Adapting Retail Supply Chains for the Race to Sustainable Urban Delivery

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Abstract: To deal with urban distribution challenges, companies are redesigning their distribution networks. This paper studies a two-echelon vehicle routing problem, one of the most employed models, with a heterogeneous fleet between echelons. Vehicles in the first echelon are mobile satellites that supply the vehicles in the second echelon. Our study aims to minimize the travel time. To solve this complex problem when facing real-life distribution, a heuristic solution approach is followed by decomposing the components of the problem and applying the well-known nearest neighbor procedure. This approach is also justified by the very large amount of delivery points, so the problem dataset can be computationally tractable. Experiments are run using real data from a delivery company in Paris, France. Different scenarios are evaluated, and results show that the consideration of cargo bikes has big potential to reduce some of the externalities caused by conventional delivery systems, while some non-intuitive impacts are also found, such as the increase in land use.

1 INTRODUCTION

Internet shopping offers more shopping possibilities to consumers, and an additional distribution channel to retailers (Kull et al., 2007). The pandemic of COVID-19 has reinforced this trend by demanding supply chain managers to rethink their operations (Montoya-Torres et al., 2021). Supply chain management are the core of activities that are relevant to e-commerce to support its exponential growth. However, its complexity has considerably boost since several operations (e.g., warehousing, inventory, packaging, product shipping and tracking) have begun to be considered (Sandhaus, 2019). In addition, demand uncertainty has increased due to its accelerated growth. Retailers and suppliers should start looking for different initiatives to minimize stock-outs and guarantee service levels (Bendoly et al., 2018).

On another side, urbanization is a constant trend generating problems in freight transportation due to the delivery of online retail orders. Their increase, the constraints linked to urban environments and policies, and environmental pressures force practitioners to rethink traditional deliveries. Indeed, urban freight transportation has become an important component of urban planning. For instance, carriers have been challenged to provide higher levels of service at lower costs to satisfy customers' needs, such as same-day-delivery (Stroh et al., 2022). They have made efforts to organize their freight transport systems as they obstruct themself and other road users by causing congestion during loading/unloading operations, with associated negative environmental impacts (air pollution and noise). In addition, current environmental agreements, as well as low-emission urban areas, are requiring freight carriers to reduce the CO_2 equivalent (CO_2e) emissions.

City logistics initiatives and strategies have been developed and modeled to improve efficiency, relieve traffic congestion, and reduce CO_2e emissions. One is the redesign of urban distribution networks by adding intermediate nodes i.e., hubs, satellites, urban logistic spaces, located in the proximity of an urban area and allowing the consolidation of freight flows (Meza-Peralta et al., 2020; Browne et al., 2005). To make last-mile delivery more efficient. Hence, significant efforts have been made to design efficient optimization models and algorithms capable of supporting logistics decision makers (Ramirez-Villamil et al., 2022; Patier and Browne, 2010).

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When designing the last-mile supply network, the most employed model is the two-echelon distribution system, which consists of delivering goods from one depot to a set of satellites and from there to a set of customers geographically dispersed within an urban area (Marrekchi et al., 2021). When dealing with routing decision, this problem is modeled as a two-echelon capacitated vehicle routing problem (2E-CVRP) (Gonzalez-Feliu et al., 2008). It is known to be NP-hard, which means that the time needed to find an optimal solution grows exponentially in function of the size of the instance. Thus, many researchers are motivated to seek approximate algorithms (heuristics and metaheuristics) to solve it. The importance and attractiveness of this research topic concerns its applicability in real cases of freight transportation planning, the research opportunity in terms of the development of efficient solution methods, the use of novel disruptive delivery technologies, and the inclusion of more realistic features (e.g., satellite synchronization, use of environmentally friendly vehicles, multiple depots, mobile depots, and considering very large amount of delivery points) (Carlsson and Song, 2018; Reed et al., 2022).

