resources between passenger and freight mobility. This article would have a major impact as it is the first that provides a new conceptual context of shared PT regarding the actual situation of COVID-19 towards useful scenarios for modelers and policy-makers.

The remainder of the paper is structured as follows. Section 3 provides an overview and an outlook for shared transportation systems, in general, and shared freight-PT, in particular. Section 4 presents a set of conceptual broad outlines of the PI framework towards resilient shared freight-PT. Section 5 discusses the expected benefits of shared freight-PT. Finally, section 6 outlines future research perspectives.

### 3. Integrating passenger and freight within a shared freight-PT system through literature

Shared systems within a transport and logistics framework, summarized in Appendix A, represent collaborative alternatives of resource-sharing arrangements that could involve different patterns of bundle flow in order to improve their management in supply chains. Sharing in freight traffic has commonly consisted of a full or partial pooling of physical resources (vehicles, trucks, depots, etc.) or human resources (drivers, shippers, etc.) with the aim of reducing generated costs.

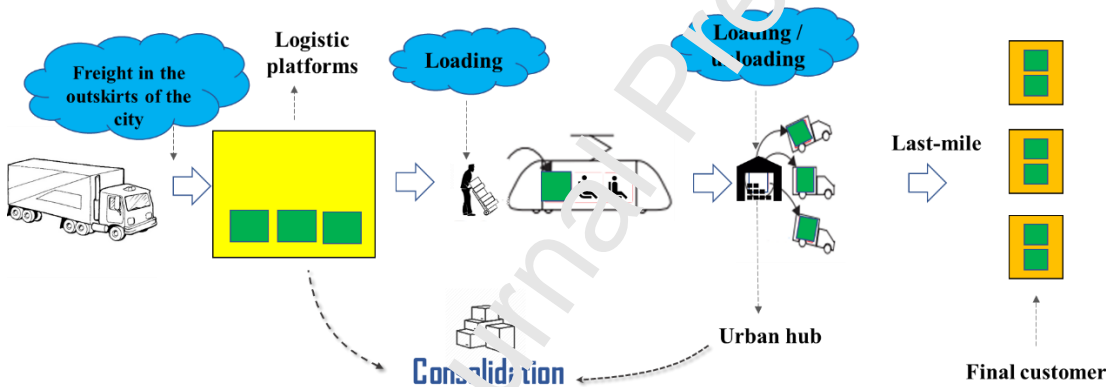


Figure 1: A representative illustration of shared freight-PT in terms of passenger and freight flows.

Shared logistics refers to rationalizing the management process of logistics flows including information, inventory, warehousing, resource-handling, packaging, and transport flow. Such sharing is one of the main pillars of sharing economy that involves the collaboration of multiple supply chain players to improve process efficiency, decrease operational costs and fulfill customer expectations [124]. Typically, shared logistics are changing the way transport operators trade and collaborate. In order to deal with sharing transport facilities, many experimentations have been proposed to streamline the urban mobility of freight. For example, Barcelona has shared the urban space, over time, on the main bus lines, some of whose lines are reserved alternately for passengers and then for goods [47]. Furthermore, there has been a long history of urban shared parking during particular periods of the day for delivery and leaving temporarily private cars in various cities around the world [45]. Public terminals of passenger transport systems have also been shared in France (La Rochelle, Paris, etc.), while the associated costs have been estimated to be excessive [46].

With the fast growth of car ownership, expended energy and land use, the potential for shared vehicles has been involved to address economic, social and environmental issues [144]. Vehicle sharing refers to the shared use of a vehicle for a short-term access regarding the requirements and convenience of system users [123]. As many new mobility options has been emerged, applications for smartphones or web bundle, these options and streamline journeys for travelers [145][147]. Thus, the commuters and delivery services are potentially changing the entire procedure of shared transportation industry. For instance, the mobility sharing has had a major impact on many areas around the world by improving the accessibility of transportation, while simultaneously reducing the need to drive private vehicles [146]. In spite of such sharing could be formalized under verbal agreements that are not formally structured as written partnership contracts, several analogies between shared logistics and collaborative transport are observed. Collaborative transport, thus, refer to the mutual use of material and immaterial logistics

### 3.1. Researches and experimentations

Increasing vehicle occupancy as an important challenge could be attained through collaborative transport including carpooling, carsharing, vanpooling, ridesharing, and PT patterns. The alternative of carpooling could involve corresponding a set of drivers' requests with a set of drivers' offers by matching their origins, destinations, and time frames [139]. In carpooling alternative, a driver and a rider group usually of different members share a part of their common itinerary, especially to work or school to minimize the travel expenses [169]. The carsharing schemes account for sharing cars regularly to travel from an origin to a destination, especially for commuting in order to decrease the personal driving and vehicle ownership and used energy [168]. However, vanpooling is the system that brings people to travel together from home or more common locations to a common location or workplace. The system would allow groups of people to share the journey like carpooling such as staff buses and the school vans [140]. In contrast, ridesharing systems are related to the ability to provide services where PT has failed with the use of smartphone applications to allocate rides in a typically privately owned car [170]. Usually, in shared vehicle alternative, the driver agrees to pick up commuters to ensure a high occupancy vehicle or to share trip costs [126]. Papers [43] and [44] have discussed the advantages and limitations of another type of sharing practiced in city centers that focuses on scheduled trips. In on-demand mobility systems with unit capacity, vehicles carry only one passenger at a time, whereas in ride-sharing on-demand mobility systems, a vehicle may carry different parts at the same time, for example, if the trips partially overlap [141]. A potential benefit of ride-sharing is increased system efficiency. However, the trade-offs between efficiency gains and reduced quality of service are more challenging tasks.

Combining commuters and goods has led to significant potential in the quality of transport services provided by the already existing ones with even fewer resources. However, sharing large-capacity vehicles involves strategic, tactical, and operational collaborations aimed at transporting in the same vehicle various flows from several shippers and thus extending their distribution radius to the last miles [48]. The levels of effective collaboration treat the problem of volatility of residual capacities exploited for resupplying the businesses, store moving, or delivering passenger baggage during downtime. The use of PT's residual capacity to transport cargo brings up the issue of deciding on the shareability issue in order to assess whether or not to mix the two flows for a given journey. This decision-making process depends on the geographical constraints of departure and arrival sites, travel times, generated deviation, and congestion rates [127].

Many recent research papers have dealt with modeling shared transports through a set of approaches given that the analysis of each has specific features. For such a complex system, modeling shared networks is not an easy task that is why a whole paper [30] has been dedicated to assess the potential of modeling such networks for goods mobility in urban areas to reduce congestion and enhance financial viability. Matching drivers and riders in real-time has been reviewed in [39] to illustrate the operational requirements of ride-sharing systems. It has provided a model for dynamic ride-sharing and outlined challenges in optimizing the development process to support ride-sharing. Article [42] has suggested combining passenger transportation with the delivery of goods to improve transportation by vehicle. Considering a model-free approach, the FlexPool algorithm has been involved to match jointly passenger and freight workloads by learning optimal shipping policies from its interplay within the environment. Article [36] has developed and simulated an integrated model of autonomous vehicles and PT to preserve high-demand bus routes while reusing low-demand bus routes and using shared autonomous vehicles as a travel option. Based on an agent-based simulation for performance assessment, the results have shown that the integrated systems are key transportation schemes to improve service quality, the use of road resources, and transportation facilities. An integrated mobility system has been proposed in which a pool of freight requests must be delivered using autonomous fleets, grounded pick-up, and delivery robots where a regular public transport service is operated [41].

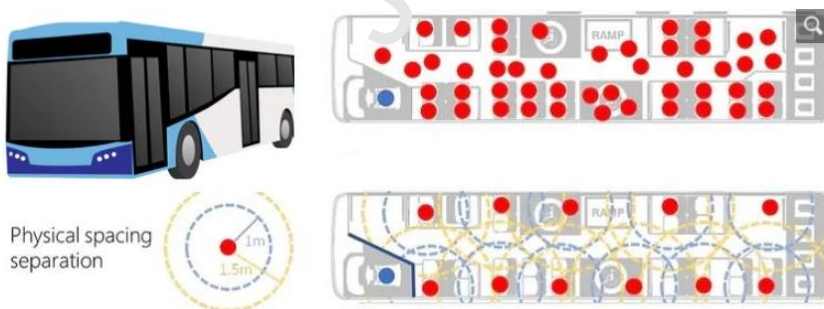


Figure 2: Interior design of a PT car respecting the safety distance.

Railroads have been a vital mobility network for the two flows' integration. Urban freight transportation using passenger rail networks has been investigated in [37] at strategical, tactical, and operational levels. The related study has been presented based on a freight-rail-transport-scheduling model with a mixed-integer program and a discrete-event simulation framework to evaluate the alternative performances. Paper [31] has involved the PI concept and synchromodal transport to present an improved alternative towards sustainable freight transport. The authors, here, have examined synchromodal and the PI models in order to include efficient modal shifts from roads to rails and inland waterways as well as connecting production operations with freight movements. Implementing PI concepts in traditional supply chain networks could achieve significant cost savings [32]. This result has been demonstrated, also, through addressing the problem of combining integrated production, inventory, and distribution decisional procedures. For more information, paper [33] has presented sharable and sustainable systems operations where people

share [142]. [143] has dealt with the problem of decision-making in the management of railway infrastructures under shared use corridors and specific tracking systems. It has provided an analysis with respect to the consolidation strategy for shared use corridors, where track systems are applied on both passenger and freight trips. The paper [35] has, in addition, focused on examining the feasibility and adaptability of shared transportation systems driven by electric vehicle and bicycle sharing to reduce congestion and environmental impacts in mega-cities. The achieved findings have indicated that shared transportation plays an important role in alleviating traffic flow and pollution problems.

