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# Delivering Paris by Cargo Bikes: Ecological Commitment or Economically Feasible? The Case of a Parcel Service Company

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1 **Delivering Paris by Cargo Bikes: Ecological Commitment or Economically Feasible? The Case of**  
2 **a Parcel Service Company**

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24

1 **ABSTRACT**

2 Urban logistics is a key step of distribution chains. It implies the use of trucks in congested areas, and  
3 generates numerous externalities (congestion, noise, pollution, etc.). In addition, supply chain  
4 configurations and consumer behaviors are undergoing deep changes. This implies a significant increase  
5 urban logistics' intensity, and a diversification of delivery channels within cities. This is an important  
6 challenge for city sustainability, as urban logistics is an essential economic activity, and yet the source  
7 of intense negative externalities. Numerous directions are currently being explored to rethink urban  
8 logistics, such as drones, cargo bikes, crowd logistics, etc. However, the economic and environmental  
9 relevance of these technologies is not yet perfectly clear.

10 This paper focuses on the conditions of the financial sustainability of cargo bikes compared to electric  
11 light commercial vehicles – LCV. The analysis of this paper is based on real data, provided by the parcel  
12 service company DB Schenker. The dataset consists of 600,000 operations made in Paris over two  
13 months. Operations with electric LCV are assumed to be identical to conventional LCV; the cost  
14 comparison is based on a total cost of ownership approach. Operations with cargo bikes assume that  
15 eligible shipments are first brought to micro-hubs within the city with an electric LCV, then delivered  
16 by cargo-bike. The number and location of micro-hubs are optimized. The results show that a cargo bike  
17 solution can be more cost-efficient than electric LCV with few micro-hubs, located where the demand  
18 is the densest as they can only be relevant financially there.

19 **Keywords:** Urban Good Movement, Cargo Bikes, Urban logistics, Micro hub, Last mile, parcel service

# 1 INTRODUCTION

2 Urban logistics is a key step in the delivery chain. The use of trucks in crowded areas such as city centers  
3 generates numerous negative externalities (congestion, noise, pollution, etc.) (1, 2). Moreover, consumer  
4 habits are currently undergoing changes that tend to significantly increase e-commerce (especially small  
5 parcels), increasing the number of delivery channels within cities (3).

6 The proposed solutions to reduce negative externalities mainly rely on breakthrough technologies that  
7 change the current codes of delivery (a round starting from and ending at a cross-docking platform  
8 located in the urban periphery) (4). Nowadays, most of new ideas (cargo bikes, delivery robots) are  
9 based on the presence of additional transfers. These transfers imply additional smaller platforms, often  
10 referred to as micro-hubs, which can be buildings (e.g., a small warehouse in a building), or mobile  
11 assets (e.g., parked container in street during the day). From this point, operations are conducted on a  
12 star-shape around it (5–8). These micro hubs are not intended to be connected to all the platforms on a  
13 national scale, but to operate and communicate only with the peripheral platforms and thus to operate  
14 as satellites of the latter (9–11).

15 However, micro-hubs are costly (rent, additional needed managers, etc.). With a high density of pickup  
16 and delivery operations, it is possible that the cost of the micro-hub is more than compensated by savings  
17 on transportation costs (12–14). On the other hand, the high cost of land is a key limitation in the  
18 implementation of these new solutions (15). For instance, in Paris, land pressure is extremely high and  
19 platforms are driven to the periphery (16).

20 Among these solutions, the bicycle has the advantage of being already technically mature as well as  
21 being already present in the urban environment (by the previous presence of cyclists). Furthermore,  
22 using bikes is possible under current regulation (which isn't true for drones, for example). However, the  
23 use of cargo bikes adds a link to the chain and multiplies the number of vehicles used to carry out the  
24 entire operation. Furthermore, the last mile is mostly done by subcontractors, which can make it more  
25 difficult for companies to fully control how parcels are operated (17). Nevertheless, the possibility to  
26 use electric cargo bikes allows to transport important loads (up to 200 kg) with no major difficulty. A  
27 review of the literature was done by Llorca *et al.* (2021) (18). Amongst the important points, cargo bikes  
28 offer other advantages such as:

- 29 - Lower vehicle costs (purchase, maintenance and insurance);
- 30 - Fast and reliable movement in dense areas (less dependent on traffic jam);
- 31 - The possibility to park close to the delivery/shipping points (14);
- 32 - Less road and parking consumption due to the smaller size of the vehicle;
- 33 - Cleaner and less negative externalities than most other modes of transportation (especially  
34 trucks) (13, 14, 19–22).

35 These new technologies are implemented to anticipate new regulations which aimed at reducing  
36 negative externalities in cities. Nowadays, these regulations mainly focus on the type of motorization  
37 (emission limitation via low emission zone), traffic and parking regulations in order to diminish negative  
38 externalities(23). In the case of cargo bikes, cities can play a crucial role via the creation of cycle lanes,  
39 zero-emission zones, reduction of drive-through traffic, etc. (12, 24, 25). The policy objective is to  
40 constrain vehicle types to reduce negative externalities without preventing carriers from operating.  
41 Different studies have already been made in Portland and Seattle to compare cargo bikes and electric  
42 light commercial vehicles but with a smaller sample size and over a smaller geographic area compared  
43 to this study (26, 27)

