An exploration of the potential benefits of Transportation and Logistics innovations in Last-Mile Urban Deliveries: A case study approach

Lavanya Meherishi[1*], Camill Harter[1], David Ciprés[2], José Luis López[2], Kostas Zavitsas[3]
1. Erasmus Universiteit Rotterdam, Netherlands
2. Instituto Tecnológico de Aragón, Spain
3. VLTN, Belgium
*meherishi@rsm.nl

Abstract:
Urban Last-Mile Delivery (LMD) is typically plagued with high uncertainty due to urban road traffic, parking spot unavailability and customer order handover process which in turn leads high operational costs accompanied by several sustainability challenges. Considering these issues, this study assesses the impact of innovative transportation and logistics strategies on LMDs. Specifically, this study examines the potential benefits emerging from the implementation of concepts such as the Physical Internet (in terms of complete collaboration) along with supporting paradigm technologies such as IoT in addition to the use of green logistics to address sustainability issues. Real data obtained from an E-commerce company operating in Madrid city center is utilized to create a simulated environment for evaluating the effects of order sharing and fleet sharing facilitated by urban consolidation centers and dynamic order reshuffling on operational, economic, and environmental indicators. In particular, an urban digital twin has been developed to assess the impact of such collaborative transport strategies on last mile deliveries. The results highlight the significant improvements that can be achieved in LMD performance including reduced delivery times, costs, and emissions. Furthermore, the research also provides valuable insights for urban planners and logistics companies looking to optimize last mile delivery operations in cities.

Keywords:
Physical Internet, Digital Twin, Agent-Based Simulation, collaboration, last-mile, Urban consolidation centers.

Conference Topic(s): *distributed intelligence last mile & city logistics; logistics and supply networks; PI impacts; PI implementation; PI modelling and simulation; vehicles and transshipment technologies.*

Physical Internet Roadmap*:* ☒ *PI Nodes,* ☒ *PI Networks,* ☒ *System of Logistics Networks*

1. Introduction:

In Last Mile Delivery (LMD), the design of the delivery rounds involves the pairing of each parcel delivery location with a vehicle, while respecting the time and operational constraints of the customer and vehicle drivers. Typically, in the last-mile, parcels located at central warehouses or distribution centers need to be distributed to customer locations all around the city. Urban LMD is typically associated with not only high uncertainty due to the busy city environment but also high operational costs as it accounts for around 30% of operators' costs (DfT, 2019) namely fuel, rental fee of consolidation centers, staff salaries, vehicle purchase, and other logistics' fixed costs such as insurance and maintenance. Furthermore, about 50% of the total delivery tour time in urban LMDs is not spent driving but spent while the vehicle is parked and the handover of orders to the final customers takes place (GLA, 2017; Allen et al., 2018). In other words, urban delivery uncertainty arises from urban road traffic, parking spot availability as well as the handover process.

The delivery rounds are typically designed using the Vehicle Routing Problem (VRP) and its variants, a popular operations research problem with wide applicability, that has been extensively researched and documented in the literature since 1960s. The VRP is a well-known NP-hard problem because it includes the Traveling Salesman Problem (TSP) as a special case (Garey and Johnson, 1979). To address large real-world delivery round design instances, heuristics and approximate methods are typically used for identifying near optimal solutions. Furthermore, the mathematically optimized solution is frequently found to lack the implicit knowledge of the urban environment and its limitations, seasoned delivery drivers have. Recent advances in improving the accuracy of the VRP utilizing historical data and Machine Learning, attempt to address this issue (Merchan et al., 2022).