On the other hand, the location of intermediate warehouses in the service network also has improved the efficiency of crowdshipping and has ensured that the total cost, i.e., the cost of the shared vehicle and the occasional driver's compensation, is minimized [143]. Typically, the crowdshipping alternative is based on the concept of connecting customers who need to send a shipment with drivers that have available space in their vehicles [142]. These drivers are considered to be casual couriers because they are not required to undergo shipper-specific training. In order to follow standard routing practices, conventional users accept to deviate from their route to drop off supplies to other people for a small compensation. In literature, the article [38] has examined the feasibility and potential behavior that could make crowdshipping more widespread in urban areas. The authors have investigated the main conditions under which passengers would be willing to act as crowdshippers and to receive their goods via a crowdshipping service. Crowdshipping can generate positive impacts such as the reduction of total and ad-hoc trips, by optimizing sharing the use of resources and infrastructures. Digital twin technology has been, similarly, investigated to create virtual models of processes that simulate the behavior of the real-world matched trips. In this context, paper [34] has aimed to propose a design and conception of a digital twin-based model to share the information among the supply chain stakeholders in view of improving trackability of products and processes. This paper has analyzed feasibility and behavioral levers that might facilitate the diffusion of crowdshipping in urban areas.

### 3.2. Potential of different PT modes

To adherence to physical distancing, shared freight-PT policies could have dissimilar potential for producing far-reaching gains in terms of restoring PT competitiveness towards continued progress and customer confidence. The tramways, for example, have been the most widely experimented with for carrying both passengers and freight in European cities. In Dresden, since 2001 a tramway has been supplying a Volkswagen plant. The assessment has been judged positively on the three aspects of sustainability [49]. In Zürich, the Cargo-Tram has been running since mid-April 2013 to move e-waste and bulky leftover in order to reduce the number of dump trucks circulating in the city. Between 2005 and 2007, a Güterbim (goods streetcar) has carried containers through the streets of Vienna. The experiment has considered quite conclusive but has not been renewed. In addition, in March 2007 an electrical light rail and van transport system has been launched in Amsterdam by the Cargo City company. The assessment of the project in terms of interoperability with the passenger network has convinced the Amsterdam municipality to support this initiative. The project has stopped because it had failed to meet its objectives, but it has not been abandoned. In Marseilles, mail carriers have borrowed the tramway to get closer to their distribution areas, starting from the post office located in the Arenc platform. The network of Monoprix markets in France has been supplied by passenger trains using the D suburban line in Paris. The type of freight has consisted of a set of selected goods such as soft drinks, textiles, cosmetics, home, and leisure products [128]. From the Monoprix depots outside Paris to a dedicated station located inside Paris, Bercy, the last kilometer has been carried out by trucks running on Natural gas vehicle (NGV) fuel, to comply with the emissions reduction challenges on the logistics line. With a length of 30 kilometers, the exploited line has allowed the transport of 210,000 pallets per year, which gives 120,000 tons using 5 trains of 20 cars per week. As a freight transport, garbage pick-up via subway stations has been performed in New York City [129]. The combined transportation has been done at night. As New York City's subway circulates 24 hours a day, it has mixed between the transport of goods which are the garbage in this example, and the transport of passengers. The New York City subway system has collected 11,000 tons of garbage per year with 11 dedicated subways, including 359 stations and 567 stops.

Formerly used, and then, abandoned in developed countries, it has been first brought up to date in Germany as part of the Multimodale Lademodul-Integration (MuLi) bus project (1996 - 1999). An express parcel service based on highway passenger transport has been discussed in paper [130]. The system has based on the unused room of the coach trunk to ship parcels between main cities. In order to achieve optimal performance. A mixed-integer programming model has been developed integrating the service decision, frequency, and distribution of the network flow. Therefore, the implementation of such a system has reduced the total cost by up to 16.3% comparing to the traditional carrier's system. In real life, intercity bus services have offered a combined transport service carrying passengers with parcels riding in luggage compartments or freight trailers strapped to the buses. The Greyhound is one example of an intercity bus operator that rely on the commuter patterns and residual capacity on the coaches to offer a competitive pricing alternative [131].

Intercity buses have provided delivery services to regions and areas that may lack other transportation alternatives and have connected these regions to main cities and other destination sites. In Finland, the bus parcel operator, Matkahuolto, has provided both freight and passenger transport and, in this respect, the Swedish and Finnish companies have cooperated for cross-border mobility [132]. However, the Greyhound and Matkahuolto shared service might increase dwell times. Despite the separation of cargo and passengers, the handling operations of shipments could lead to delays for passengers, which in turn diminishes the passenger travel experience given the type of transported cargo [133]. Also, the combined transport of passengers and parcels has been investigated in Heinsberg as part of the MultiBus project. These services operate only in a time period specified during "idle hours" [134]. Compared to the commuter's bus service, the MultiBus service has operated more cost-efficiently.

In the literature, shared transportation has experimented with in order to improve the performance of a taxi sharing system. In this respect, Li et al. (2016) have proposed an adaptive large neighborhood search heuristic for optimizing profit of serving a set of

passenger-based heuristic for solving the share-a-ride problem to conduct combined trips of the taxi for parcels and commuter's service. A dynamic taxi-sharing system taxi-sharing system has been addressed in paper [137] based on the use of Intelligent Transportation System (ITS) technologies in Taipei City. The findings have shown that this system has been user-friendly for the members and low-cost for the service provider. The taxi-sharing concept has enabled modeling the associated benefits according to passenger inconveniences and efficient calculation of optimal sharing strategies based on an example from New York City. The benefits have been associated with shared tariffs and low passenger discomfort, with up to five minutes of additional travel time, suggesting broad passenger acceptance of such a shared service [138]. Some examples of sharing experiments in the subway sector in Chicago, London, and Tokyo are available in the paper [50].

The existing literature illustrates through the investigation of real or simulated cases the potential of integrative schemes for passengers and freight mobility. In general, combined transportation of commuter and freight flows remains associated with urban mobility. Using shared mobility in terms of both flows could lead to significantly reduced total costs for all collaborative players. In general, integrating passengers and freight in transportation projects improve the accessibility of flows to coordinate the business capacity to supply the intended customers with the capacity of people to reach key public facilities. Economic productivity and income expansion on behalf of PT operators by combining passengers and freight should avoid impacts that are already accounted for in travel time. However, this would allow to compose them in the form of savings in vehicle costs, emissions or safety gains. In numerous cases, the balance of impacts between different stakeholders could be extremely relevant. For example, from the point of view of the service consumer comfort feature could be tolerated in contrast to the additional running time and/or costs. In such a scheme, the reduction of transportation costs for both users including travel time, vehicle operating costs is the major incentive encouraging the customer to share journeys.

The current circumstances indicate that the consumer now could deliberate a multifaceted choice of PT alternatives putting in first consideration the social-distancing and health measures to limit the contamination risk. Costs, availability and convenience and so on must not be neglected in the policy planning for treating the biggest barriers to integrative transport flows. Through consistent vehicle layouts, the PT could streamline again the movement flows, keep essential PT transport moving and allow transport costs to become more competitive and advantageous. In order to boost achieving such strategic objectives, the remaining capacity due to distance requirements as preventive measures could prompt PT operators to recover revenue objectives towards safe, sustainable and efficient transportation.

Instead of promoting the use of individual cars, the pandemic could be seen as a major trigger for competitive capacity-sharing of PT in terms of passengers and freight. In a city, there are different networks of PT as subways, tramways, buses, etc. According to the revised literature, tramways, buses, and subways are the PT modes with the highest potential to share the residual capacity. For example, the average length of a bus is 9 meters, the width dimension is 2,55 meters and the height practically is about 3 meters. If we assume the full capacity, these dimensions show that the residual capacity exceeds 11,475 m<sup>2</sup> by excluding 50% due to the social-distancing. Since it will be devoted to freight transportation, the residual capacity in our example denotes the given surface multiplied by the bus height, which gives 34,425 m<sup>3</sup>. The quotidian flows of freight scheduled to be transported in the shared vehicle would typically be invoiced according to the required volume, which implies expected savings on the unused bus capacity.

Regarding the remaining capacity under different traffic conditions, the system could draw benefits from adding small residual capacities per time slot. Then, the consolidation process of small orders is susceptible to deal with single movements in order to set regular large shipments. Despite the PT sharing, the integration of cost-efficient networks of consolidation process accounts for a more environmentally friendly aspect. Limiting the number of cars on the roads also helps to reduce diesel and fuel consumption. Over time, this reduced consumption could contribute to lowering the pollutant emissions. The limited exploration of fossil reserves and offshore oil drilling might be important in order not to disrupt the nature of the ecosystem. This includes the biophysical and behavioral patterns of living beings, including all people. Furthermore, public policy-makers could receive financial gains associated with the increased sustainability of shared transit operations requiring lower funding subsidies. The social benefits would also be represented by the cheaper transport operations to and from major transit nodes or corridors. The additional services are particularly well suited to areas in decline, which increase their attractiveness of current and future customers.

### 3.3. Contextual characteristics

In various contexts, shared freight-PT could be performed over paths such as roads, rails, monorails, tunnels, water, and air. However, based on the previously reported literature review, it could be concluded that user preferences for different modes differ according to the contextual characteristics. The contextual characteristics refer, actually, to a set of dynamic factors that influence establishing strategy choice within the social, cultural, economic, political, technological, and institutional environment of the concerned area [157]. In order to support such an explicit analysis, contextual characteristics have to become essential elements of shared transport research involving different flows. As such, they need both an assessment in the contextual frameworks to evaluate the shareability of PT systems.

The contextual factors lack explicit identification in the search for shared transportation, especially within PT schemes. Though, some researchers have recognized the presence of contextual factors in structuring shared PT patterns. For example, the paper [156] has dealt with determining which PT users are susceptible to exclusion regarding the contextual characteristics such as the geographic, economic, environment, and the existing multimodal transport system. These factors need essentially assessing the spatial and temporal dimensions of service, with particular considerations of the ability to match users with their preferred destinations at appropriate times to undertake the desired activities. Understanding contextual factors considered by users in selecting a non-urban PT mode has been strongly influenced by previous works on transport mode choice. Several kinds of

contextual state of the customer when selecting a PT mode [148]. The discussed results have highlighted that the choice between two PT is linked to some contextual factors such as the length of the associated route. In addition, such contextual impacts on shared PT are associated with transportation resource use and choice in terms of access to this resource itself, or to some similar alternatives, which affect mainly the users' specific demands. The authors of the paper [158] have assessed the importance of accessibility factors in improving PT efficiency, accessibility, and interconnectivity indicators from the perspective of co-modality. The need for the accessibility factor to PT transportation has been involved in controlling the passengers' mode choices.