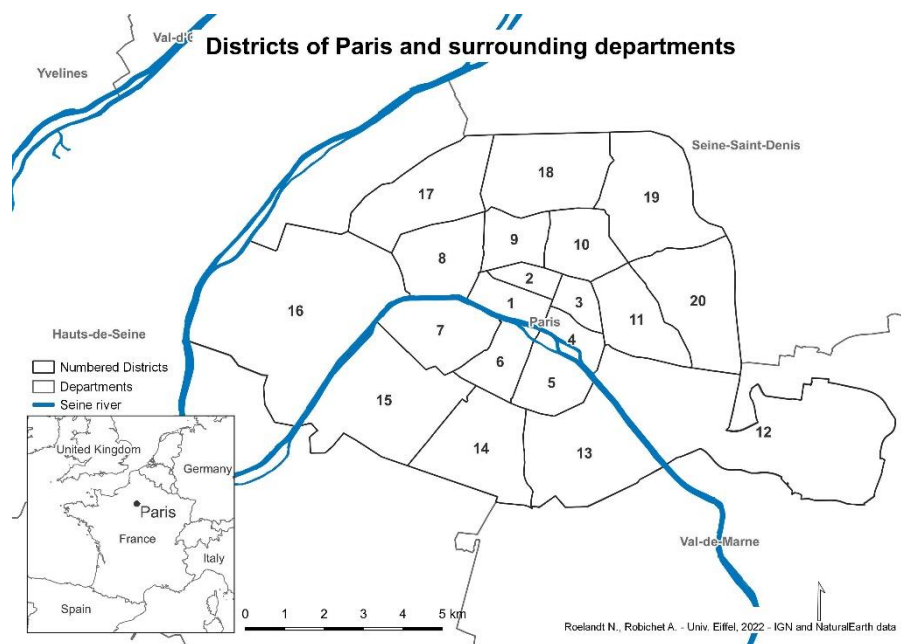
44 In this study, we address the possibility to deliver by cargo bikes shipments which are traditionally delivered by  
45 trucks. To compare two low-emission solutions, delivery by cargo bikes will be evaluated against a fleet of electric  
46 LCVs (Light Commercial Vehicles). Thermal trucks are not considered because their costs are not comparable  
47 (much cheaper) to the two solutions mentioned above. The originality of this study is that it is based on an  
48 operational database of DB Schenker's activities during two months in the Ile-de-France region (600,000 data) in  
49 a sector where the lack of data is problematic (18, 28–30). DB Schenker is the second largest parcel company in  
50 France after the Geodis group and is principally oriented B2B (Business to Business consists of transactions

1 between two companies, it is opposed to B2C, Business to Consumers) (31). From there, it was possible to conduct  
2 an economic analysis to compare the current costs to those of a cargo bikes' delivery system by estimating the fleet  
3 needed in both scenarios. In the scenario using cargo bikes, micro hubs are needed. We have studied two methods  
4 to implement micro hubs by district or by minimizing the distance between the delivery/pickup points and micro  
5 hubs (facility location problem).  
6

7 This study is based on the same data base that Robichet and Nierat (2021) (9). This last study discusses  
8 the geographical implementation of DB Schenker's terminals in regards to the logistics sprawl at the  
9 Paris metropolitan area scale. In comparison, this study focuses on Paris intramuros and the possibilities  
10 for a green last mile.

## 11 **MODEL PRESENTATION**

### 12 **Territory studied**



13  
14 **Figure 1 – Map of Paris with districts**

15 Paris has a population of 2,175,601 inhabitants for an area of 105.4 km<sup>2</sup>, which corresponds to a density  
16 of 21,000 inhabitants/km<sup>2</sup> (32). Paris is part of an urban area of 12,475,808 inhabitants and is located in  
17 the center of the Paris metropolitan area, a region that generates 30% of the French Gross Domestic  
18 Product.

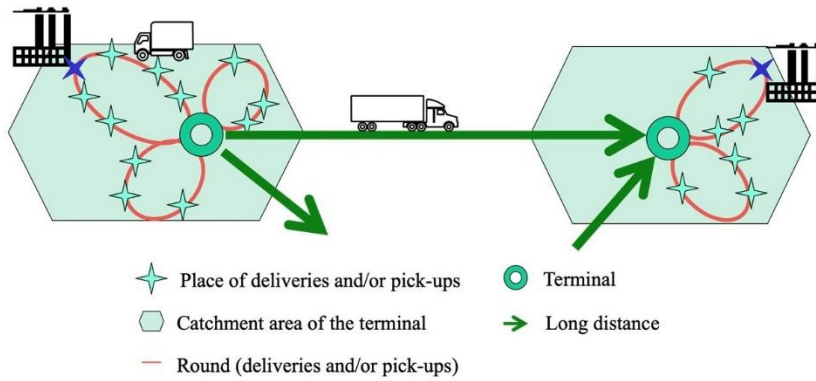
19 From a geographical point of view, as shown in Figure 1, Paris is cut in two (North/South) by the river  
20 Seine and is composed of 20 districts (built in a snail shape). Districts 12 and 16 are mainly composed  
21 of two large parks, the Bois de Vincennes and Bois de Boulogne.

### 22 **Running of parcel service carrier**

23 Parcel service is a specific segment of freight transport. Goods are transported from the sender to the  
24 recipient under the supervision of a single company (which may deal with subcontractors). Transported  
25 goods generally weight between 1 and 500 kg. The average weight for Paris city is 88 kg in our database  
26 (Table 1). In terms of volume, shipments are generally limited to 3 pallets (beyond that, it is generally  
27 more attractive to use LTL – less than truckload – service).

28 Parcels are collected via rounds and transported to cross-docking terminals. From there, parcels are  
29 carried to the final terminal by heavy goods vehicles making long-distance connections (tractions).  
30 There may be additional transshipments between the first and the last terminals. There, the parcels are

1 affected to rounds to be transported to the recipients. Deliveries and pick-ups are integrated in same  
 2 rounds.