Current practices in LMD design and implementation are limited both by the lack of evidence as well as the unwillingness of operations to alter existing practices and go through the risk of changing processes that work. However, a ray of hope to change this is given by the rise of the Physical Internet (PI) concept. The Physical Internet seeks to transform logistics and supply chain management by applying the principles of the internet to the physical world. This approach involves creating a modular and interconnected network of transportation and logistics infrastructures that can enable more efficient, sustainable, and collaborative freight transportation, including LMD. Key aspects of the Physical Internet include the use of standardization, modularity, and interoperability, as well as the adoption of digital technologies such as the internet of things, blockchain, and artificial intelligence (Montreuil, 2011)

This paper focuses on the integration of collaborative and Physical Internet principles in LMD operations with the objective of enabling efficient urban logistics and to aid the transition towards a PI paradigm. Therefore, a simulated environment is established via the development of an urban digital twin, to examine the effects of order sharing and fleet sharing in three different scenarios. In the baseline scenario (as-is), multiple companies are delivering parcels to customers in Madrid city centre using their own distribution centres and fleet. In the second scenario (collaboration), companies' distribution centres are used as shared urban consolidation centres (UCC), in which orders can be redistributed and vehicles can be shared. Urban consolidation centres are logistics facilities located in an urban area that are designed to consolidate goods from multiple suppliers or distribution centres before delivering them to their final destination within the city. Moreover, a *dynamic reshuffling process* is established in this scenario, which matches delayed vehicles with vehicles that have buffer capacity to mitigate the impact of arising delays in daily operations. In the third scenario (collaboration + green vehicles), the collaboration setup is complemented by the use of green vehicles and cargo bikes to further drive down emissions and assess if there is an associated performance loss.

The findings clearly indicate that the integration of Physical Internet principles, particularly the collaboration on orders and fleets among competing companies, enabled by technologies such as IoT and blockchain, not only leads to cost reduction, thereby benefiting a company's financial performance, but also facilitates carbon footprint reduction for each participating company. By employing Urban Consolidation Centers (UCCs) and utilizing green vehicles within the PI vision, these enhancements can be achieved without compromising performance.

2. Literature review

Table 1 highlights the key articles reviewed in the field of carrier collaborations in last-mile deliveries with a special emphasis on the different technologies and logistics innovations considered and the methodologies used to address the research objectives

As can be seen from Table 1, limited number of studies explicitly address the use of different technology and logistics innovations for fostering efficient collaboration between carriers. While certain studies, such as Handoko and Lao (2016), Los et al. (2020), and Guo et al. (2021), emphasize the role of digital market platforms in coordinating logistics operations through order and capacity allocation, they do not delve into the examination of sharing and collaboration within the context of Physical Internet strategies. In Physical Internet strategies, collaborative sharing surpasses mere allocation facilitated by digital platforms and involves profound collaboration and coordination among participants. Although the extant literature recognizes UCCs as a common form of collaboration, studies like Handoko and Lao (2016) and McLeod et al. (2021) often assume that the responsibility of arranging fleet capacity for last-mile deliveries lies with the UCC operator. Furthermore, even

Table 1: Review of key extant literature

	Transportation Modes					Collaboration Type				
	Trucks	E-vans	E-bikes	Technology	T&L innovations	UCC	Carrier Fleet Capacity Sharing	Carrier Order Sharing	Methodology	Objective Type
Liu et al. 2010)	✓							✓	LSO	Empty vehicle moves (Min)
Handaku and Lau (2016)	✓				Platform	✓		✓	GT	CS(Max)
Wang et al. (2017)	✓				Platform			✓	LSO	P(Max) & fair P sharing
Chabot et al. (2018)	✓							✓	LSO	Costs,Emissions (Min)
Los et al. (2020)	✓				Platform	✓		✓	GT	Service, Profit (Max), Time (Min)
Guo et al. (2021)	✓				Reshuffling, Platform	✓		✓	LSO, GT	Costs,Emissions (Min
McLeod et al. (2021)	✓		✓	GPS		✓		✓	LSO	Costs,Emissions (Min
Current Study	✓	✓	✓	BC,IoT,	Reshuffling, PI enabled platform	✓	✓	✓	LSO	Costs (Min)

CS: Cost Savings, GT: Game Theory, LSO: Large Scale Optimization, Max: Maximization, Min: Minimization, P: Profit, BC: Block Chain, PI: Physical Internet, IoT: Internet of Things

though studies such as Chabot et al. (2018), Guo et al. (2021), and McLeod et al. (2021) consider the objective of minimizing emissions in the system considered, they do not capture the impact of using greener transportation options such as E-vans and E-bikes for last mile deliveries instead. This current study aims at filling the gaps highlighted above. The main research questions of this study are delineated below:

- T&L innovation impact: To what extent can an urban digital twin be used to analyze the influence of implementing a Physical Internet strategy, supported by paradigm technologies like IoT and blockchain, on the collaboration between logistics providers in terms of order and fleet-based coordination during the last-mile phase? In particular:
  - Order-Sharing: What is the impact of implementing urban consolidation centers within a Physical Internet strategy on service performance?
  - Dynamic Fleet-sharing: To what extent can the adoption of dynamic fleet-sharing strategies within a Physical Internet strategy mitigate uncertainties, such as traffic congestion and parking slot unavailability, that commonly affect last-mile delivery operations?
- Green vehicles: To what extent does the replacement of conventional last-mile delivery vehicles with electric vehicles and cargo-bikes, within a Physical Internet strategy, impact the overall system performance considering the collaboration between logistics operators on orders and fleet management?

3. Methodology:

To address the main research questions of this paper, a scenario-based case study has been constructed in the city of Madrid. A digital replica of the Madrid urban city, referred to as the *urban digital twin* is developed to evaluate the magnitude of impact on last mile deliveries resulting from the different collaborative transport strategies considered. The digital twin comprises two key components: a dynamic simulation model and a route optimization engine. The dynamic simulation model utilizes multi-agent technology, enabling the digital twin to simulate the behavior and dynamics of entities within the system (hubs, vehicles, routes, and orders), thus, providing valuable insights into their interactions and performance. Through the simulation, detailed statistics are obtained, including aggregated and per-route/vehicle metrics such as distance, cost, emissions, on-time deliveries, and fill rate. The model is built on a standardized data model that efficiently collects essential information, including the number and position of hubs, fleet size, vehicle characteristics, as well as comprehensive details about orders, such as location, weight, and time windows. Additionally, effective communication is established between the simulation model and the route optimization engine, ensuring seamless integration between the two components. Through this digital twin, with strategic focus on urban logistics and commitment to the Physical Internet vision, answers are provided to the main research questions of this study, allowing users to make decisions based on the results of applying what-if scenarios.

The main assumptions are: three logistics companies operate in the city and hundreds of orders synthetically generated based on real demand data must be delivered during a normal day of operation. A description of each of the simulation scenarios is presented below:

(i) *Scenario 1. As-is*

In the baseline scenario, the three companies operate in the centre of the city in the traditional, non-collaborative manner. Each company has a fleet of three conventional delivery vehicles, which start their routes from their company's hub located on the outskirts of the city, as shown in Figure 1 (left). The distribution of demand among the companies, represented by the different colours (where each colour represents the demand to be fulfilled by a single company) are also shown in Figure 1 (right).