In the context of more sustainable deliveries, delivery by cargo bikes is booming, as a preferred solution for environmentally oriented decision-makers (Silva et al., 2023). However, they are constrained in terms of distance. This paper focuses on the implementation of mobile urban storage via delivery vans loading the goods in the satellites for further last-mile delivery by cargo bikes. Delivery time was also considered as part of the total travel time, to make the problem more realistic. To the best of our knowledge, there is no literature that addresses not only a two-echelon delivery network using mobile satellites to transport parcels until certain points within the city where cargo bikes are loaded to perform last-mile delivery; but also, that includes the delivery time as part of the total travel time to make the problem more realistic. The problem includes both the transport from the depot to satellites (first echelon) and from these mobile satellites to customers (second echelon). This delivery network can contribute to the reduction of the travel distance, and of the number of trucks in cities, and consequently, it could decrease congestion.

This paper proposes a decomposition heuristic based on the Nearest Neighbor procedure (NN). As a real-life case study of a company delivering in the city of Paris, France is considered, the rationale of choosing a heuristic to solve the routing problem is justified by the very large amount of delivery points. Indeed, although research on VRP has witnessed a variety of solution approaches, including exact, heuristic and meta-heuristic algorithms (e.g., (Cattaruzza et al., 2017; Vega-Mejía et al., 2019; Soeffker et al., 2022)), the literature has also highlighted the need of fast yet comprehensive solution algorithms for easy understanding in practice, instead of black-box complex algorithms (Juan et al., 2015). As an objective function, the minimization of travel times is considered. Key performance indicators like, CO_2e and fine particles emissions, as well as fixed cost and land use are also addressed.

The approach is tested over different scenarios simulating the actual options decision-makers may encounter in real life. Hence, two scenarios for urban freight distribution networks are proposed.

The remainder of this paper is organized as follows. Existent literature is firstly reviewed, followed by description of the case study. The solution approach is then described, as well as the results obtained. The paper ends with some conclusions, explaining some managerial implications, and suggesting future research lines.

2 RELATED LITERATURE

The Internet has created opportunities for retailers to increase sales (Nguyen et al., 2019), causing an evolution with the constant expansion of e-commerce. This phenomenon has generated growth in online retail by around an average of 10% each year from many years and approximately 14% in western Europe in 2020 (Lone et al., 2021). Currently, online retailers offer a variety of delivery options that are the result of combining features such as: delivery speed, time slot, day or overnight delivery, delivery date and delivery fee.

Over the years, there have been efforts to improve and make online retail operations more efficient with the aim of generating value for the customers. (Buijs et al., 2016) illustrated the importance of leveraging opportunities in the design and control of a retail distribution network. The results obtained with the simulation model applied in a case study in The Netherlands show a reduction in travel distance by more than 40% when applying their multi-echelon approach and demonstrate how even small changes in the distribution network design can lead to significant improvements in cross-docking performance.

As pointed out before, one of the most widely used models in urban freight delivery is the 2E-VRP. The problem has been studied since 1980 (Jacobsen and Madsen, 1980). However, the first study was presented by (Crainic et al., 2010), who promoted the use of satellite platforms to redistribute goods in zones where big trucks could not circulate due to the physical or regulatory constraints, and showed a reduction in the use of large vehicles by up to 72%. Since then, this VRP variant has been extensively studied. In e-commerce, (Zhou et al., 2018) proposed a multi-depot two-echelon vehicle routing problem with delivery options (MD-TEVRP-DO), where customers are allowed to pick-up orders at intermediate facilities. After applying a multi-population genetic algorithm, results showed that the final cost can be reduced by 16% (in comparison with the “no pick-up option”).

Nowadays, the use of different types of vehicles in both first and second echelons has become more relevant in city logistics, but system becomes more complex. In the first echelon, trucks supply the satellites, while in the second echelon, other transportation modes (e.g., cargo bikes, electric vehicles, UAVs, vans, autonomous vehicles) perform the last-mile deliveries (Cattaruzza et al., 2017; Stamadianos et al., 2023). Moreover, new variants of 2E-VRP have been studied in sustainable applications. For example, different scenarios using cargo bikes for freight transportation in inner-city areas have been proposed. (Anderluh et al., 2019) present some of the successful cases of cargo bikes in Europe for the cities Budapest, Vienna, and Copenhagen. Other works also evaluated the use of cargo bikes on different performance indicators including cost and environmental impacts, to analyze their use alone of as part of a mixed-fleets with electric vehicles i.e. (Caggiani et al., 2021). The impact of cargo bikes in system performance was shown to be very positive. However, none of previous work in the literature evaluate an extended set of performance indicators, as in the current paper.