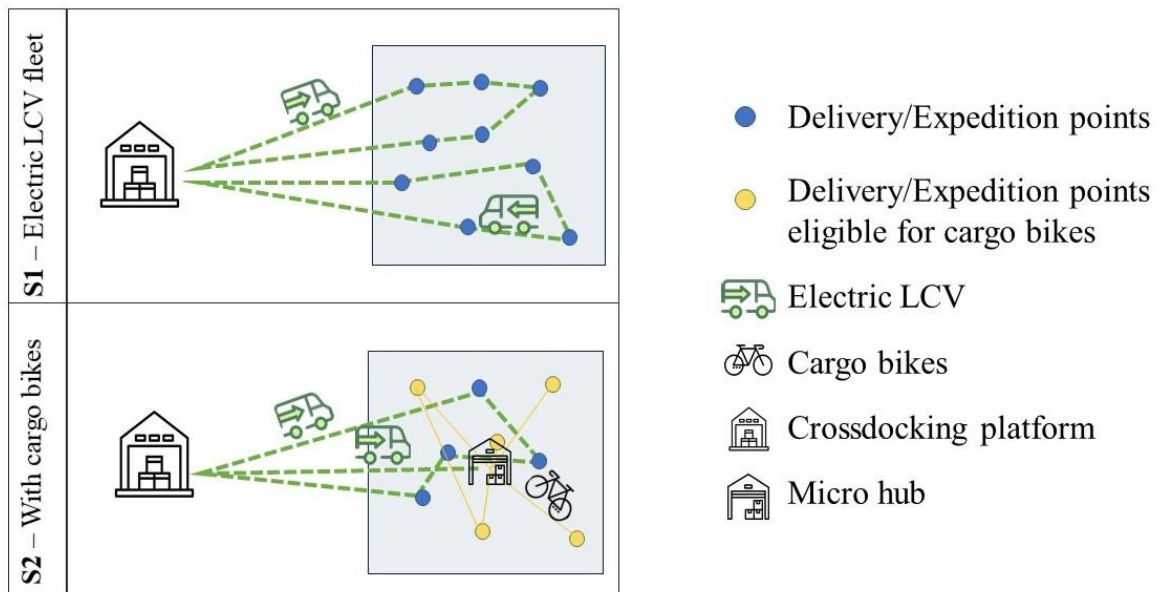


3  
 4

**Figure 2 – Diagram of the operation of a parcel service carrier company, (9)**

5 DB Schenker operates in Paris from two hubs on the outskirts (one to the north and one to the south)  
 6 which respectively manage the north and the south areas of Paris. These two hubs are connected to other  
 7 hubs nationwide via the national transport plan.

8 In this study, we aim at comparing two scenarios in terms of GHG emissions for the last mile. The first  
 9 case consists in keeping the traditional organization and substituting the thermal LCV by electric LCV.  
 10 Rounds being relatively short in dense areas such as Paris, they are rarely more than 80 km long, a  
 11 distance that can be achieved with the autonomy of an electric LCV. This is scenario S1. The second  
 12 one is based on the use of cargo bikes. As the operating area of a cargo bike is smaller than that of a  
 13 LCV, supplementary hubs, called micro hubs, are set up in dense areas. Micro-hubs support the national  
 14 hubs at the local level (they are not directly connected to the national network). Cargo bikes operate in  
 15 a radial pattern around micro hub. The number of operations per round is limited by their payload  
 16 (200 kg). In addition to cargo bikes, electric LCV provide, firstly, the connection between terminals and  
 17 micro hubs, and, secondly, operations for parcels over 200 kg and parcels more than 2 km away from  
 18 the micro hubs. Those operations are summarized in Figure 3.



19  
 20

**Figure 3 - Current situation with electric LCV and the scenario studied with the use of cargo bikes**

1 **Data**

2 The database has been acquired by extracting all DB Schenker's parcel activities in Paris metropolitan  
 3 area over the period January to February 2018 (only 34 days over the two-month period were retained  
 4 to avoid side effects). It is composed of two tables: deliveries and pick-ups. One record represents one  
 5 shipment, it can be composed of one or several parcels. For both tables, each record has 19 variables  
 6 including an ID (identification's key), date and time of the pick-up, names and addresses of senders and  
 7 recipients, weight, first and last terminals, date and time of delivery and the round ID of delivery (the  
 8 round ID of pick-up is not available).

9 The average weight of parcels (deliveries and pick-ups) in the Paris area is 88 kg (Table 1), which is  
 10 lower than the average weight for the whole Ile-de-France region (105 kg). Furthermore, 91% of these  
 11 parcels weigh less than 200 kg, which is the limit to be operated by cargo bikes. This high percentage  
 12 encourages to study the feasibility of cargo bikes from an economic point of view. Furthermore, in  
 13 comparison to the literature, the share of parcels that can be operated by cargo bikes (91%) is much  
 14 higher than the 55% announced by Llorca *et al.* (2021) however the weight limit in Llorca *et al.* (2021)  
 15 is 10 kg compared to the 200 kg limit in this study (18) (some cargo bike trailers can also move – as a  
 16 cart of dolly – packages weighing more than 50 kg).

17 Table 1 shows that there is a strong imbalance between deliveries (31,536) and pick-ups (5,098) within  
 18 Paris. Conversely, there are more pick-ups than deliveries in the whole Paris metropolitan area.