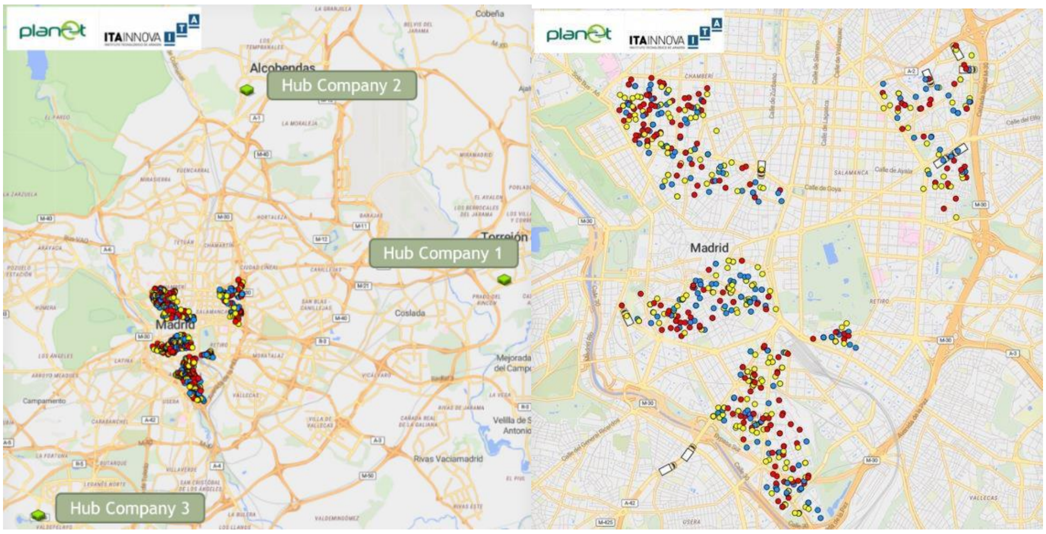

Figure 1: Companies' hub location and demand distribution

(ii) *Scenario 2. Collaboration across companies*

To enable collaborative cargo distribution using the PI concept, two types of collaborations are implemented, namely,

1. Collaboration on orders through the implementations of **two** Urban consolidation centres. These facilities serve as centres for receiving parcels from the three firms,

sorting, and redistributing the parcels to their final destinations. The study assumes that the two UCCs are established and operated jointly by the three logistics players. Furthermore, rather than being located on the outskirts of the city as in Scenario 1, the two UCCs are assumed to be strategically located in and around Madrid's metropolitan city center, where the end-consumer demand is concentrated.

2. Collaboration on fleets. Fleet sharing between the companies can occur in two stages: static and dynamic. The static stage represents the start of the planning horizon where vehicles of each company are assigned delivery rounds comprising of parcels that have been sorted at the UCCs based on location proximities. The route optimization in the static stage is undertaken using the route optimization engine component of the digital twin. On the other hand, the dynamic stage represents the stage when the delivery operations by the vehicles are underway and a delay arises in at least one of the delivery rounds due to extrinsic factors such as traffic, parking spot unavailability etc. In such as case, a dynamic reshuffling service is responsible for identifying optimal help from any vehicle operating in the vicinity regardless of the company, re-assign the parcels and re-design the routes. In this scenario, a decision support algorithm is developed which is an automated process for addressing parcel delivery delays, that otherwise was undertaken manually (Scenario 1: As-is). The decision support algorithm tracks the progress of delivery vehicles through the digital twin, dynamically analyzes assistance and collaboration options, identifies optimal synergies and updates driver delivery instructions. The decision support tool focuses on effectively exploring all collaboration options in proximity for single or multiple operators, to alleviate late deliveries and non-completion of delivery rounds. Figure 2 further highlights the types and sequence of collaborations in the static and dynamic stages.

Through such collaboration, the system aims to reduce traffic congestion and emissions, as well as increase the efficiency of delivery operations.