In particular, besides accessibility, travel distance, fare rate, intercity travel time per hundred kilometers, quality of service of transportation hubs, and ticketing methods are key factors that have influential contributions for explaining decision-makings [159]. Likewise, the attitudes towards intercity passenger transportation are changed regarding the level of accessibility to a rail line [160]. In this respect, the shared transportation systems need to provide route information about different shared transportation users. Since users of a shared transportation service might have different pick-up locations and/or locations, the system could then provide information that is specific to individual users of the shared transportation service based on geographic location data [161]. Consequently, shared transport is mainly related to the infrastructure and user location of the shared transport service. Travelers react immediately to changes in travel conditions, so changes in mode/route are considered short-term effects. In contrast, the destination is characterized by its demographic and socioeconomic properties and the conditions of travel from the origin. Along with relative changes in travel conditions for different origin-destination pairs, travelers accept to select a new destination that is closer to the target destination. As a result of these changes, more longer trips are observed, i.e., extra trips are taking place [163]. The renovation and transport facility development campaign wield also, particularly strong influence over the soundness of long-term decisions. To this end, sharing opportunities might rise more in the areas with connected networks undergoing regular maintenance in terms of prevention and road safety in maintenance programs [164]. The Road Fund derives its resources from road tolls and other resources that collect and transfer funds under the responsibility of the road revenue improvement program (tolls, penalties, and axle tax).

Contextual characteristics are potentially associated with shared mobility behaviors especially in the implementability of different alternatives across understanding the community contextual influences on urban mobility plans. The carpooling and carsharing as shared systems explore the potential contextual commuting among a set of contextual determinants including the population density, the social mix index, and the deprivation index [150]. Firstly, the population density in an implementation area has been significant to make the modal share of PT increasing and, then, leading to sustainability through economies of scale [151]. Besides, it has been argued in paper [152] that increased population density decreases the average distance of PT access leading to shorter trips, which encourage more corridors and improve the sustainability of the system. Secondly, the social mix index is the indicator measuring the regularity of the percentage distribution of the major socio-professional classes such as agricultural professionals, craftspeople, management staff, and skilled tradespeople [153]. Thirdly, the deprivation index has not been explained by car ownership in the past, where it has been more restricted. Therefore, the lack of access to private cars has had a less stigmatizing effect on PT and the urban environment as is the case today [154]. To boost the use of shared modes assessing these contextual indicators remains a necessity for the major role in achieving sustainable PT services. The paper [149] has claimed that there is a relationship between the population density of the home environment and carsharing, but not carpooling. The residential context of carsharing tends to be significantly crowded compared to that of non-carsharing. The social mix index has a significantly reduced social mix rate in the residential carsharing context compared to that of the non-carsharing context, however, the difference is neglected in carpooling alternatives. Moreover, the deprivation index is notably higher in the residential context of carpoolers than in the residential context of non-carpoolers. Similarly, the evolution of smart public bike-sharing service structure is mainly linked to the contextual factors of the urban areas [155]. The paper has proposed a model that explicitly includes the contextual dynamics of public service that use the Internet of Things (IoT). Based on the achieved results, the more appropriate public bike-sharing scheme is that adapts to the public motives, user preferences, and governance of the host city. Hence, the safety distance for implementing transport policies requires inclusion to provide mixed traffic behavior models [162]. This is related to the contextual safety factors associated with the urban crowded areas that exhibit their own region's demographic, social and cultural frameworks were taking into account the behaviors of the targeted community at large is worth considering within heavy vehicles [165]. The paper [166] has identified an additional asset namely the network accessibility that could make the development of shared systems in urban areas more attractive, which will, in turn, increase the land and property value. Accordingly, shared transport is distinguished by its integration into urban areas while paying attention to the preferred location of stations and their design to develop a greater level of accessibility [167].

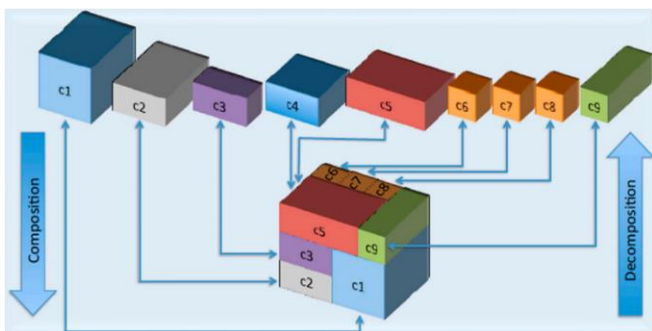


Figure 3:  $\pi$ -containers are both unitary and composite [55].

The PI (or  $\pi$ ), introduced by papers [51][52][53][54][55], is a concept that could support shared freight-PT by applying the concepts of the digital Internet to integrative logistics of passenger and freight flows. Its principle is based on the manipulation of goods within consolidation hubs, similar to data traffic over computer networks. The PI approach is an emerging logistics concept that draws on shared distribution chains, which adapt shared networks to the global supply-chain depending on a set of universal standards [112]. In other words, all players in the supply chain, including manufacturers, forwarding and retailers, interact mutually to increase the size of loads of trailers and reduce the miles traveled by empty vans. As a pooling approach, the PI proposes an efficient system that relies on modular containers with system identification and location tracking through shared facilities.

The PI is relatively complex with the aim of achieving an open global logistics system based on physical, digital and operational interconnectivity through encapsulation, interface definition and protocol design [191]. The key goal of this open global logistics concept is to achieve an efficient and sustainable supply chain that is sufficiently resilient to address the environmental, social and economic issues. The approach introduces an innovative type of collaboration model that uses interconnected computer networks and the digital Internet environment. It is based essentially on the most advanced logistics collaboration strategies keeping their drawbacks minimized [190]. PI collaborations are aimed at long-term working relationships, contrary to transportation businesses, where short-term transactions only take place to fulfill unique transportation requests. This type of long-term collaboration is more desirable through mutual confidence, enhanced commitment and higher reliability than short-term relationships. Indeed, PI proposes a global vision of supply schemes for more open, shared, and sustainable logistics that aims at:

- (i) *improving the use of logistical resources;*
- (ii) *minimizing the off-loading cost.*

#### 4.1. PI concepts for shared freight-PT

##### 4.1.1. $\pi$ -Containerization

In shared freight-PT, goods should be seamlessly moved between PT facilities, consolidation hubs, and delivery vehicles to the end customer. The  $\pi$ -containerization would simplify the entire logistics process and, ultimately, the real implementation of this transportation scheme, which could lead to a revolution in mixed transport and international trade in the coming years. Generally, the containerization process is a key solution that has been primarily introduced for "packaging" goods for maritime transport [56]. However, to address the requirements of both passengers and freight carriage in the PT vehicles, the PI approach provides a set of suitable  $\pi$ -container prototypes that are in line with all needs of the shipping within integrated schemes. In this respect, there are no restrictions on transporting the identifiable and hermetically sealed composite  $\pi$ -container in a PT vehicle provided it does not contain dangerous goods [71]. Within the PI networks, multifunctional load units transported in the same vehicle of passengers will bring huge benefits to international trade in terms of reducing transportation costs, damage to goods, and theft. The ways in which  $\pi$ -containers could save space, money and handling smoothly the two flows, are intelligible enough, once the related features are applied.

The PI approach returns to this process to standardize  $\pi$ -container as the elementary freight format that would allow organizing handling, storage, and transport of goods it contains as the standardized packets called "datagrams" in the digital Internet [51]. Hence, a  $\pi$ -container is, physically, a lightweight box whose modular and composite design allows different assemblies (Figure 3). Its main goal is to ensure freight routing regardless of vehicle category [56][70]. With general cargo, the containers of specific characteristics could allow a suitable packaging for various goods by respecting the safety, hygiene, and acceptance for the containerized goods and for the consumer. That is, the  $\pi$ -containers could ensure the developed integrity of freight in real-time when fitted with temperature, humidity, and acceleration sensors [66][67][53]. The climatic conditions inside  $\pi$ -containers are in particular set in the PI according to the generated deviation of the routed path when willing a collaborative transportation planning. Additional climatic conditions should also be included such as the current weather, time of day, and season. In addition, the encrypted conditions in  $\pi$ -containers are defined by the commodity characteristics in terms of the cargo mass as well as the cargo surface area readily accessible to be diminished. With the modularity of  $\pi$ -containers, transported freight could take different configurations inside the vehicle and make handling easier, as well as more protected under optimal conditions to prevent passenger service loss and damage to the goods.

The key advantage of the PI is that it defines two additional types of containers according to the function they serve. The T-container is for transport and H-container serves for freight transport and handling respectively [57]. Goods would remain inside the  $\pi$ -containers from the origin and then from the manufacturer to the final customer; the distribution chain would be simplified and each movement would be fully automated using specific equipment. Such  $\pi$ -containers could be monitored through tracking and data identification technologies in order to supervise the movement traceability [58]. Several technologies have supported the intelligent interfaces of  $\pi$ -containers, such as those based on interior identification systems like Radio-Frequency Identification (RFID) and ultrasonic sensors [84], passive Ultra High Frequency (UHF) RFID [59], and exterior ones like Global Positioning System (GPS) [60][65], Wireless Sensor Network (WSN) [54][62][63] and Internet of Things (IoT) [64]. With the shared freight-PT framework, freight would not remain passive loads but become physical entities communicating with their environments and exchanging information. That is, the  $\pi$ -container could play an active role in managing logistics platforms in particular, and in the supply chain in general. Even better,  $\pi$ -containers could interact with several environments for fast and synchronized transfer of goods on each of the supply chain nodes, mirroring what is usually performed on the Internet.