	Paris city		Paris metropolitan area	
	Deliveries	Pick-ups	Deliveries	Pick-ups
Average weight [kg]	91	71	112	98
Median weight [kg]	53	35	54	52
Share with a weight <200 kg	90%	93%	87%	88%
Stock	31,536	5,098	271,293	311,971
North terminal	21,912	3,702	-	-
South terminal	9,624	1,396	-	-

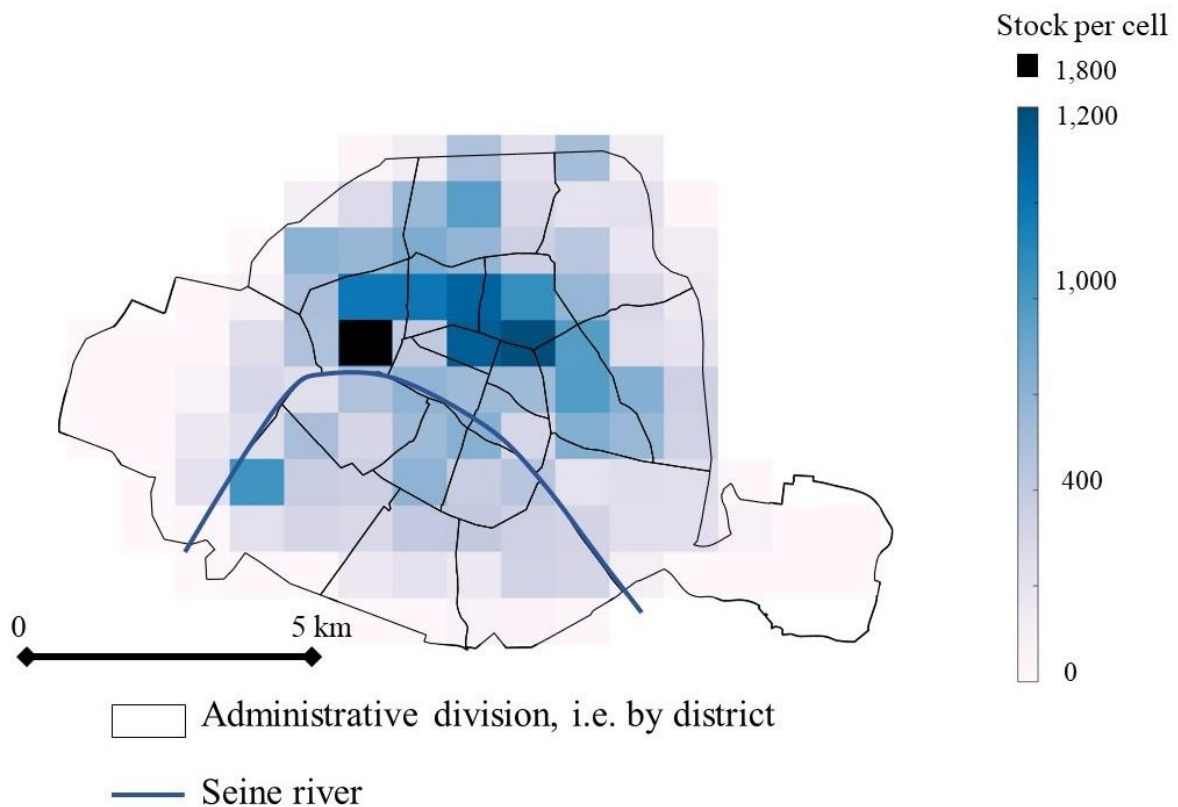
19 **Table 1 – General information of DB Schenker's activity in Paris metropolitan area, two months flow**

20 **Geographical distribution**

21 First, when studying the proportion of deliveries (31,536) vs. pick-ups (5,098) (Table 1), it is clear that  
 22 Paris receives many more shipments than it sends. This is due to the limited number of production sites  
 23 inside Paris.

24 Figure 4 shows the density of DB Schenker's operations (deliveries and pick-ups) within Paris for the  
 25 two months. The scale is linear from 0 to 800 operation per km<sup>2</sup>, excepted one cell with a much higher  
 26 density (1,216 operations/km<sup>2</sup>), colored black.

27 The concentration of operations is high (in average 10.3 operations/km<sup>2</sup>/day) inside Paris; however, it  
 28 is not uniformly distributed. Density peaks are mostly in the northern half.



1

2

**Figure 4 - Density of deliveries and pick-ups in Paris city for two months, 1.5 km<sup>2</sup> grid, MATLAB**

3 Finally, the figure shows that the delivery density is heterogenous inside administrative districts: it is  
 4 relevant noting that this administrative partition is not necessarily the most relevant one to design a  
 5 delivery operation process (section Model).

## 6 **Model**

7 In this section, the cost models of the different scenarios are described, and so are the two algorithms  
 8 (facility location and vehicle routing problem) used for this study. The P-median algorithm is used to  
 9 solve the facility location problem and for the spatial partitioning of Paris. Secondly, the vehicle routing  
 10 problem was used to determine the size of the fleet needed to perform all the operations. Both algorithms  
 11 are accessible in the Matlog package's (33). Those models were chosen over other more complex models  
 12 as we do not have all necessary information to implement those (among the missing information, the  
 13 delivery and pick-up time slots) (34) .

### 14 *Cost models and assumptions*

15 The following equipment was taken as a basis to derive the cost model:

- 16 - an electric LCV with a payload of 1,420 kg (Renault Master): it was chosen because it is the  
 17 electric vehicle with the highest payload without need for a heavy vehicle license;
- 18 - an electric LCV with a payload of 4,500 kg (Fuso eCarter): it was chosen because it is an electric  
 19 vehicle that is already part of DB Schenker's fleet;
- 20 - an electric cargo bike with a payload of 200 kg.



1 The daily costs (total cost of vehicles, energy, maintenance, driver) are available in Table 2 assuming  
 2 vehicles are used 7 h/day. It is assumed that a driver needing a heavy goods vehicle license (total weight  
 3 over 3.5t) is paid on the basis of a heavy goods vehicle driver, while the others are paid the minimum  
 4 wage.  
 5

Vehicle	Daily cost [€]	Payload [kg]	Number of operations per day
Cargo bike	80	200	17
Renault Master	143	1,420	22
Fuso eCanter	211	4,500	22

6 **Table 2 – Characteristics per vehicle**

7 Under scenario S1, the fleet is calculated as the minimization of the total transport cost. The fleet mixes  
 8 small LCVs and large LCVs (see *Vehicle Routing Problem*).