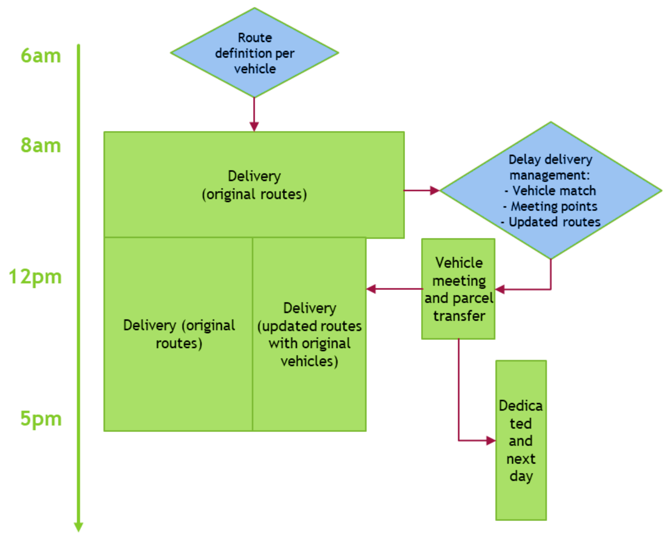

Figure 2: Sequence of events in the Static and dynamic collaborations stages

(iii) Scenario 3. Collaborative urban hubs + e-vehicles

This scenario extends Scenario 2 by further assessing the potential of using electric vehicles and cargo bikes instead of traditional delivery vehicles in collaborative cargo distribution networks. (Figure 3). In this situation, while the number and locations of UCCs are the same as in Scenario 2, the two depots are designated for different vehicles: one for cargo bikes and one for electric trucks. The electric trucks have a similar capacity to the conventional trucks in Scenario 2 while the capacity of cargo bikes is lower. It is assumed that the vehicles have sufficient autonomy to operate throughout the day without the need for additional charging or battery replacements. These assumptions allow for a general exploration of the viability of implementing the PI concept, while acknowledging that further detailed analysis may be required to account for specific cost factors and energy considerations.

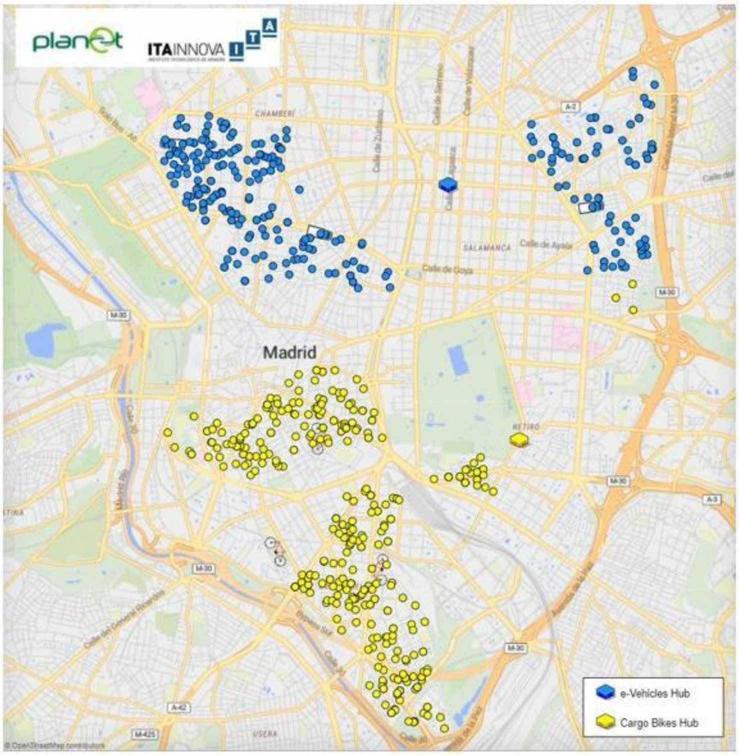

Figure 3: Collaborative urban hubs location and order-hub assignment

Table 2 Overview of technologies and logistics innovations modelled in each scenario

Technology/ Logistic innovation modelled	Characteristics considered	Scenarios		
		(i)	(ii)	(iii)
Physical internet	Open logistics environment to share asset (viz. trucks, depots) capacity, routes, and customer order data to improve the last-mile delivery performance.		✓	✓
IoT	End-to-end visibility over different operators and means of transport		✓	✓
Blockchain	Enabling technology for the Physical Internet, offering robust security measures and fostering trust in information exchange among operators		✓	✓
Optimized decision-making	•Vehicle routing Problem: Optimal routing of parcel deliveries in the last mile •Dynamic matching of delayed and non-delayed vehicles		✓	✓
Green Logistics (E-vans+cargo bikes)	Replacing the conventional diesel trucks with more sustainable vehicle options to carry out the last-mile deliveries			✓

4. Results and Conclusion:

This work had the objective to assess the impact of adopting a Physical Internet strategy on last mile delivery performance.

In order to achieve this we developed an urban digital twin which allowed for a holistic analysis of the entire LMD system by enabling a close examination of the different logistics players and their processes. The unique aspect of the model examined is the application of different state-of-the-art PI enabling technologies such as IoT, Blockchain, AI/ML, and electric vehicles which replicate the actual progress observed in the last-mile delivery space.