Several projects (e.g., *Physical Internet* (PI) [65], *Seamless Logistics Units in Shared Co-modal Networks*; 2014), and LIBCHIP (Physical Internet Enabled Interconnected Consumer Goods Logistics; 2015), have dealt with the informational aspects of  $\pi$ -containers to enhance their “active” character. The results have identified that the potential of autonomous decision-making (i.e., choosing the shortest path between origins and destinations) depends on the ability to communicate over a long and short-range. In this case, the potential of IP to improve urban logistics could be envisaged through dealing with the falling occupancy rates of trucks (<45%). Experiments have shown that it is possible to considerably increase the rate of occupancy of transport vehicles after using a  $\pi$ -containerization [68][69][67].

Table 1: Flow format per interconnection layer.

	OSI Model		OLI Model	
1	Physical	Bit	Physical	II-containers H-containers T-containers
2	Link	Frame	Link	
3	Network	Packet	Network	
4	Transport	Segment, datagram	Routing	
5	Session	Data	Shipping	
6	Presentation	Data	Encapsulation	
7	Application	Data	Web logistics	

#### 4.1.2. II-Standardisation

In PI, handling the so-called  $\pi$ -containers is based, in particular, on standardized collaborative  $\pi$ -protocols. In this sense, PI derives the Open Systems Interconnection model (OSI) and Transmission Control and Internet Protocols (TCP/IP) for building a logistics standard to transfer fragmented freight stream between two hosts. The OSI model is a repository structured in seven hierarchical layers including the TCP/IP layers. Each layer  $i$  is the service provider of the next higher layer ( $i+1$ ) [72]. The physical layers (1, 2, 3, 4) describe how information circulates between nodes (routers, switches, ...). Therefore, the conceptual layers (5, 6, and 7) manage the dispatching of data by means of exchange protocols [73]. If the parallel is made, logistics networks should only deal with the physical flow of goods (Table 1). However, this is not the case because it is necessary within shared freight-PT to handle information, financial, institutional, etc. flows. The Open Logistics Interconnection (OLI) model standardizes the interconnection of such flows within a  $\pi$ -logistics network. Through a multi-level architecture, this OLI model is equally constituted of seven conceptual layers [74][75][76]:

- **The physical layer:** standardizes  $\pi$ -nodes for transport, physical resources for loading/unloading, transshipment or storage infrastructures and  $\pi$ -composite containers;
- **The link layer:** focuses on the detection and correction of unexpected events that occur at the physical layer;
- **The network layer:** organizes the composition, decomposition of  $\pi$ -containers and their assignments to  $\pi$ -conveyances;
- **The routing layer:** maps goods path between  $\pi$ -nodes and  $\pi$ -segments of the network from the source to the final destination;
- **The shipping layer** handles the exchange of  $\pi$ -containers between shippers and receivers;
- **The encapsulation layer:** provides the link between demand routing and supply chain management. This layer ensures the  $\pi$ -containerization of goods before they are shipped;
- **The web logistics layer:** models contact with the final customer; it includes the monitoring of orders and  $\pi$ -contracts.

#### 4.1.3. II-Routing

Within a  $\pi$ -network, the routing layer is a key connectivity strategy-wise because it helps to optimize the path of a commodity between two points. In shared freight-PT, logistics networks are dedicated to multiple players and are therefore only insecurely interconnected with each other. This hermetic configuration strongly constrains alternative routes and therefore limits the performance of the overall mobility network.

In the scope of the study cited here [56], the authors have investigated real flows of mass consumption with different transport PI protocols and following multiple scenarios. The achieved results have revealed that distributing urban freight based on the IP approach could engender gains in CO<sub>2</sub> (carbon dioxide) emissions, costs, etc. One of the constraints to consider is the processing capacity and timing of the logistics  $\pi$ -nodes then the fluctuating demands. The time that freight takes to pass through  $\pi$ -nodes is, thus, changeable. This constraint supposes combining travel and handling time optimization of both passenger and freight to propose an interoperable routing protocol able to identify and distinguish various cargo types. Though, restricting constraints to transport delay cannot optimize  $\pi$ -containers routing. The article [74] points, in this way, an extension of the Border Gateway Protocol (BGP), which is dedicated to the interconnection of heterogeneous Autonomous Systems (ASs) in the Digital Internet. To define the next destination of a  $\pi$ -container it is necessary to identify the nearest available facility taking into account the schedule of the transport resource. To this end, the route attributes would include several factors: weather, traffic, availability of the next platform and fleets, etc. These facilities for hosting freight to improve transmission performance in the PI are named  $\pi$ -hubs and are discussed in the next section.

#### 4.2. II-Hub: Helpful features for shared freight-PT schemes

In today's mobility, the number of shipments still increasing dramatically, but each shipment is getting smaller due mainly to the growth of e-commerce. Here, parcels could be moved effectively through a network of consolidation centers in order to all transport resources are rationally utilized. The tendency towards smaller shipment volumes is leading to a key concept of the PI namely  $\pi$ -hub for efficient logistics and physical parcel supply chains. A  $\pi$ -hub is actually a  $\pi$ -collaborative node used to sort, redirect and transfer goods on a  $\pi$ -many-to-many interconnected network to achieve economies of scale. It comprises three zones where goods are exchanged between combined modes of transport: rail-rail, rail-road, and road-rail zones (Figure 4). That is,  $\pi$ -hubs must be able to process and consolidate goods from multiple shippers to multiple customers so that a vehicle or  $\pi$ -container routing between terminals is suitably full at all times. In the PI, consolidation is no longer limited to pallet handling. The focus is on parcels and all logistics units are deconsolidated into individual units after they have been consolidated. Such a solution for logistics networks manages this consolidation and rebuilds operations in a large number of  $\pi$ -hubs.

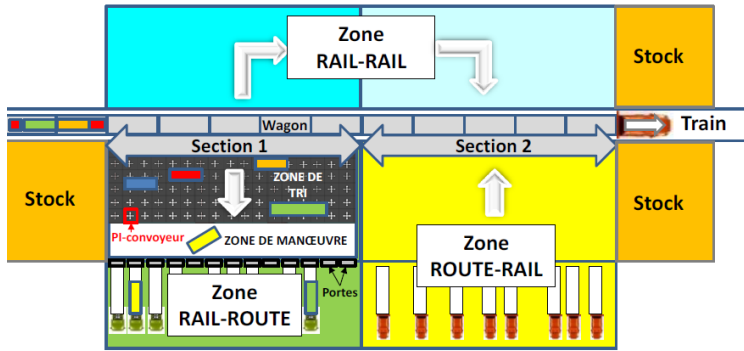


Figure 4: Internal configuration of a  $\pi$ -hub.

In general, there are different basic reasons why transshipment still meaningful in shared freight-PT. For example, in order to shift goods from one country to another, sometimes the transshipment could evade trade barriers. Then, it could take place effectively when small shipments are made by the PT in order to combine them into one large shipment for forwarding in the same last-mile vehicle. This represents an attractive alternative to deal with PT's failure to load freight due to low residual capacity or if PT vehicles are no longer able to accommodate large loads. In addition, when no direct link between the source and destination is available or very expensive, the  $\pi$ -hub network receives the flows for a short duration of time and then and arranges its resending to receiving node.

During peak hours, many passengers may use PT systems that cannot be provided for goods. Taking full use of the residual capacity on the other time slots is an opportunity to bring goods into the city. However, a set of light vehicles must quickly evacuate  $\pi$ -hubs so as not to decrease the processing capacity of these facilities during peak periods. There are relatively predictable variables including, arrival times, logistics demand, residual capacities of PT,  $\pi$ -hubs, small fleets, etc. that vary from one day to the other. In addition, unforeseen events should be taken into account, such as the very frequent traffic problems in cities (breakdowns, accidents, bad weather, etc.) which inevitably have consequences on the demand flow capacity [69]. By understanding the complexity of shared PT systems, the possibility of relocating the routing decision in real-time to the container becomes certainly valuable.

At the microscopic scale, flow management in a  $\pi$ -hub is determined by various parameters especially the capacity of handling  $\pi$ -containers. Handling capacity depends on the number of  $\pi$ -containers transported by mass transit, and thus, on its residential capacity. In the PI paradigm, collaborative  $\pi$ -hubs have limited processing and sorting capacities. In addition, some processing time delays might result, which is particularly noticeable when a  $\pi$ -hub is functioning near its maximum capacity. The level of congestion could be affected by the level of collaboration of a  $\pi$ -hub with its network as well as the volume of flows to be handled as well as the maximum capacity of the  $\pi$ -hub. For instance, there would be no delay if a  $\pi$ -hub operating at less than 50% of its capacity, whereas a significant delay might arise if a  $\pi$ -hub operates at more than 95% of its capacity. Here, to deal with this problem, foreseeing systems for fully synchronizing passenger/goods flows as well as the system's levels are required. Such a type of system allows the allocation of space in a transshipment  $\pi$ -hub to the  $\pi$ -containers according to the frequency of loading and unloading activities. The major focus lies in efficiently moving  $\pi$ -containers within the  $\pi$ -hubs between its zones to minimize internal traffic congestion. Besides the flow volumes that need to be handled by the  $\pi$ -hub, the dimensioned capacity represents an additional source of internal congestion. For a robust dimensioning of the  $\pi$ -hub capacity, the decision-maker needs to identify strategic demand predictions to reduce internal congestion and the service time.

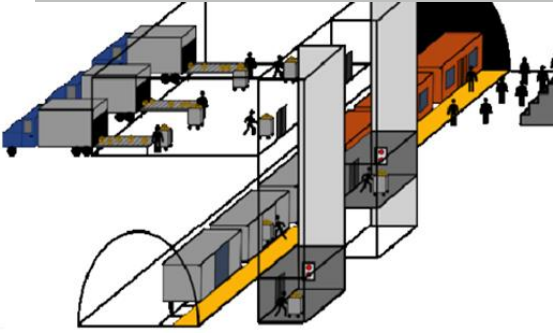


Figure 5: A sample of shared freight-PT  $\pi$ -hubs [76].