9 Under scenario S2, additional costs come from the micro-hubs, and the vehicles to supply those from  
 10 the peripheral terminals. Each micro hub has a fixed rental cost ( $C_{MH}$ ), calculated from the average  
 11 commercial actual estate prices for a 150 m<sup>2</sup> space (around 310 €/day). Therefore, the total retail cost is  
 12 proportional to the number of micro-hubs.

13 To supply one micro-hub, we assume that LCVs ( $N_{LCVsupply,i}$ ) are required for 2 hours per day (the  
 14 LCV type depends on the actual load, the least expensive solution is kept).

15 The question is then to derive the number and location of these micro-hubs. Denote by  $n$  the number of  
 16 micro-hubs. From micro hub  $i \in \{1, \dots, n\}$ , the cargo bikes can operate  $p$  parcels up to 2 km around (this  
 17 spatial limitation is an exogenous assumption ; it is consistent with the organization of DB Schenker in  
 18 Paris and other French cities, and with the literature (27)).Therefore, the total cost per day ( $TC_{CB,i}$ ) to  
 19 deliver  $p$  parcels for the micro hub  $i$  with  $N$  cargo bikes ( $N_{CB,i}$ ) is:

$$TC_{CB,i}(p) = C_{MH} + C_{CB} * N_{CB,i}(p) + \frac{2}{7} * C_{LCV} * N_{LCVsupply,i}(p) \quad (1)$$

20

21  $C_{CB}$  and  $C_{LCV}$  denote, respectively, the daily cost of a cargo bike and a LCV (values in Table 2.) For  
 22 the cost of the LCV, it depends on the actual type of vehicle required to supply the micro-hub (either a  
 23 Renault Master or a Fuso eCanter).

24  $TC_{FleetLCV,n}$  is the per day cost of the fleet of LCVs needed to operate parcels that cannot be operated  
 25 by cargo bike, i.e. all the parcels that either weigh more than 200 kg and/or that are to be delivered 2 km  
 26 from each of the micro hubs (see *Vehicle Routing Problem*). Hence,  $TC_{FleetLCV,n}$  depends on the  
 27 number of micro hubs.

28 Therefore, the total cost of S2 for  $n$  micro hubs is:

$$TC_{S2,n} = \sum_{i=1}^n TC_{CB,i} + TC_{FleetLCV,n} \quad (2)$$

29

1 For both scenarios, the cost was calculated for each day over the study period. From this, a sizing at  
2 80% of the activity has been chosen, in order not to consider the non-representative peak periods of  
3 activity or inactivity. During the study period a snowy episode has impacted the activity (decrease of  
4 activity) and the following days (increase in activity to balance).

#### 5 *Facility location – P-median Problem*

6 Based on the carrier’s activity, the question is whether or not it would be possible to optimize the  
7 location of the micro hubs. The algorithm is based on the P-median Model (35). This continuous  
8 optimization model finds optimal locations for the terminals by minimizing the sum of the distances  
9 between these terminals (variable) and the delivery and pick-up points (input parameters). The following  
10 assumptions are made:

- 11 - Euclidean distance (assumption that the topography of the Paris road network has no  
12 impact);
- 13 - Land price ignored;
- 14 - Existing infrastructures and buildings not considered;
- 15 - No construction of the rounds in the minimization (congestion ignored).

16 In order to respect DB Schenker's current organization (i.e. operations at the north of the Seine river are  
17 carried out from a platform which is located in the North of Paris, and vice versa for the South), Paris  
18 has been divided into two areas (referred to as North and South), and the cargo-bikes and electric LCV  
19 can hardly go from one of these areas of the other. In other words, a micro-hub cannot have a catchment  
20 area that overlaps the two sides of the river. Thus, the results are in line with the current organization of  
21 DB Schenker. Numbers of micro hubs from 1 to 20 were tested.

22 The locations of the micro hubs were calculated considering all delivery and pickup points over the  
23 whole period. To ensure that the set of locations found was a global solution and not a local optimum,  
24 the algorithm was run 100 times for each set of parameters with randomized initial states to avoid local  
25 optimum.

#### 26 *Vehicle Routing Problem (VRP)*

27 The VRP problem is solved with the Matlog package (33). The objective is not to study the distances  
28 traveled but to obtain the minimal number of vehicles needed to operate a given number of parcels,  
29 considering:

- 30 - The payload of the vehicles;
- 31 - The weight of the parcels;
- 32 - The number of operations per round (Table 2). It appears from interviews and field visits  
33 that there are few parcels with time constraint for this operator, therefore, it is not  
34 considered.

35 The fleet optimization is performed separately for cargo bikes and electric LCVs. For cargo bikes, the  
36 fleet is calculated at the micro hub level and includes all parcels under 200 kg and within 2 km of the  
37 micro hub.

## 38 **RESULTS**

39 This study provides results on two levels: first, the optimization of the location of the micro hubs is  
40 essential to cost-efficiency and, second, the renting price of the micro hubs is the most limiting element  
41 for the implementation of a delivery by cargo bikes.

## 1 **Location of micro hubs**

2 There is a practical importance for a parcel operator to organize their operations with respect to existing  
3 administrative partitions, as it leverages easily available information, eases the burden on information  
4 provision and processing, both at the level of information systems and at the level of the operators  
5 actually making the deliveries. However, this principle may be costly, as it comes with an exogenous  
6 constraint on the design of the delivery process. This is tested below.

7 To address the impact of location of the micro hubs, two scenarios were compared:

- 8 - In the first one, administrative districts are used as a basis for micro-hub location;
- 9 - In the second one, the number and location of the micro hubs are optimized without considering  
10 the administrative division.

11 More precisely, in the first case, for each district, the potential location of one micro hub is fixed and  
12 set at the centroid of all operations in that district. As for the order of opening of the micro hubs, they  
13 are opened from the most economically profitable to the least profitable.