Specifically, we assessed two different collaboration strategies within the PI paradigm: order sharing by implementing UCCs and fleet sharing by deploying dynamic parcel reshuffling (Scenario 2). Additionally, the impact of deploying green delivery vans and cargo bikes was analyzed (Scenario 3)

Results show that the two collaboration strategies lead to a drastic reduction of the average distance travelled and emissions, as shown in the comparison between 'As-is'-Scenario 1 and Scenario 2 in Figure 4. Hence, not only performance and utilization are improved, but also a great positive impact on sustainability is achieved. A smaller number of vehicles can serve the same demand, resulting in more efficient use of the resources of each company. The average route time remains constant, which indicates that performance improvements mainly stem from improved bundling of parcels across different companies in UCCs. The deployment of green vehicles and cargo bikes (Scenario 3) further drives down emissions as conventional vehicles with high emissions are replaced by low emission vehicles and zero emission bikes. The use of cargo bikes additionally leads to a higher fill rate as they can be deployed more flexibly with smaller loads. At the same, this does not come at the cost of longer distances travelled due to our optimization.

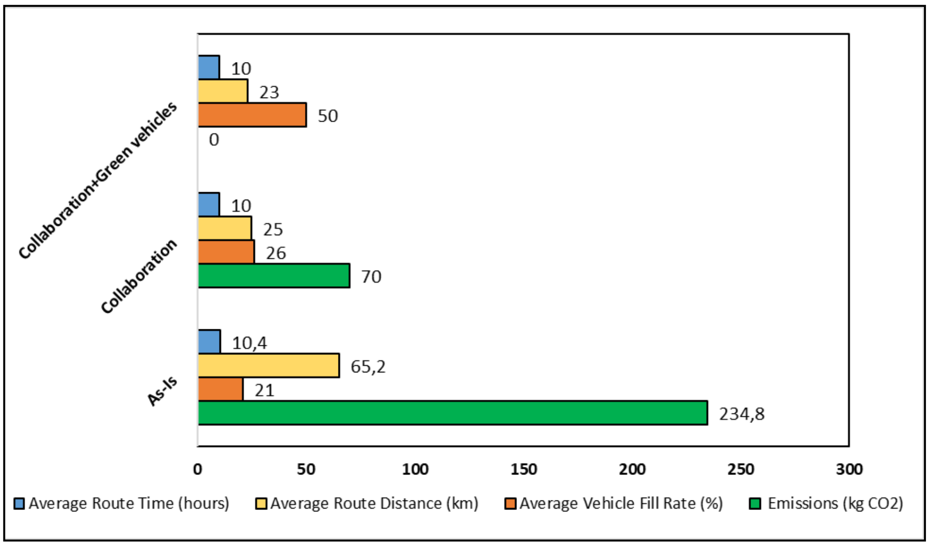

Figure 4: Comparison of Operational and environmental indicators across the three scenarios