3 PROBLEM DESCRIPTION

A major French delivery company for the city of Paris is taken as case study. It is a key player of the last-mile and a leading brand in delivery, with the distribution of approximately 63 million parcels. 95% of deliveries are made on the first attempt and 65% of parcels are delivered directly to mailboxes. Its services are used by major B2C clients, as well as B2B. For this study, the company provided the data of 90,627 deliveries in Paris from four depots around Paris. Figure 1 presents the location of the four depots (purple points) and the location of the 90,627 customers (green points). Furthermore, Paris is administratively divided into 20 districts. The data provided are split according to these districts. Actual demand and location of points are kept confidential. Such distribution problem is modeled as a two-echelon capacitated vehicle routing problem (2E-CVRP) (Gonzalez-Feliu et al., 2008). This problem, in its deterministic version, is known to be NP-hard, which means that the time needed to find an optimal solution grows exponentially in function of the number of delivery points. The sub-problems that will be presented in the next section depend on the scenarios presented in table 1.

Figure 1: Delivery points in Paris and four warehouses.

4 SOLUTION APPROACH

Since the 2E-CVRP is known for its hard complexity (Gonzalez-Feliu et al., 2008), approximation algorithms are good approaches to obtain feasible solutions for medium- to large-sized instances in reasonable computational time. Since the case study is a very large-sized instance, a decomposition algorithm (Figure 2) is proposed and the routing is solved using the NN procedure (Taiwo et al., 2013). This algorithm splits the problem into four sub-problems to reduce its complexity, and aggregates the corresponding results to guarantee the quality and feasibility of the solutions and render it computationally tractable.

The first subproblem is the random selection of the location point for the satellites in each district of Paris; the second one is to randomly cluster the satellites to the depots; the third sub-problem is to find a set of routes starting from the depot to serve the corresponding satellites (first echelon), and the last step is to determine the routing from satellites to serve the clients (second echelon).

4.1 Routing from Depots to Satellites

This subsection explains in a detailed way the heuristic algorithm used to solve the first three sub-problems. The location of the satellites (first sub-problem) depend on the scenarios presented in table 1. So, it is important to note that the number of satellites and how they operate will depend on the scenario.

The second sub-problem consists of a random allocation of the previously selected satellites to the

Table 1: Differences between scenarios proposed.

Scenario 1	Scenario 2
From depots to satellites and from satellites to customers (last-mile delivery)	From depots to nodes where mobile satellites meet cargo bikes for last-mile delivery
Homogeneous fleet between echelons	Heterogeneous fleet between echelons
1st and 2nd echelon transportation mode: Delivery van (800 kg)	1st echelon: Delivery vans as mobile satellites (900 kg) 2nd echelon: Cargo bikes (180 kg)
One node randomly selected to be the satellite in each district of Paris	The number of mobile satellites in the district depends on its demand and vehicle capacity
A total 20 satellite facilities with unlimited capacity	A total of 96 mobile satellites with a limited capacity of 900 kg
	Delivery time was considered
	sc2-min: considers a delivery time of 2 min per client
	sc2-max: considers a delivery time of 8 min per client