Once the expected demand is actually loaded on the PT, smart tracking systems of the PI paradigm help to manage flows within the  $\pi$ -hub. The recipient receives in real-time the consignment details. If the cargo is transhipped and the receivers are not informed, the consignees might have difficulty in retrieving their deliveries, which implies keeping goods stored in their location. Besides gathering cargo data, the problem of fast sharing has been overcome in the PI approach by the implementation of smart interfaces that notify the consignee when the cargo is transhipped and/or update details on the type of vehicle and the location of the offloading point as well as the allocated  $\pi$ -hub(s). With wireless sensors recording the physical conditions, locations, and collaboration between users, cross-docking  $\pi$ -hubs might act as a fast-builder of logistic flows with multiple suppliers and retailers for limiting negative externalities that could affect the efficiency of  $\pi$ -hub network. Keeping track of  $\pi$ -containers is responsible for increasing the overall security of passengers, commodities, and installed equipment in shared vehicles of PT. Through data recording, the tracked movement of each system user helps anticipate problems and accidents and successfully eliminate them. Ultimately, we can conclude that moving  $\pi$ -containers via  $\pi$ -hubs could reduce injuries, accidents, breakdowns, and damages in shared freight-PT systems.

#### 4.2.2. Interconnecting $\pi$ -networks with urban delivery sites

A relevant portion of passenger and freight journeys follow the same path across several areas; however, they are basically interconnectable. In PI,  $\pi$ -hubs are organized in transportation networks in such a way that different flows converge towards these facilities, and merge to become one consolidated flow. These  $\pi$ -hubs establish the interconnection nodes of the sub-networks involved in the mobility of the two users. However, flows have to be split up again so that merchandise could reach its final destination. When using the remaining capacity, PT would be able to fulfill the logistics demand of a customer's orders totally or partially during a given timeframe. That is, several cars of PT that are allocated to road or rail trips could carry a one demand split into a number of  $\pi$ -containers. Consequently,  $\pi$ -hubs shall be located.

The number and location of such nodes in the networks a question to which we have firstly give an answer according to the characteristics of demand seasonality and geographic proximity. This step, known in the literature as the "strategic configuration", in other words, the way in which the network of hubs is interconnected, affects the quality of consolidation and distribution of freight over the long-term [77]. There is a substantial body of literature that addresses the problem of locating consolidation hubs. "Hub Location Problem" is a common approach to this literature, especially in terms of optimizing implementation costs [78] [79]. LRP (Location Routing Problems) combine operational and strategic considerations for selecting bundling locations [80]. Other approaches such as the spatial [81] or multi-criteria [82] approaches could also be used to ensure the optimal demand coverage. On the other hand, the PI approach provides maximum interconnection between hubs, which enables sub-networks to be reached based on frontier  $\pi$ -hubs. These are structured according to a multi-level topology with a limited number of  $\pi$ -links [83]. However, this multi-level topology is moving from a  $\pi$ -hub and spoke topology, currently dominant in cities, to a topology based on multi-plane and meshed networks through locating  $\pi$ -hubs at the level of each plane [47]. In shared PT, this step could require two levels of analysis. The first level is concerned with the reception and dispatch of goods accessing the city via PT (tramway for example). The second level is dedicated to urban micro-consolidation in the vicinity of the mainline to load and/or unload goods without negatively impacting passenger service.

For shared freight-PT, the target is to minimize external costs while fulfilling customer demand. As such, strategic coverage of potential networks ought to reach consumers while observing the geographic concentration of goods movements to connect passenger networks to consumer ones. That is, over the long term, a consolidation facility and its last-mile fleet need to have capacity and location that are closely matched to the zone supporting demand sites [85] [192]. Given such a framework, each zone could be regulated and "call" freight only at convenient times. These autonomous zones (Figure 6) are similar to the concept of ASs in the digital Internet. They are characterized by specific  $\pi$ -routing protocols to select relevant distribution paths. In IP, such zones encompass "brother nodes",  $\pi$ -certified, with common characteristics, aims, routing standards, and communication facilities. With the data sharing between  $\pi$ -hubs and local collaborators in each AS, particularly in terms of capacity, physical properties, and destinations, co-loading could become less expensive.

Depending on the vocation of location zone, three types of potential hubs within a shared PT network could be defined:

- **Type 1:** Available (to fit out), which represents both passenger pick-up and/or drop-off stops and  $\pi$ -containers loading/unloading sites (Figure 5).
- **Type 2:** Inexistent (to locate), correspond to platforms for loading  $\pi$ -containers to be transferred to a second last-mile vehicle, immediately or after a transshipment process.

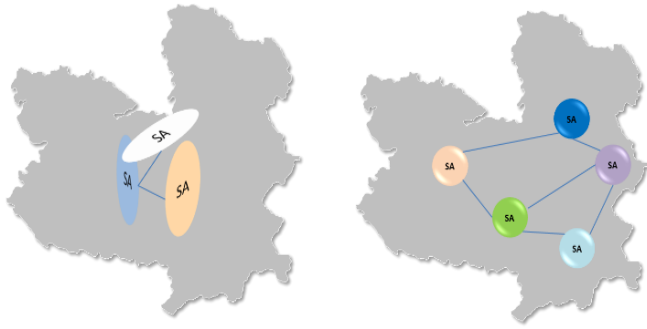


Figure 6: A geographical vision of ASs (figure on the right) Vs A conceptual vision (figure on the left) [80]: Freight exchange between ASs in this second case occurs also at the intersection areas.

Within the future shared freight-PT for totally safe, open, and connected logistics, physical, digital, operational, and financial connections are required to manage the shared  $\pi$ -hubs. The existing facilities are still the starting base for contributing to the development and testing of the shared freight-PT concept. However, innovative management approaches are needed to accommodate the additional flow of freight traffic. For example, logistics platforms such as terminals, warehouses, airports, etc. are likely to offer layouts for multimodal transport and then efficient itineraries. Next to this, additional comfort and convenience for users should be provided by integrating the  $\pi$ -hubs into a nearby site, with links to trade and industry locations. The selected  $\pi$ -hub among the existing ones, in this sense, would depend on the decision-making system supporting operators to detect, prevent, and respond to threats to passenger safety, assets and delivery processes. In selecting  $\pi$ -hubs, the complementarity of PT and the other mobility alternatives, including electric cars, bicycles, etc. shall be considered supporting smart information servers connected to the entire consolidation network. As well, implementing universal mobile information and payment systems would help travelers to choose transportation modes, optimal fares, and alternative transportation services in case of delays.

The configuration of new  $\pi$ -hubs is essentially focused on the joint economic, environmental and societal efficiency and sustainability. In this way, the long term planification could provide logistical organization for the movement of containerized goods along the transport chain. Each consolidation node processes typically, a large number of inbound sources and outbound destinations. The location of  $\pi$ -hubs in the global network has to be highly accessible and must not interfere with the other traffic scheduling. In new platform implementations, the accessibility challenge is often considered controlled as a measure of proximity in terms of distance or density of structures or professional and users. Indeed, some specific  $\pi$ -hubs are often assigned to these sources and destinations, with great stress on their capacity. In location areas, the choice of suitable sites is essential to balance the workload across the entire network for fast, transparent, reliable, and resilient long-term functioning.

From one mode to another, through transshipment, sustained connectivity plays a major role in boosting traffic fluidity in areas that lack logistic platforms already in place. The estimation of demand in the planning of the network of  $\pi$ -hubs is a primordial factor in determining the capacity required to handle the user flows. After the demand estimation, the minimum fleet size could be used in the location selection as a step to limit service blockage and traffic congestion at the road level in the future.

In certain areas, shared  $\pi$ -hubs could create a great deal for passenger comfort and serious trouble in service quality that PT could fall further and further behind. For example, it could be quite inconvenient for passengers to borrow a shared vehicle from mixed  $\pi$ -hubs that suffer from physical congestion and stress. In such  $\pi$ -hubs, there could be a higher risk of infection by diseases as often crowded compared to other terminals. In addition, sharing  $\pi$ -hubs might lead to delays in reaching a destination in certain zones. In this respect passengers and/or freight could have to wait quite a long time until the next vehicle arrives, especially in rural areas. In this respect, detours could also cause serious waiting times. On the other hand, the intensive use by different users could increase waste and garbage polluting the  $\pi$ -hubs as well as the location area, especially in city centers. For these reasons, to significantly improve the shared freight-PT benefits, the use of this system should not exceed a rational limit to maintain a well-balanced use of private vehicles in critical areas.

Based on the above remarks, the shared functioning of such infrastructures could lead to some conflicts. It might even lead to a deterioration in passenger service on all or part of the transport patterns. For example, waiting times and downtimes are likely to increase due to loading, unloading, and cargo handling procedures. As a result, the arrival time at the next  $\pi$ -hub and the total duration of the trip in order to reach the final destination could be affected. Other problems, shown in (Table 2), might arise when routing both passenger and freight flows together. However, the fundamental concepts of IP provide key solutions to systems whilst maintaining shared freight-PT systems.

Table 2: PI approach provides solutions to shared freight-PT challenges.