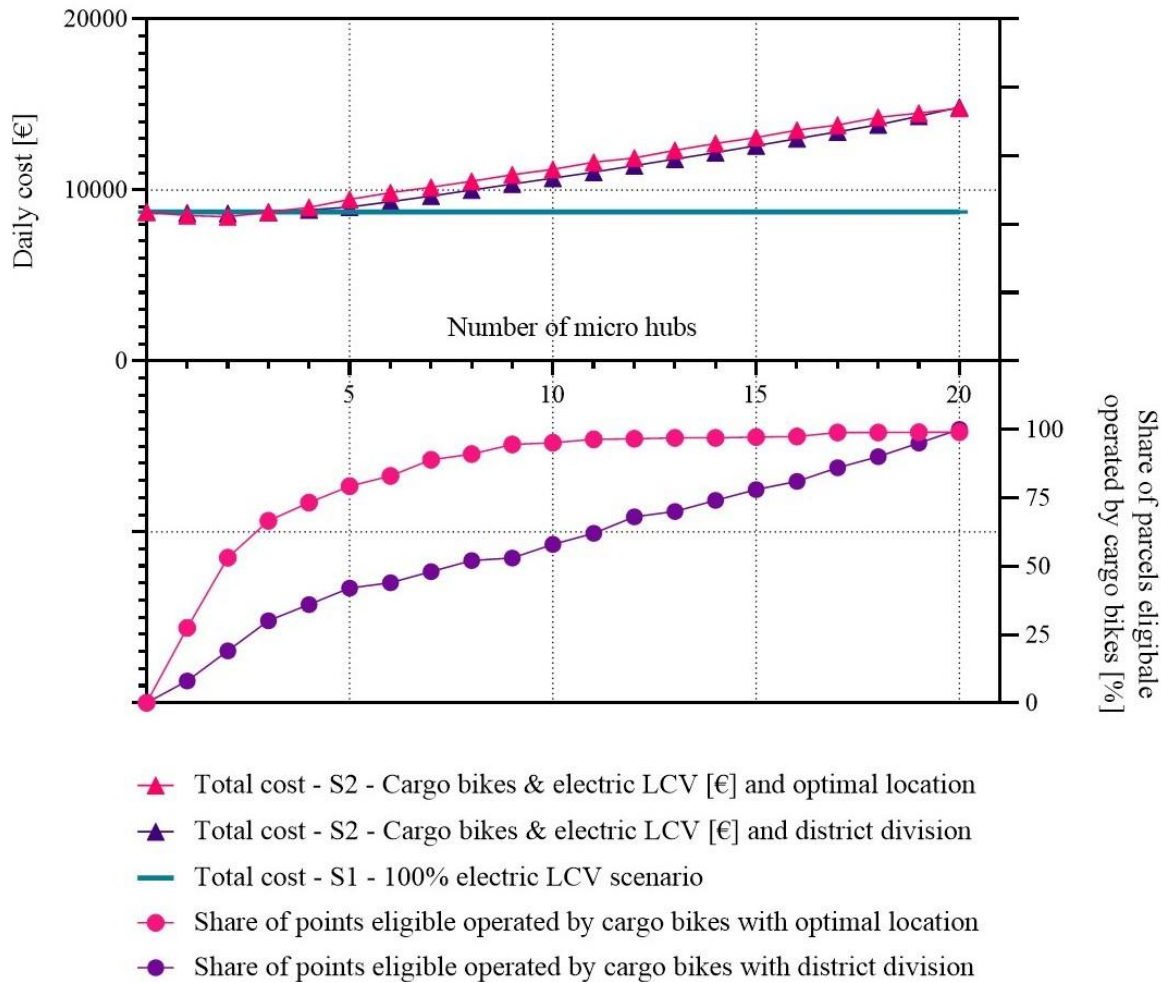
14 In the second case, for each iteration (i.e. number of micro hubs, ranging from 0 to 20), we start from a  
15 blank slate. For each iteration, the share of parcels operated by cargo bikes, the total cost (cargo bikes,  
16 micro hubs rent, needed LCVs) are calculated.

17 Figure 5 shows the evolution of the daily cost of operation and of the share of parcels operated by cargo  
18 bikes of both scenarios, as functions of the number of micro hubs. For scenario S2, two solutions are  
19 represented: the one with unconstrained optimization of the localization of micro hubs – the bright red  
20 curve – and the one where the locations of micro-hubs are constrained to the district centroids – the  
21 purple curve. Scenario S1 is also presented (dotted red line). In this case, no parcel is operated by cargo  
22 bike.

23 First of all, for this particular stakeholder, it is not profitable to deliver the entire Paris area by cargo  
24 bikes. The cost would be much greater than that of using a 100% electric fleet.

25 The second result is that it is possible to set up a network of 3 micro hubs (optimal location) performing  
26 67% of the daily operations for a similar – even slightly lower – cost than the one with a 100% electric  
27 LCVs fleet. However, with more than 3 micro hubs, the network of micro hubs and cargo bikes quickly  
28 gets more expensive than a traditional organization with a fleet of electric LCVs.

29 Assume that the objective is to maximize the share of operations done by cargo bikes (with optimal  
30 micro-hub location), it is possible to do by increasing the number of micro hubs. However, there are  
31 decreasing returns: beyond 10 micro-hubs, the share of parcels operated by cargo bike increases by less  
32 than 2% per additional micro-hub. A network of 10 micro hubs optimally located is sufficient to address  
33 more than 90% of the eligible shipments. However, the daily operation cost would be 30% higher than  
34 a fully electric fleet of LCVs.