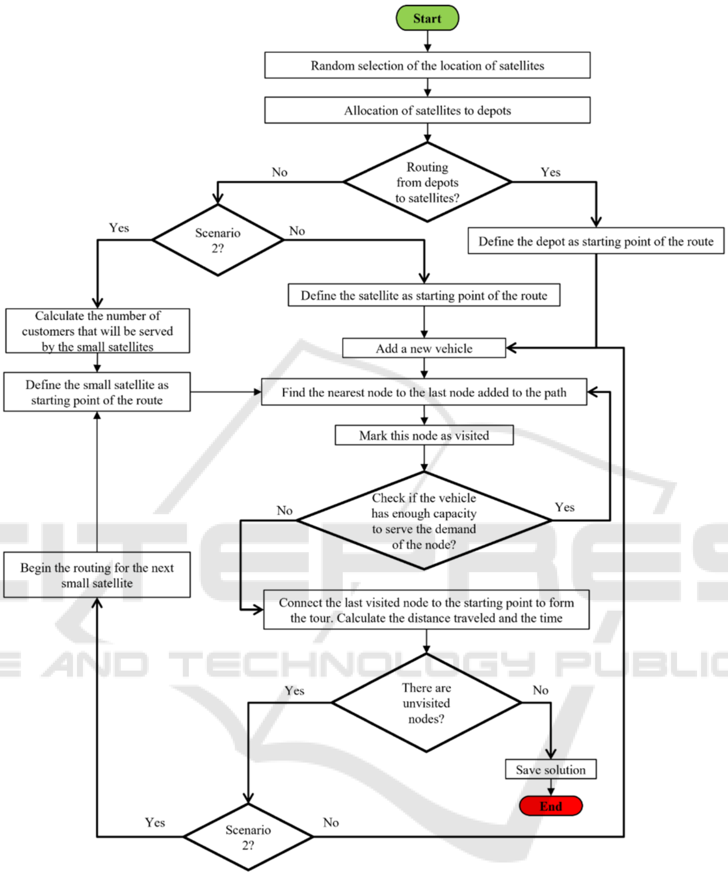

Figure 2: Flowchart of the proposed solution approach.

four depots (Figure 1). For scenario 1, it was decided that 5 satellites would be assigned to each one of the depots. While, for scenario 2, 5 districts would be assigned to each one of the depots.

The third sub-problem is the first-echelon routing by an algorithm based on the NN procedure and follows the next steps:

1. Define the starting point of the route (Depot).
2. Find the nearest node to the last node added to the path. If the nearest node is already in the path, then choose the next closest.
3. Repeat step 2 until the vehicle reaches its maximum capacity.
4. Connect the last visited node to the depot to form the tour. Calculate the distance traveled by the vehicle and the total route time.
5. If there are unvisited nodes, add one more vehicle and return to step 2.

4.2 Routing from Satellites to Clients

The last sub-problem is the design of routes for last-mile delivery (second-echelon). For both scenarios, satellites can only serve the nodes that belong to the district assigned to them. It is important to note that in scenario 1 the solution approach works in the same way as the algorithm based on the NN procedure presented before. However, for scenario 2, as it has different number of satellites for each district, the solution algorithm has some modifications. So, the problem is solved by following the next steps:

1. Divide the total number of clients of the district into the number of satellites located into this district.
2. Define the starting point of the route (Satellite i).
3. Find the nearest node to the last node added to the path. If the nearest node is already in the path, then choose the next closest.
4. Repeat step 3 until the vehicle n reaches its maximum capacity.
5. Connect the last visited node to the satellite to form the tour. Calculate the distance traveled by the vehicle and the total route time.
6. If there are unvisited nodes, add one more vehicle and return to step 3.
7. If the total number of nodes for the satellite i were already visited, the procedure for the satellite $i+1$ is started (step 2).
8. Execute this procedure until all nodes are visited.

5 SCENARIOS SIMULATION AND ANALYSIS OF RESULTS

The proposed solution procedure was coded in Python, and experiments were run on a computer with processor Intel® Core™ i7-10510U, CPU at 2.3 GHz and 16 GB RAM. All below values were given by the delivery firm. Two main scenarios are simulated. Table 2 shows the distribution of the 96 satellites into the 20 districts of Paris for **scenario 2**. In this scenario, delivery time was considered, which is the time that the delivery man takes to unload the parcel, deliver it, and return to the cargo bike to continue his route. Different values were considered for the delivery time from a minimum value of 2 minutes per delivery point to a maximum of 8 minutes. Moreover, the working hours of the delivery man are included, so the number of trips required to visit all the delivery points with 5, 5.5 and 6 working hours is calculated. The value presented for the number of tours is the average of the three options of working hours.

Key performance indicators (Tables 3 and 4) such as the number of vehicles, CO_2e emissions, fine particles, fixed cost, and land use were considered to make comparisons between scenarios. Mainly to assess if the distribution network does not invade public space in large proportions, if it is sustainable and if the fixed costs associated with the operation are low.

Table 2: Number of satellites per district in scenario 2.

District	N° of satellites	District	N° of satellites	District	N° of satellites	District	N° of satellites
D1	2	D6	3	D11	6	D16	8
D2	3	D7	4	D12	6	D17	7
D3	2	D8	5	D13	8	D18	5
D4	2	D9	4	D14	5	D19	3
D5	3	D10	4	D15	10	D20	6

Table 3: Fixed cost in euros per transportation mode.