Challenges	Solution in PI	Details
Freight compatibility	$\pi$ -containers	<ul style="list-style-type: none"> <li>✓PI handles cargo only based on modular <math>\pi</math>-containers that enable easy and standardized transportation.</li> <li>✓<math>\pi</math>-containerization makes shipment run efficiently on any vehicle or platform, which prevents flow managing conflicts that might obstruct the functionality of shared mobility.</li> <li>✓Economies of scale could be derived from intermodal mobility thanks to transporting <math>\pi</math>-containers.</li> <li>✓Improved security and safety by isolating the incorporated goods.</li> </ul>
Managing flow routing		<ul style="list-style-type: none"> <li>✓Flow routing in the PI is based on the shortest path algorithms to forward flows between the PI network nodes.</li> <li>✓PI attempts to deal with three key issues: filling <math>\pi</math>-containers, filling vehicles, grouping and ungrouping</li> </ul>

		<ul style="list-style-type: none"> <li>✓ PI includes sustainability assets namely evaluation metrics of transit delay, handling time, operational, strategic management costs, and pollutant emissions.</li> </ul>
Workload Balancing	$\pi$ -protocols	<ul style="list-style-type: none"> <li>✓ If the routing protocols have obtained the same weight for several routes according to the applied metrics, balancing load between paths shall be involved supporting the multi-path mode.</li> <li>✓ Organizing freight forwarding by routing transfer stores through the intermodal network.</li> </ul>
Promoting collaborative logistics		<ul style="list-style-type: none"> <li>✓ Various retailers and wholesale suppliers collaborate by consolidating shipments and preparing shipments of multiple suppliers sorted for individual customers.</li> <li>✓ Collaborative flow management in PI focuses on long term collaborations between supply chain actors rather than short term trades involving mutual confidence, enhanced engagement and better dependability towards more sustainable logistics.</li> </ul>
Consolidating freight flow	$\pi$ -hubs	<ul style="list-style-type: none"> <li>✓ PI recommends a full consolidation of freight flows from autonomous shippers in logistics networks.</li> <li>✓ PI systems are expected to provide resilient door-to-door services consolidating and deconsolidating shipments within a supply chain network where all resources, capacities and facilities are fully monitored, accessible, and operational for efficient shared transportation.</li> </ul>
Transshipment operations		<ul style="list-style-type: none"> <li>✓ Shared freight-PT might opt for a transshipment process permitting cargo to reach several customers through road and intermodal rail.</li> <li>✓ The fluctuation of residual capacity per time, the challenges of eliminating single movements, and maintaining PT service quality require transshipment operations before being shipped-off to final destinations.</li> <li>✓ The flexibility to shift seamlessly between modes is often associated with lower costs compared to transport without transshipment.</li> </ul>
Minimizing the number of stops	$\pi$ -containerization / $\pi$ -fragmentation	<ul style="list-style-type: none"> <li>✓ Assigning containerized goods of the same origin and destination to more than one vehicle to improve capacity exploitation and reduce stoppage number and time.</li> </ul>
Minimizing loading/unloading time	$\pi$ -containers	<ul style="list-style-type: none"> <li>✓ PI allows to speed up its logistic workflow dramatically through the efficient use of containers.</li> <li>✓ <math>\pi</math>-containers reduces the loading time at the origin of a journey as well as the unloading time at the final destination.</li> <li>✓ This leads to an immediate reduction of dwell time for all shared vehicles whether it is a bus, streetcar, ship, or plane.</li> <li>✓ The transport fleets would be able to dispatch more goods in a shorter period of time.</li> </ul>
Reducing the complexity of the system management	Multi-layer structure	<ul style="list-style-type: none"> <li>✓ The systemic nature of PI process (hierarchical structure) would allow reducing complexity of the proposed system by monitoring supply (residual capacity, consolidation hubs,) and demand (people and goods to be transported) per layer.</li> <li>✓ Inter-layer detection of problems.</li> </ul>
Interoperating the routing of passenger and freight	Routing protocols	<p>Flow routing is performed following two types of <math>\pi</math>-protocols:</p> <ul style="list-style-type: none"> <li>✓ External: routing policy for flows between (ASs).</li> <li>✓ Internal: routing policy within (AS).</li> </ul>
Interconnecting and streamlining movements	Smart interfaces	<ul style="list-style-type: none"> <li>✓ Interconnecting existing transportation schemes to urban delivery/pick-up areas.</li> <li>✓ Grouping/ungrouping of <math>\pi</math>-containers and/or composition/decomposition of <math>\pi</math>-containers to streamline the functioning of shared transportation systems.</li> </ul>
Allocating routing path	Scheduling weights	<ul style="list-style-type: none"> <li>✓ Path selection is carried out in a PI network by attributing weights constructed by looking at several factors as weather conditions, congestion, capacity, path length and so on.</li> <li>✓ When several routes for forwarding parcels from a router to a destination are available, the router (<math>\pi</math>-hub) is responsible for choosing the best route based on routing tables.</li> <li>✓ Optimal path selection relies on routing protocol preferences and road metrics. In cases where several routes share the identical routing protocol preference and metrics, workload balancing between routes is performed to alleviate network stress.</li> <li>✓ Multiple routes with different routing protocol preferences and measures allow route backup to be implemented across routes to improve network reliability.</li> </ul>
Tracking shipments	$\pi$ -servers and $\pi$ -sensors	<ul style="list-style-type: none"> <li>✓ Starting from the moment of departure, it is crucial to increase <math>\pi</math>-container tracking to keep informed of shipment to verify that transshipment and arrival occur as scheduled.</li> <li>✓ Shipment information could be gathered based on shared servers between the <math>\pi</math>-certified players enabled to get details and keep updated in terms of pick-up and delivery.</li> </ul>
Enabling synchronomodality	$\pi$ -modes	<ul style="list-style-type: none"> <li>✓ Synchronomodality is treated in the PI approach within a cooperative, open and network to pool resources in analogous ways as packet data across connected and synchronized inter- and co-modal transport modes.</li> <li>✓ PI prevents affecting responsiveness and quality of transportation service to exploit existing resources of transport in an optimized and sustainable manner by switching flows between several modes.</li> </ul>

## 5. Benefits discussion

### 5.1. At the pandemic level

Shared freight-PT remains leading to a variety of perceptions, spin-offs of which are sculpting supply chains, time, and demand characteristics. Adopting urban travel plans that deal separately with passengers and goods mobility would continue to be retained under some critical characteristics. The hybrid scheduling is even more pronounced in areas with relatively few logistical facilities, but which are experiencing a growth in the number of convenience customers requiring deliveries. It is also required in order to avoid disrupting the PT service during rush hours. With the global COVID-19 epidemic, the concept of transit demand has been largely changed since a major part has been dramatically declined compared to before. This situation has quite strongly shaped the major aspects in how the PT has been required and consumed. In the COVID-19 situation, the benefits of shared freight-PT are more explicit beyond the financial stress, falling occupancy rates, and trip frequencies.

**Financial stress:** Operational costs of mass transit have been increased enormously as emergency actions have evolved. PT operators have witnessed in rate incomes but still have important fixed costs including premises rents, staff wages, and administrative expenses. Under these circumstances, many countries have been powerless to fund PT operators for facing serious economic impacts. On the other hand, short-term contingent funding provided by governments could not lead to extended coverage of financial stress. In other cases, conventional agreements actually shift demand losses to the operating companies,

threatening significant slowdown transportation companies should consider adopting the initial changes in PT operating and business models within rapid limiting of the virus spread to recover PT competitiveness.

In this respect, the suitable solution to help PT systems stay ahead is to provide shared policies that could attract new markets and boost customer loyalty. Shared freight-PT will make it possible to dispense with fixed-cost pricing models and adopt variable-cost contracts to support efforts to gradually return to “normal” passenger traffic patterns. Focusing on service price, this system would keep a cap on price making travel and travelling cheaper for users sharing transportation costs. The cost savings associated with various PT modes would be very advantageous as there are usually more expensive to pay for separate shipments than to share a long-haul portion of trips. The economic benefits of optimizing PT operation within shared vehicles allow covering the drop in revenue, rather than passing costs onto commuters. If the PT sharing would generate relatively short delays, commuters could recoup given miles in terms of low-cost tickets. Many operators could receive wider economic benefits and costs through the effects on a potentially diverse set of development outcomes, such as revenue growth, jobs, economic resilience, etc.

**Falling occupancy:** The occupancy rate of a vehicle accounts for the number of passengers in the vehicle according to the number of seats provided in the technical specification expressed as a percentage. The COVID-19 virus has led to a significant correlation between the occupancy of buses and the mandatory social distancing. The separation zone between travelers of a radius about of 1.5 meters on a bus, for example, that generally carries 48 persons can be reached by capping the capacity to 11 travelers, which means an occupancy rate of 23% (Figure 2) [193]. To overcome the low average occupancy rate, shared freight-PT systems allow cost synergies and significant occupancy rate. Consequently, increasing the occupancy rates of vehicles by globally managing empty car seats could drastically improve the efficiency of transportation while reducing the risk of contagion. The extra use of the residual capacity depends on the design options for fitting out seats to accommodate either passenger or cargo. The high occupancy of PT modes has to comply with the universal accessibility features of the interior design, which ultimately achieve maximum passenger comfort with spacious interiors and transport flexibility [25]. Beyond the seat occupancy, the total capacity use of PT would be increased slightly over the daytime as it differs for different time slots as well as between path trips. Peaks in traffic demand and increased traffic saddles during the day, week, month and year lead to variation in occupancy rate. Changes in demand generate difficulties for transport carriers that have to decide for capacity scheduling. These challenges also occur in system dimensioning, and it affects the number of required fleets too. The planning of the transport is also affected by the requirements for the dynamic sharing of crowding data in real time with all users through data gathering servers. Crowding levels on PT vehicles in a specific platform empowers users to make convenient decisions about their trips and would remain to edit value to the user experience beyond the outbreak.

**Trip frequencies:** Due to the urgent need for social isolation after the approved health guidelines PT trips have fell by between 30%, 40% for people in the lowest income households and 70% for the highest income households [25]. Through a higher rate of car occupancy PT could switch back to the regular number of trips boosting rider confidence and providing new system customers. The sector would also show a decrease in downtime due to improved verification of social distancing measures, which in turn will not impose extra costs. The limited number of passengers in the loaded vehicles and goods would lead to the chance of increasing trip frequencies as the full fares or cost savings would be achieved.

## 5.2. At the PI level

*Why shared freight-PT is presenting an asset for the PI?* The brief answer is that the integration in the PI approach of passenger flow is an innovative idea that could improve the openness and interconnection of universal transportation. However, the main question, in this paper, is *why is PI representing an opportunity for shared freight-PT?* The implementation of a new shared transit strategy entails different fundamental criteria to fully guide integrative movements. The proposed system, in a broad sense, requires process changes in terms of four key measures for providing a more efficient scheduling process, and minimal total logistics cost, especially shipment and transshipment costs.