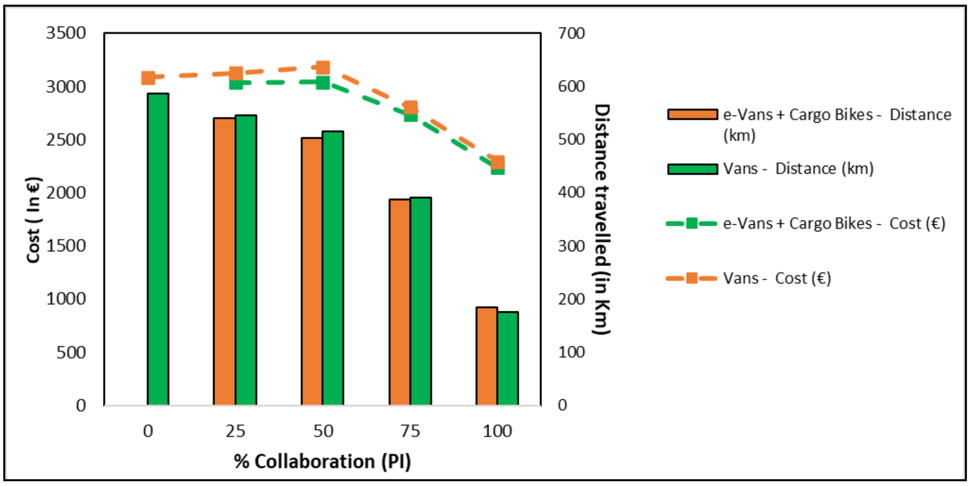

Figure 5: Comparison of Economic Indicators for different PI adoption levels

Figure 5 further highlights the extent of impact of different adoption levels of the PI concepton fixed costs, such as vehicle activation, as well as variable costs, such as fuel and driver expenses. Since the PI concept here refers to the extent of collaboration between the different last-mile delivery players, the different adoption levels represent various levels of information sharing, trust, and thus, overall collaboration on the logistics processes in the last-mile. In the case Scenario 2 depicted in Figure 5, 100% adoption representing full or complete implementation of the PI concept leads to the most significant enhancement to the environmental performance along with better delivery performance for the whole system. In Scenario 3, the use of electric vehicles results in a complete elimination of emissions. This demonstrates that transitioning to alternative fuel vehicles can effectively reduce the environmental impact of transportation systems while maintaining or improving performance in other areas, such as cost savings.

The results of this study are based on a simulated environment, and further research is needed to validate the findings in real-world scenarios. Nonetheless, the insights gained from this research can be used to inform the development of collaborative transport strategies in a PI paradigm. Further, future research can also look at addressing the financial aspects of implementing the different collaborative strategies (i.e., UCCs and dynamic parcel reshuffling) by considering the capital investment costs, parcel sorting costs, electric vehicle charging and battery constraints etc.

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References:

- Allen, J., Piecyk, M., Piotrowska, M., McLeod, F., Cherrett, T., Ghali, K., Nguyen, T., Bektas, T., Bates, O., Friday, A., Wisee, S., Austwicke, M. (2018): *Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London*,Transportation Research Part B.
- Chabot, T., Bouchard, F., Legault-Michaud, A., Renaud, J. and Coelho, L.C. (2018): *Service level, cost and environmental optimization of collaborative transportation*, Transportation Research Part E: Logistics and Transportation Review, 110, pp.1-14.
- Department for Transport (DfT) (2019): *Better delivery: The challenge for freight*,National Infrastructure Commission.
- Garey, M.R. and Johnson, D.S. (1979): *Computers and intractability,* San Francisco: freeman,v174.
- Greater London Authority (GLA) (2017): *Agile 1 - Final report.*
- Guo, C., Thompson, R.G., Foliente, G. and Kong, X.T. (2021): *An auction-enabled collaborative routing mechanism for omnichannel on-demand logistics through transshipment*, Transportation Research Part E: Logistics and Transportation Review, 146, p.102206.
- Handoko, S.D., Lau, H.C. and Cheng, S.F. (2016): *Achieving economic and environmental sustainabilities in urban consolidation center with bicriteria auction,* IEEE Transactions on Automation Science and Engineering, 13(4), pp.1471-1479.
- Los, J., Schulte, F., Spaan, M.T. and Negenborn, R.R. (2020): *Collaborative vehicle routing when agents have mixed information sharing attitudes*, Transportation Research Procedia, 44, pp.94-101.
- McLeod, F., Cherrett, T., Bates, O., Bektaş, T., Lamas-Fernandez, C., Allen, J., ... & Oakey, A. (2020): *Collaborative parcels logistics via the carrier's carrier operating model,* Transportation Research Record, 2674(8), 384-393.

- Merchan, D., Arora, J., Pachon, J., Konduri, K., Winkenbach, M., Parks, S. and Noszek, J., (2021): *Amazon last mile routing research challenge: Data set,* Transportation Science.
- Montreuil, B. (2011): *Toward a Physical Internet: meeting the global logistics sustainability grand challenge,* Logistics Research, v3, no2-3, 71-87.
- Wang, Y., Ma, X., Li, Z., Liu, Y., Xu, M., & Wang, Y. (2017): *Profit distribution in collaborative multiple centers vehicle routing problem,* Journal of cleaner production, 144, 203-219.