Indicator / Parameter	Cargo bike	Vehicle
Private cost per km	0.13	0.45
Time value per hour	8.47	13.10
Revenue index	0.83%	1.00%
Time value per hour according to the revenue	7.03	13.09
Speed (km/h)	14	15
Time value per km	0.50	0.87
Total fixed cost per km (€)	0.63	1.32

Table 4: CO_2e emission factors, fine particles and land use per transportation mode. Source: French Environmental Agency (ADEME).

	Cargo bike	Vehicles
CO_2e emission factors according to the average utilization (ton/km)		
10%	0	5.099
20%	0	2.55
30%	0	1.7
40%	0	1.275
50%	0	1.020
60%	0	0.85
70%	0	0.728
80%	0	0.637
90%	0	0.567
100%	0	0.510
Fine particles (g/km)	0	0.01
Land use (m2)	1.77	9.15

Regarding the results obtained in the first echelon (Table 5), it was found that in scenario 2, the number of vehicles needed to deliver the parcels from the depot to the satellite in each district of Paris is lower. Therefore, by using fewer vehicles, CO_2e emissions and fine particles, as well as the fixed cost and land use are also lower. On the other hand, focusing on Depot 2, it can be observed that the number of vehicles used and the land use are equal in both scenarios, nevertheless, although CO_2e emissions are lower, these vehicles are traveling a longer distance to deliver the parcels to the assigned satellites, which generates higher fixed costs and more fine particle emissions, both indicators are dependent on the distance traveled, that in scenario 1 is 1374.79 km and in scenario 2 is 1376.69 km.

Table 5: Results for the first echelon: Routing from depots to satellites.

	Scenario	Number of vehicles	CO_2e emissions (kg)	Fine particles (g)	Fixed cost (€)	Land use (m2)
Depot 1	sc1	24	1167.6	14.9	1966.3	219.6
	sc2	23	1004.7	14.5	1912.7	210.5
Depot 2	sc1	20	1063.6	13.7	1814.7	183.0
	sc2	20	949.7	13.8	1817.2	183.0
Depot 3	sc1	37	2818.9	35.8	4722.7	338.6
	sc2	34	2288.4	32.7	4313.3	311.1
Depot 4	sc1	18	334.8	4.2	552.4	164.7
	sc2	19	269.1	3.9	508.6	173.9

Scenario 2 uses cargo bikes for last-mile delivery, so CO_2e and fine particle emissions are zero. Regarding the number of vehicles (Figure 3) and land use, for instance, in district 15 scenario 1, the number of trips or vehicles needed to deliver all the parcels is 12 which occupy 109.8 m2 of public space. However, in sc2-min there are 35 trips or cargo bikes using 61.9 m2 of land, which means that in District 15 there is a reduction in land use of 44% and, in relation to the fixed cost, the cost of scenario 2 is 48% lower than scenario 1. It is evident that the larger the district and its demand, the more cargo bikes or trips using them will be needed, which would cause a quite remarkable increase of bicycles parked in different areas of the city such as bike lanes or sidewalks, then it would be another way to invade public space. Even between scenario 1 and scenario 2 there is an average reduction in terms of land use in the second echelon of 32%, and 56% regarding fixed cost (Table 6). As sc2-min and sc2-max are the ones that considered cargo bikes, we can say that 3189.8 kg of CO_2 emissions and 39.7 g of fine particulate can be saved using this transportation mode for last-mile delivery either if the delivery time per node is 2 or 8 minutes. Further studies should consider the stochasticity of this parameter to make scenario 2 more realistic.

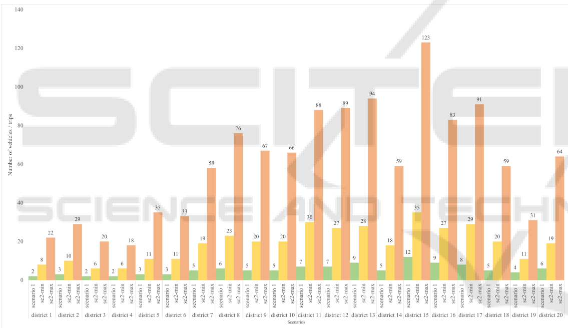

Figure 3: Number of vehicles or trips per scenario in each district of Paris (notes: sc2-min refers to the 2min lowest delivery time, sc2-max to the maximum delivery time of 8 minutes).