1

2 **Figure 5 - Comparison of the daily cost of operating a solution with and without cargo bikes according to the number**  
 3 **of micro hubs**

4 Coming back to the question of the administrative division: it appears, expectedly, that respecting the  
 5 administrative division is costly. More precisely, the lowest cost is obtained with two micro-hubs, and  
 6 only 53% of shipments are operated by cargo-bikes. Moreover, in that scenario, the number of micro-  
 7 hubs necessary to cover a sizable share of eligible shipments would be much higher than in the  
 8 unconstrained scenario. This mirrors the very important spatial heterogeneity of the density of  
 9 operations.

## 10 **Impact of the micro hubs rent price**

11 The rent of the micro hubs is a critical limitation to the implementation of cargo bikes. In order to further  
 12 investigate the sensitivity of cargo-bike financial profitability to real estate prices, the following was  
 13 done. Consider the scenario with electric LCVs as a base case: for each share between 0 and 100%, it is  
 14 possible to determine the maximum micro-hub renting cost per m<sup>2</sup> such that it is possible to transport

1 that share of shipments by cargo-bikes for a lower daily cost than the base case: 100% of electric LCV.  
 2 Figure 6 is built with the following input parameters from the data:

- 3 -  $S_{MH}$ : Surface of the micro hub: 150m<sup>2</sup>;
- 4 -  $N_{CB}$ : Number of operations per day per cargo bike (value: 17);
- 5 -  $N_{LCV}$ : Number of operations per day per electric LCV (value: 22).

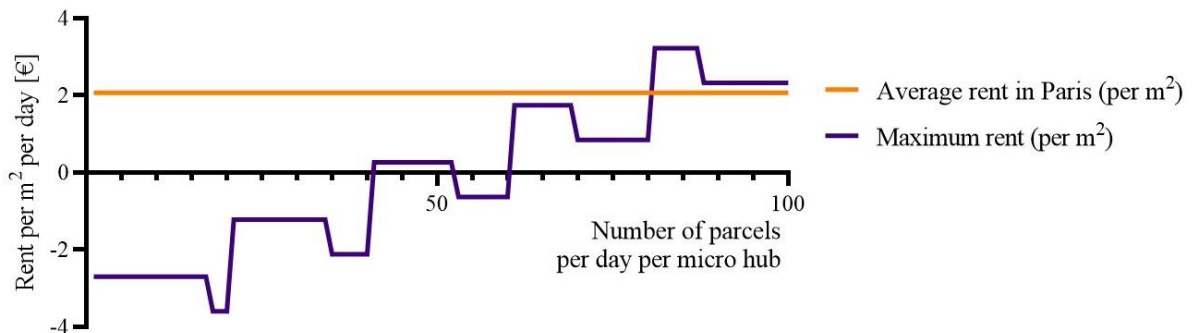
6 Thus, it is possible to define the equivalent electric LCVs fleet needed to operate  $p$  parcels ( $TC_{LCVeqCB}$ ).  
 7 From Equation (1), by equalizing the costs of the two formulas (i.e.  $TC_{LCVeqCB} = TC_{CB}$ ), we deduce  
 8 the maximum rent per m<sup>2</sup> as:

$$Max\_rent\_per\_m^2(p) = \frac{[TC_{LCVeqCB}(p) - (C_{CB} * N_{CB}(p) + \frac{2}{7} * C_{LCV} * N_{LCVsupply}(p))]}{S_{MH}} \quad (3)$$

9 Function  $Max\_rent\_per\_m^2$  is represented on Figure 5. Due of the number of operations that differ  
 10 between vehicles, the curve is by plateau, according to the number of operations to realize. For example,  
 11 three cargo bikes and one electric LCV for supply or three electric LCVs (similar cost) are needed to  
 12 perform 41 to 52 operations per day. However, four cargo bikes and one electric LCV for supply or only  
 13 three electric LCVs are required to perform 52 to 60 operations.

14 With our assumptions, cargo bikes are interesting when there is a significant number of daily operations  
 15 (81 in Paris). Even if local authorities provide free premises or space for mobile premises, a minimum  
 16 of 41 daily operations is required for it to be economically viable for the transporters. This underlines  
 17 the importance of having a high density of operations to set up a network of micro hubs for cargo bikes  
 18 deliveries.

19 In addition, it is found that while high density is necessary to implement cargo bikes, due to the different  
 20 number of operations per transportation mode, increasing the density does not necessarily imply a direct  
 21 decrease in the operating cost per cargo bike.



22  
 23 **Figure 6 - Maximum price per m<sup>2</sup> of a micro-hub rent according to the number of parcels per day**

24 **DISCUSSION**

25 Results show that it is technically possible to pick up or deliver a large majority of the parcels by cargo  
 26 bikes (91%). However, it is not economically interesting to operate all parcels by cargo bikes. This  
 27 confirms the hypothesis made by Conway *et al.* (2012) about the economic feasibility of delivering Paris  
 28 by cargo bikes without subsidy (36). The study was conducted with the data of one company, however,  
 29 the method, and some results, are generalizable. On one hand, it appears that a high density of operations  
 30 is necessary for cargo bike operations to be competitive. On the other hand, a higher density of

1 operations is found in places where land prices are higher, thus compromising the competitiveness of cargo  
2 bikes operations, given the fact that those require a micro-hub at close hand.

3 This raises the issue of pooling shipments between several operators. Consolidation has been shown to  
4 be highly advantageous through modeling, especially in the Frankfurt case (37) as it is the easiest way  
5 to increase density, but it does come with specific issues (cost of delivery, responsibility for the parcel,  
6 additional sorting points, etc.). The use of subcontractors specialized in cargo bikes deliveries can  
7 represent an opportunity to pool flows.

8 Moreover, in this study, the condition to operate a parcel by cargo bikes is the weight (200 kg max). We  
9 have no information about the volume of the parcels. It would be interesting to take this aspect into  
10 account as a cargo bike can carry a limited volume (approximately 1.5 m<sup>3</sup>).