The first measure is to look for in selecting compatible goods that could be loaded in PT vehicles. This measure is two-fold, both for transport safety and economic cooperation. For the safety of transportation, this concerns both users, i.e., passengers in the first place to avoid the problem of crowding and service quality loss, and the goods to prevent perishability and/or product damage. For example, if freight is loaded on the same emplacement as fragrant goods such as perfume bottles, scented products, etc. users might claim about spread smell or smell changes of the delivered freight.

Secondly, the economic factor involves the portion of profit margin in transportation costs regarding the selling price of this product. This means that the profit margin of compatible freight depends on the unit value of the transported product taking into account the potential savings to realize based on the remaining capacity. The PI proposes to avoid these inefficiencies using standardized packaging that protects goods, facilitate handling and decrease empty space because of inefficient cargo loading. The third measure is the stakeholder cooperation to establish the service providers and requesters network that track the districts/markets where potential customers are located. This could be more critical with different aims of users tending to operate their logistics demand across a flexible network without promoting player benefits at the expense of others. In an open network, PI provides a hyperconnected logistics system enabling shared mobility based on standard protocols and consolidation platforms for more convenient, and reliable goods transfers. Due to the inaccessibility of the PT in the heart of the city walls, merchandise could be delivered by using shared freight-PT in the vicinity of the customer so that light vehicles continue the last-mile delivery. Therefore, the third measure to be ensured is the trackability of freight streams in order to up-to-date goods location from a given source. Flow trackability is supported in PI by intelligent interfaces that enabled monitoring the real-time status of containers. The fourth measure is the system management that still very difficult to fulfill with different levels of coordination such as strategic, operational and tactical levels. To utilize shared networks in PT in freight shipment, rely on shared servers rather than local ones,

which shared freight-PT such as procedures for loading/unloading, pickup/delivery and consolidation of freight. Fortunately, they are fully incorporated in the PI approach.

### 5.3. At the environmental level

Urban and non-urban transportation accounts for significant total Greenhouse Gases (GHG) leading to climate change and global pollution [172]. Depending on the key published investigations, the proposed system could help slow the emission rates of GHG [172]. For example, the transportation sector in California is the largest contributor to GHG emissions accounting for more than 40% [176] and 65% in New Zealand [171]. This sector produces a quarter of GHG emissions in Europe [175]. In 2013, the European transport sector has emitted 24.4% of the region's total GHG, of which 94.6% came from road transport [180]. Including freight and passenger transportation, the sector causes a large part of the annual energy consumption and GHG emissions in the US; about 30% of US energy and 33% of US CO<sub>2</sub> emissions [177]. However, freight transportation accounts for a portion of total US transportation energy use and emissions about 30%. Also, it is estimated that UK freight transport generates 33.7 million tons of CO<sub>2</sub>, about 21% of the transport sector's emissions and 6% of the total emissions of all sectors. In this respect, road transport accounted for 92% of these transport-related CO<sub>2</sub> emissions. About 35% of all van-km, has been responsible for 13% of total freight emissions. Despite its relatively smaller size, the freight transport sector in Lebanon is estimated to consume 30.6% of total transport energy and produce 31.4% of total GHG emissions from road transportation [181].

Globally, the transportation sector as a whole is responsible for approximately 23%; road transport contributes 20% to total CO<sub>2</sub> emissions [173]. So, this accounts for over one-fifth of fossil fuel consumption that is the backbone of the world's energy production and the 26% of GHG emissions [174]. Heavy-duty on-road vehicles account for 70% of all freight transport and 20% of transportation-sector GHG emissions in the US [178]. In addition, heavy-duty road vehicles generate 70% of all freight transportation and 20% of GHG emissions [179]. During the same period, 75% of the emissions is linked to the participation of the road transport of urban freight [183]. An additional complication of the increase in urban freight traffic is the significant contribution to the GHG, which accounts for 25% of CO<sub>2</sub> emissions [182].

The proportions of emissions from buses and taxi systems are continuously reduced to less than 20%, for example, according to an example from China [186]. If analyzed in the context of shared freight-PT based on diesel buses, the rate of reduction of polluting emissions might increase depending on the residual capacity exploited in freight transport. By considering a rate of residual capacity use from 10% to 50%, the GHG emissions related to freight transport using diesel buses could be reduced by 2% to 10%, which leads to a reduction of 22% to 30% of the transport sector emissions. However, compared with a diesel bus, an electric bus could reduce from 19% to 35% in CO<sub>2</sub> emissions and even more [185]. Next, the use of tramways as a simple substitution of the road mode has the potential to mitigate at least 71,000 tCO<sub>2</sub>e or about 9% of the total city emissions according to the paper [184]. Relying on the emission rate that is relative to the road transport of urban freight, it is expected that the use of shared tramway systems could reduce the GHG emissions of freight mobility from 75% to 68.25% with a drop rate of 6.75%.

A reduction rate could be, also, attributed to the PI involvement in shared freight-PT versus conventional freight transportation. Following previous studies [155-189], the GHG emissions are significantly lowered by 10% in the PI scenarios thanks to increasing the occupancy rates by 70% to 75.5%. In addition, it is stated that a 6% CO<sub>2</sub> reduction is possible when the key principles of the PI are applied. That is, the PI approach would reduce the total CO<sub>2</sub> emissions by 16% [187]. Finally, the modal shift that aims to ensure delivery to the last kilometers could be responsible for key reductions in GHG emissions by 60% [188].

## 6. Conclusion & research prospects

Due to the evolution of transportation systems currently available, customers have become more discerning and want to be transported and delivered quickly and inexpensively. Therefore, customers would not be able to miss the full affordability of PT and service efficiency. In several cases, PT use has been often accompanied by a significant lack of efficiency, rationalization, and sustainability during the pandemic; it represents the primary sectors affected due to the precautionary measures.

To overcome such challenges, PT networks have to further integrate prevention planning to face poor performances due to epidemiology risks in the coming years. Innovative alternatives for PT services still have to be provided to remain meeting the socio-economic and ecological PT assets. In this respect, logistics sharing and integrative transport plans must undergo profound development to exploit residual capacities with a perspective of making key management tools of shared trips. Through schedule plans, the transportation demand of both commuters and goods is likely to be structured by actors and by opportunity so as to reach similar destinations. As a result, the advocated patterns are able to assume different layouts with shared fleets, infrastructures, pooled management of supplies, and/or urban platforms.

A few of the aforementioned articles have indicated that such systems have been already experimented with and failed, a fact that could lead to a lack of stakeholder interest. Still, the related business model does not yet seem to be clearly established, making the majority of initiatives, especially from the private sphere, obsolete. Conversely, the environmental and social benefits remain undisputed, which leads us to continue our researches on such systems. They could generate interesting economic scales with fewer resources and emissions. Next to this, they would not contribute to congestion since they are already operational, but they could reduce the number of private trips. In this paper, we highlighted the main issues involved in using a shared freight-PT system that aims at rationalizing the mobility resources to cope with pandemic impacts and enhance sustainably. We analyzed systems that respect social separation and allows to maintain meeting socio-economic, competitiveness, and ecological PT challenges towards new customers.

By studying the PI, we move forward examining a key triplet: selected zones, interconnected consolidation platforms, and interoperable routing protocols. Thus, we aimed to advance investigating shared freight-PT by positing the PI as an analytical framework. According to the provided insights, the approach seemed appropriate. In this paper, we identified the conceptual framework and solutions to promote shared PT under the PI, namely containerization, standardization of logistics processes, and routing protocols. To boost further the obtained results, future works will focus on quantification of the system benefits that could be derived from incorporating the PI paradigm. In doing so, it is a matter of specifying the level of openness appropriate to shared PT in a city, as far as its particular characteristics.