About the global results, Table 7 shows the reduction in CO_2e emissions and fine particles when using scenario 2, because the entire operation of the second echelon is executed by cargo bikes that will not affect the environment with CO_2e emissions. Therefore, these results should be analyzed together with the other indicators to evaluate their performance so the company can better understand the impact of applying the second scenario in its operations. In terms of fixed cost, it can be noted that in 95% of the districts the cost is lower when considering scenario 2, with an average reduction of 25%. On the other hand, when analyzing land use, the average reduction in this indicator between scenario 1 and sc2-min is 17%, whereas between sc2-min and s2-max there is an increase in land use of 47% because it takes more trips or more cargo bikes circulating in the city of Paris if the delivery time is 8 minutes per delivery point.

Table 6: Second echelon results: Routing from satellites to clients.

District	Scenario	CO_2e emissions (kg)	Fine particles (g)	Fixed cost (€)	Land use (m2)
D1	scenario 1	79.1	1.0	127.8	18.3
	sc2-min	0.0	0.0	42.0	14.1
	sc2-max	0.0	0.0	42.0	38.9
D2	scenario 1	86.9	1.0	131.9	27.5
	sc2-min	0.0	0.0	102.0	17.7
	sc2-max	0.0	0.0	102.0	51.3
D3	scenario 1	55.8	0.6	84.1	18.3
	sc2-min	0.0	0.0	32.7	10.6
	sc2-max	0.0	0.0	32.7	35.4
D4	scenario 1	93.5	1.1	138.8	18.3
	sc2-min	0.0	0.0	35.8	10.6
	sc2-max	0.0	0.0	35.8	31.8
D5	scenario1	88.4	1.1	142.3	27.5
	sc2-min	0.0	0.0	66.7	19.4
	sc2-max	0.0	0.0	66.7	61.9
D6	scenario 1	84.6	1.0	133.9	27.5
	sc2-min	0.0	0.0	55.0	19.4
	sc2-max	0.0	0.0	55.0	58.3
D7	scenario 1	115.9	1.6	210.2	45.8
	sc2-min	0.0	0.0	83.1	33.6
	sc2-max	0.0	0.0	83.1	102.5
D8	scenario 1	207.7	2.4	314.1	54.9
	sc2-min	0.0	0.0	115.6	40.7
	sc2-max	0.0	0.0	115.6	134.4
D9	scenario 1	152.2	1.8	238.5	45.8
	sc2-min	0.0	0.0	81.6	35.4
	sc2-max	0.0	0.0	81.6	118.5
D10	scenario 1	169.5	2.1	272.6	45.8
	sc2-min	0.0	0.0	95.6	35.4
	sc2-max	0.0	0.0	95.6	116.7
D11	scenario 1	192.4	2.3	299.7	64.1
	sc2-min	0.0	0.0	135.9	53.0
	sc2-max	0.0	0.0	135.9	155.6
D12	scenario 1	221.4	2.7	354.0	64.1
	sc2-min	0.0	0.0	192.2	47.7
	sc2-max	0.0	0.0	192.2	157.4
D13	scenario 1	191.5	3.1	410.6	82.4
	sc2-min	0.0	0.0	184.5	49.5
	sc2-max	0.0	0.0	184.5	166.2
D14	scenario 1	198.4	2.4	319.4	45.8
	sc2-min	0.0	0.0	135.1	31.8
	sc2-max	0.0	0.0	135.1	104.3
D15	scenario 1	286.9	3.4	449.9	109.8
	sc2-min	0.0	0.0	233.6	61.9
	sc2-max	0.0	0.0	233.6	217.5
D16	scenario 1	252.7	3.4	445.1	82.4
	sc2-min	0.0	0.0	218.1	47.7
	sc2-max	0.0	0.0	218.1	146.7
D17	scenario 1	236.7	2.9	380.5	73.2
	sc2-min	0.0	0.0	176.6	51.3
	sc2-max	0.0	0.0	176.6	160.9
D18	scenario 1	169.7	2.1	272.6	45.8
	sc2-min	0.0	0.0	127.7	35.4
	sc2-max	0.0	0.0	127.7	104.3
D19	scenario 1	133.5	1.6	216.7	36.6
	sc2-min	0.0	0.0	100.0	19.4
	sc2-max	0.0	0.0	100.0	54.8
D20	scenario 1	173.0	2.1	278.0	54.9
	sc2-min	0.0	0.0	142.4	33.6
	sc2-max	0.0	0.0	142.4	113.2

Two important factors increase the total travel time. The first factor is the speed of the cargo bike, which is lower than the average speed of the vehicle. Secondly, when adding the delivery time in scenario 2, the increase in travel time is evident because it is an extra time of 2 to 8 minutes to make what is known in practice as a delivery in the street. Travel time in sc2-min and sc2-max generates an increase in the number of trips because the smaller capacity of the cargo bikes means that more trips are needed to cover the total demand of the delivery network. Moreover, working hours are limited to approximately 5.5 hours per day and the driver of the bicycle needs time to hydrate, have lunch, take some kind of break. In practice the delivery time is stochastic because the delivery man does not take the same time in every de-

Table 7: Final results for each scenario.

District	Scenario	Travel time (h)	CO_2e emissions (kg)	Fine particles emissions (g)	Fixed cost (€)	Land use (m2)
D1	scenario 1	14.1	150.9	2.0	259.9	21.8
	sc2-min	37.5	95.0	1.4	220.9	32.4
	sc2-max	109.6	95.0	1.4	220.9	57.2
D2	scenario 1	20.4	232.9	2.9	376.6	54.9
	sc2-min	56.2	150.9	2.2	397.3	45.1
	sc2-max	147.6	150.9	2.2	397.3	78.7
D3	scenario 1	12.1	121.9	1.7	223.7	36.6
	sc2-min	34.7	100.2	1.4	218.6	28.9
	sc2-max	142.0	100.2	1.4	218.6	53.7
D4	scenario 1	10.3	117.7	1.4	190.6	36.6
	sc2-min	26.2	35.6	0.5	101.6	28.9
	sc2-max	83.5	35.6	0.5	101.6	50.1
D5	scenario1	13.9	159.2	1.9	256.6	54.9
	sc2-min	46.6	59.5	0.9	181.2	46.9
	sc2-max	155.2	59.5	0.9	181.2	89.3
D6	scenario 1	14.2	165.6	2.0	263.1	54.9
	sc2-min	42.4	64.4	0.9	175.4	46.9
	sc2-max	155.3	64.4	0.9	175.4	85.8
D7	scenario 1	37.0	381.5	5.2	684.2	91.5
	sc2-min	95.0	211.3	3.1	491.4	70.2
	sc2-max	289.8	211.3	3.1	491.4	139.1
D8	scenario 1	52.82	613.96	7.4	976.2	109.8
	sc2-min	129.9	336.3	4.9	758.2	86.4
	sc2-max	370.2	336.3	4.9	758.2	180.1
D9	scenario 1	32.9	362.7	4.6	607.8	91.5
	sc2-min	100.2	177.5	2.5	418.2	72.0
	sc2-max	324.1	177.5	2.5	418.2	155.1
D10	scenario 1	42.3	472.7	5.9	782.6	91.5
	sc2-min	107.2	239.9	3.4	549.3	72.0
	sc2-max	330.2	239.9	3.4	549.3	153.3
D11	scenario 1	42.6	484.8	6.0	786.7	128.1
	sc2-min	133.1	245.4	3.6	606.4	107.9
	sc2-max	418.3	245.4	3.6	606.4	210.5
D12	scenario 1	46.7	529.5	6.5	862.3	128.1
	sc2-min	136.0	249.6	3.5	660.6	102.6
	sc2-max	412.4	249.6	3.5	660.6	212.3
D13	scenario 1	63.1	659.4	8.8	1167.0	155.6
	sc2-min	152.0	382.4	5.5	909.9	122.7
	sc2-max	440.2	382.4	5.5	909.9	239.4
D14	scenario 1	41.5	476.1	5.8	767.6	91.5
	sc2-min	100.9	237.6	3.5	594.6	77.6
	sc2-max	291.5	237.6	3.5	594.6	150.1
D15	scenario 1	100.1	1116.7	14.0	1849.4	219.6
	sc2-min	211.7	659.4	9.3	1459.2	141.0
	sc2-max	585.7	659.4	9.3	1459.2	257.7
D16	scenario 1	86.6	923.2	12.1	1599.6	164.7
	sc2-min	162.0	557.2	8.1	1287.4	120.9
	sc2-max	417.4	557.2	8.1	1287.4	219.9
D17	scenario 1	74.5	845.8	10.4	1377.0	146.4
	sc2-min	160.0	495.6	7.0	1098.8	115.3
	sc2-max	444.5	495.6	7.0	1098.8	224.9
D18	scenario 1	22.8	261.6	3.2	421.0	91.5
	sc2-min	80.9	58.2	0.8	237.9	81.1
	sc2-max	266.7	58.2	0.8	237.9	150.1
D19	scenario 1	23.7	258.6	3.3	438.1	73.2
	sc2-min	50.8	104.4	1.5	301.5	46.9
	sc2-max	141.2	104.4	1.5	301.5	82.3
D20	scenario 1	20.9	239.9	2.9	386.7	109.8
	sc2-min	84.9	51.4	0.7	240.1	88.5
	sc2-max	280.0	51.4	0.7	240.1	168.1