#### Appendix A: A summary of literature review on shared transportation systems.

Article	Authors	Origin	Context	Problem variant	Flows	Contribution	Methodology	Findings
[1]	(Cleophas et al., 2019)	UK	Urban	Collaborative transportation	Freight	Research gaps, operational planning problems and solution approaches.	Conceptual	A need for research in line with operational research and civil engineering.
[4]	(Manser et al., 2020)	Switzerland	Urban	large-scale PT networks	Commuters	Agent-based simulation framework for multi-modal transport.	Empirical	Predicting PT ridership at a lower level of subsidies and identifying corridors for potential capacity upgrades.
[5]	(Liu et al., 2019)	China	Urban	Bike-sharing	Commuters	Algorithm of hybrid operation modes that combine fixed and dynamic frequencies in a bimodal period.	Empirical	Improved performance comparing with genetic algorithm-II and efficiency validation of the “morning fixed and evening demand-responsive” versus the “morning demand-responsive and evening fixed service and fixed operation” mode.
[6]	(Gkiotsalitis & Stathopoulos, 2016)	Greece	Urban	Demand-responsive public transportation	Commuters	Modeling and solving through sequential heuristic method the demand-responsive PT service scheduling.	Empirical	Improved operations of the demand-responsive PT systems by increasing the service quality and their ridership related to joint-leisure-trips via timetable rescheduling.
[7]	(Berggren et al., 2019)	Sweden	Urban	PT	Commuters	Scheduling strategies on waiting times of PT.	Empirical	Improved operations by indicating the significance of having access to pre-trip information, especially for long trips above one hour's duration, to pre-plan and thereby optimize waiting times.
[8]	(Huang et al., 2020)	China	Non-urban	Bus network	Commuters	Integrated decision-making framework for the demand-responsive customized bus network design.	Empirical	Formulating the interactive mechanism between the operator and passengers in a hierarchical decision-making model.
[28]	(Rodrigue, 2020)	US	Non-urban/last-mile	Distribution network	Freight	Assessing the distribution network of Amazon and the footprint of freight digitalization.	Empirical	Improved locational behavior to achieve a distribution hierarchy of facilities granting logistical access to consumer markets.
[30]	(Thompson et al., 2020)	Australia	Urban	Shared freight networks	Freight	Analyzing, modelling, and designing a shared network.	Empirical	Reduced congestion and lower transport costs.
[32]	(Ji et al., 2019)	China	Non-urban/last-mile	Production-inventory-distribution problem	Freight	A mixed-integer linear programming formulation for addressing the combination of the integrated production-inventory and the distribution problem.	Empirical	Cost savings compared to the traditional supply chain network with a dynamic configuration and a hybrid configuration.
[33]	(Mourad et al., 2019)	France	Non-urban/last-mile	Shared mobility	Commuters & freight	Prearranged and real-time problem settings, solution methods, and real-case applications	Review	A need for researches on combining trip synchronization, traveler cost aspects as well as the quality of the provided service.
[35]	(Sun et al., 2018)	China	Urban	Shared mobility	Commuters	The effect evaluation of alleviating or solving the traffic and environmental issues of mega-cities.	Empirical	A significant potential of the shared systems from perspectives-resource, environment, convenience, economy and governance.
[36]	(Shen et al., 2018)	Singapore	First-mile	Shared mobility	Commuters	An integrated autonomous vehicle and PT system.	Empirical	Improved service quality with fewer road resources and lower costs.
[37]	(Behiri et al., 2018)	France	urban	Integrative PT mobility	Commuters & freight	Investigating urban freight transportation using passenger rail network.	Empirical	Optimized loading time considering existing loads and taking into account disturbances in operations such as train delays or incidents.
[38]	(Marcucci et al., 2017)	Italy	urban	Shared mobility	Commuters & freight	Investigating the potential of crowdshipping under a connected shared mobility for passengers and freight.	Conceptual	Reduced total and ad-hoc trips by optimizing the use of resources and infrastructures: 87% of students would be willing to act as crowdshippers (i.e., supply) with compensation, while 93% of them are willing to receive their goods through a crowdshipping system (i.e., demand).
[39]	(Agatz et al., 2010)	Netherlands	urban	Ride-sharing	Commuters	Dynamic ride-sharing.	Conceptual	Traffic optimization challenges are supported by dynamic ride-sharing.
[40]	(Ursavas & Zhu, 2017)	Netherlands	Non-urban	Shared mobility	Commuters & freight	An analytical model for an integrated passenger and freight planning on shared-use rail corridors.	Empirical	Increased flexibility and reduced waiting times probability at railway yards and sidetracks.
[41]	(MOURAD et al., 2020)	France	Urban	Shared mobility	Commuters & freight	Modelling the pickup and delivery problem using a stochastic process.	Empirical	18.2% of cost saving compared to the conventional freight system.

[43]	(Cleophas et al., 2019)	UK	Urban	Collaborative transport	Commuters & freight	transportation systems, assessing pros and cons.	Review	passengers and freight are important for urban sustainability.
[48]	(Gonzalez-Feliu et al., 2018)	France	Urban	Collaborative transport	Commuters & freight	Multi-stakeholder collaboration.	Review	The topic still at an emerging stage.
[50]	(Trentini, 2012)	France	Urban	Mixed transport	Commuters & freight	Shared PT.	Conceptual	The implementation in a medium-sized city does not necessarily issue from the potential of heavy use, unlike in big cities where the number of potential users is a determining factor for the building of tramway lines.
[71]	(Li et al., 2014)	Netherlands	urban	Share-a-Ride	Commuters & freight	Taxi-based people-freight sharing systems modelling.	Conceptual	From a city perspective, the system has the potential to alleviate congestion and environmental pollution. From the perspective of a taxi company, new benefits from the parcel delivery service can be obtained.
[77]	(Lis Lesmini et al., 2017)	Indonesia	Non-urban	Integrated transport	Freight	Integrated logistics center to improve smooth flow of goods.	Qualitative approach	Lower logistics costs.
[85]	(El Ouadi et al., 2020)	Morocco	Urban	Shared transport	Commuters & freight	A Machine learning based zoning to support shared transportation systems.	Empirical	The most efficient models for zoning cities to implement shared transportation systems are the k-means and Support Vector Machine models.
[123]	(Machado et al., 2018)	Brazil		Shared mobility	Commuters / freight	Fundamental aspects and current systems.	Empirical	A significant potential to enhance the efficiency, competitiveness, social equity, and quality of life in cities.
[124]	(Morana et al., 2014)	France	Urban	Logistics pooling	Freight	Information systems-based framework for planning and evaluation.	Conceptual	New variables could appear with the development of shared management and planning.
[125]	(Gonzalez-Feliu & Morana, 2011.)	France	-	Collaborative Transportation Sharing	Freight	Modelling the information sharing.	Empirical	Identification of five elements in information system management: the enterprise solutions, their deals, sharing management, organizational features and information, and communication technologies.
[126]	(Teal, 1987)	US	Urban	Carpooling	Commuters	Characteristics types and comparisons.	Review	The feasibility problem increases in carpool mode share.
[127]	(Gansterer et al., 2020)	Australia	Urban	Shared transportation	Freight	Collaborative pickup and delivery problem.	Empirical	Considerable cost savings by limiting customer or profit share losses and enabling carriers to keep some of their most valued customers.
[129]	(Behiri et al., 2016)	France	Urban	Shared transport	Commuters & freight	Transporting freight by using urban rail infrastructure.	Empirical	The model is able to quickly solve moderate size instances.
[135]	(Li et al., 2016)	Netherlands	Urban	Share-a-Ride	Freight	Share-a-Ride problem with stochastic travel times and stochastic delivery locations.	Empirical	Stochastic information is valuable in real-life and can dramatically improve the performance of a taxi sharing system, compared to deterministic solutions.
[136]	(Li et al., 2016)	Netherlands	Urban	Share-a-Ride problem	Commuters & freight	An adaptive large neighborhood search (ALNS) heuristic.	Empirical	Improved time and quality of solution.
[137]	(Tao, 2007)	China	Urban	Taxi-sharing	Commuters	An overview of the taxi-sharing services.	Review	Valuable implications based on the use of intelligent transportation system are required for better taxi-sharing service in the future.
[138]	(Santi et al., 2013)	US	Urban	Taxi-sharing	Commuters	A network-based approach to social sharing problems.	Empirical	Reduced service cost, traffic, and emissions.
[139]	(Ben Cheikh-Graiet et al., 2020)	France	Urban	Carpooling	Commuters	A novel Tabu Search based metaheuristic.	Empirical	Improved efficiency and users' satisfaction.
[140]	(Tusher et al., 2020)	Bangladesh	Urban	Ride-sharing	Commuters	A ride-offering plan in Dhaka City.	Review	Improved straightforwardness, accommodation, and reassurance of the city occupants.
[141]	(Ruch et al., 2020)	Switzerland	Urban	Ride-sharing	Commuters	Quantifying the Efficiency of the ride-sharing.	Empirical	Improved efficiency and better adaptability of smaller vehicles than larger and more expensive vehicles such as minibuses.
[142]	(Punel et al., 2018)	US	Urban	Crowdshipping	Freight	Environment and personal attitudes influencing the propensity to use the studied system.	Quantitative analysis	Men, youth, full-time employees, urban areas and environmental concerns are highly related to crowd-shipping systems.
[143]	(Macrina et al., 2020)	Italy	Urban	Crowdshipping	Freight	Conventional capacitated vehicles and occasional drivers with a single central depot and several transshipment nodes.	Empirical	Reduced costs when using occasional drivers and transshipment.
[144]	(Ma et al., 2020)	China	Urban	Carpooling	Commuters	A carpooling model.	Empirical	Systematic plans, decreased emissions and maximum social benefits.
[145]	(Caballero-Gil et al., 2017)	Spain	Urban	Carpooling	Commuters	Trust-based cooperative social system applied to a carpooling platform for smartphones.	Empirical	Increased safety and reliability to overcome the psychological barrier that slows down the carpooling use.
[146]	(Nazari et al., 2018)	US	Urban	Shared mobility	Commuters	Comparing shared and private mobility.	Empirical	Gains in terms of the user groups based on the socio-economic, built environment, and daily/commute travel behavior attributes.
[147]	(Agatz et al., 2011)	Netherlands	Urban	Ride-sharing	Commuters	Simulation of matching drivers and riders in dynamic setting.	Empirical	Improved performance of ride-sharing systems and a significant potential of use in sprawling areas.
[149]	(Bulteau et al., 2019)	France	Urban	Carpooling / carsharing	Commuters	Implementability assessment.	Empirical	The use of carpooling mainly concerns people who live in rather deprived neighborhoods, while carsharing is overrepresented in well-to-do and denser

[162]	(Cheng & Sester, 2018)	Germany	Urban	Mixed traffic	Commuters	Long short-term memories recurrent neural networks model.	Empirical	Predicting three-second trajectories in complicated situations in a shared space.
[163]	(Yao & Morikawa, 2005)	Japan	Non-urban	Integrated transport	Commuters	Integrated intercity travel demand modelling.	Empirical	Explicit intercity travel behavior and capturable induced mobility.
[168]	(Martin & Shaheen, 2011)	US	Urban	Carsharing	Commuters	Impact of carsharing on PT and non-motorized travel.	Empirical	Carsharing members tend to have shorter commutes than most people living in the same zip code. Also, the analysis finds that average driving reductions are consistent across population densities up to 10,000 persons/square kilometer but become more varied at higher densities.
[169]	(Huang et al., 2018)	Belgium	Urban	Ride-sharing	Commuters	Merging PT and carpooling networks for multimodal route planning.	Empirical	Enhanced multimodal route planning with retaining the desired flexibility, and thus a higher network interconnectivity.
[170]	(Hoffmann et al., n.d.)	US	Urban	Ride-sharing	Commuters	Impact on PT use.	Empirical	A positive correlation between ride-sharing and subway usage and increased exogenous shocks.

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### Highlights:

- This paper explores the major trends in the theory and practice of shared transport systems under the COVID-19 pandemic;
- Suggests a Physical Internet (PI) framework promoting shared public transportation (PT) systems in cities;
- In exploring the PI approach, a number of proposals appear providing answers and advance researches towards shared PT.