livery point, that is why one scenario is considered with more optimistic times than the other, to analyze these differences. Finally, the increase in total travel time between Scenario 1 and Scenario 2 is approximately 62%, while the increase between sc2-min and sc2-max is 67%.

6 CONCLUSIONS AND PERSPECTIVES

The retail industry has evolved with the increasing expansion of e-commerce. Disruptive unexpected events, such as the COVID-19 pandemic, have reinforced this global trend, so that supply chain and logistics operations have been redesigned. Since last-mile supply chains are the core of e-commerce delivery operations, effective operational behavior is key to allow e-commerce business to continue growing. In addition, the configuration of last-mile supply chains has evolved to nowadays require the design of two-echelon urban delivery networks, in which urban consolidation centers (UCC) are key nodes between the main supplier and the final customer. This network structure is known in the literature as a two-echelon supply chain.

This paper analyzed the problem of designing delivery routes in such two-echelon distribution systems. Because of its complexity to be solved when dealing with large sized datasets, this paper evaluated the implementation of an approximation algorithm based on the well-known NN routing heuristic. A set of numerical experiments were carried out on datasets taken from a real-life French company delivering products to more than 90,000 points in Paris. A heterogeneous fleet of delivery vehicles was evaluated, using vehicles and cargo bikes in the first and the second echelon, respectively. Different operational scenarios were evaluated, and the performance of the system was assessed. Results show that the consideration of mobile storage instead of conventional satellites can generate savings not only in emissions, fixed costs and land use, but also regarding investment cost of locating satellite facilities within the city because transshipment activities between the delivery van and the cargo bike could be performed in smaller areas such as a parking lots or public space areas designated only for these purposes, while satellites in scenario 1 could provide parcel storage service, which leads to additional costs not considered in this study. Moreover, the inclusion of eco-friendly modes of transportation like cargo bikes has a lot of potential to reduce some of the externalities caused by the usual urban parcel delivery systems that have conventional vans. Furthermore, although the consideration of scenario 2 increases the invasion of public space in inner-city areas, it does guarantee important savings in CO_2e and fine particulate emissions and, fixed costs are lower. However, given the advantages of using cargo bikes in the second scenario, a mix between electric vans and cargo bikes, taking advantage of the benefits of each transportation mode, could be considered in future research.

Based on the outcomes of this research, several opportunities for further research are open. The research on 2E-VRP and its variants has a lot of opportunities for example, the consideration of additional constraints, like load or route balancing among vehicles, stochastic delivery times, heterogeneous fleet in the same echelon (electric vehicles, electric cargo bikes, etc.), the design of distribution network configurations with multimodal transportation for parcel distribution systems in big cities, among other challenges. Another line for future research is the design of other solution procedures, especially to deal with very large amounts of delivery points. Finally, since the proposed solution approach is used to generate a solution to the problem, another research avenue will address the design of improvement heuristics to obtain better results in terms of routes.

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