11 Finally, it seemed interesting to raise the question of the rent cost of the micro hub as a limiting element.  
12 The analysis of the maximum rent as a function of the number of operations per day in the micro hub  
13 catchment area highlights the non-linear nature of the two parameters (rent and number of operations).  
14 This implies that, depending on the input parameters, there is no single threshold passed which one  
15 solution is universally better than the other. In addition, it is true that the input parameters (cost of rent,  
16 number of operations per tour, etc.) vary among case studies (territory studied, operator); however, the  
17 equation remains valid. Therefore, so is the shape of the curve, and the previous result is generalizable.  
18 This brings another point of view to the widely discussed comparison in the literature between cargo  
19 bikes and LCV by discussing the relationship between one limiting parameter of the cargo bike solution  
20 and a LCV fleet. One direction for further research is to conduct a more detailed analysis accounting for  
21 the variation of rents between districts (in this paper, the average rent is considered) and the density of  
22 operations.

## 23 **CONCLUSION**

24 The objective of this study is to compare two sustainable scenarios for the last mile via cargo bikes  
25 and/or electric LCVs fleet within Paris based on DB Schenker's operating data. The first important result  
26 is that it is economically feasible to operate a part of the parcels via cargo bikes but not all of them.

27 Secondly, the renting of micro hubs is a major cost barrier. As the average price of a commercial space  
28 in Paris is high, this requires a minimum density of parcels to make cargo bike operations profitable.  
29 Even if there were no rent to pay (i.e. subvention, free provision of facilities, etc.), it is necessary to  
30 have a minimum density to compensate for the cost of transporting the parcels between the micro-hubs  
31 and the cross-docking terminal by vehicle.

32 Moreover, as far as the location of micro hubs is concerned, it is interesting to be free of administrative  
33 borders. Indeed, it allows to operate cheaper a large number of operations (67% of daily operations)  
34 with only 3 micro hubs and with a relatively small catchment area (2 km radius around the micro hubs).

35 A priority direction for future research is the integration of negative externalities. Indeed, both electric  
36 LCVs and cargo bikes would strongly reduce greenhouse gas emissions, compared to today's situation.  
37 However, LCVs' impacts with regard to congestion and noise pollution would be distinct. As a final  
38 note, it is important to keep in mind that even if cargo bikes became prominent, trucks would not be  
39 simply put out of the picture, as they would be needed to, first, supply the micro hubs and, second, pick  
40 up and deliver oversize or overweight packages.

## 41 **AUTHOR CONTRIBUTION STATEMENT**

42 The authors confirm contribution to the paper as follows: study conception and design: F. Combes, P.  
43 Nierat, A. Robichet; data collection: F. Combes, P. Nierat, A. Robichet; analysis and interpretation of

1 results: F. Combes, P. Nierat, A. Robichet; draft manuscript preparation: F. Combes, P. Nierat, A.  
2 Robichet. All authors reviewed the results and approved the final version of the manuscript.

### 3 **BIBLIOGRAPHY**

- 4 1. Hammami, F. The Impact of Optimizing Delivery Areas on Urban Traffic Congestion.  
5 *Research in Transportation Business and Management*, Vol. 37, 2020, p. 12.  
6 <https://doi.org/10.1016/j.rtbm.2020.100569>.
- 7 2. Olsson, J., D. Hellström, and H. Pålsson. Framework of Last Mile Logistics Research: A  
8 Systematic Review of the Literature. *Sustainability (Switzerland)*, Vol. 11, No. 24, 2019, pp.  
9 1–25. <https://doi.org/10.3390/su11247131>.
- 10 3. Savelsbergh, M., and T. Van Woensel. City Logistics: Challenges and Opportunities.  
11 *Transportation Science*, Vol. 50, No. 2, 2016, pp. 579–590.  
12 <https://doi.org/10.1287/trsc.2016.0675>.
- 13 4. Szymczyk, K., and M. Kadłubek. Challenges in General Cargo Distribution Strategy in Urban  
14 Logistics - Comparative Analysis of the Biggest Logistics Operators in EU. No. 39, 2019, pp.  
15 525–533.
- 16 5. Gruber, J., A. Kihm, and B. Lenz. A New Vehicle for Urban Freight? An Ex-Ante Evaluation  
17 of Electric Cargo Bikes in Courier Services. *Research in Transportation Business and*  
18 *Management*, Vol. 11, 2014, pp. 53–62. <https://doi.org/10.1016/j.rtbm.2014.03.004>.
- 19 6. Affonso, P., and D. Ormond. Using Urban Consolidation Centre with Cycloscargos Support to  
20 Increase the Performance and Sustainability of Urban Logistics: A Literature Review and a  
21 Case Study in the City of São Paulo. 2019.
- 22 7. Lenz, B., and E. Riehle. Bikes for Urban Freight? *Transportation Research Record*, No. 2379,  
23 2013, pp. 39–45. <https://doi.org/10.3141/2379-05>.
- 24 8. Marujo, L. G., G. V. Goes, M. A. D’Agosto, A. F. Ferreira, M. Winckenbach, and R. A. M.  
25 Bandeira. Assessing the Sustainability of Mobile Depots: The Case of Urban Freight  
26 Distribution in Rio de Janeiro. *Transportation Research Part D: Transport and Environment*,  
27 Vol. 62, No. March, 2018, pp. 256–267. <https://doi.org/10.1016/j.trd.2018.02.022>.
- 28 9. Robichet, A., and P. Nierat. Consequences of Logistics Sprawl: Order or Chaos? - The Case of  
29 a Parcel Service Company in Paris Metropolitan Area. *Journal of Transport Geography*, Vol.  
30 90, 2021, p. 102900. <https://doi.org/10.1016/j.jtrangeo.2020.102900>.
- 31 10. Klauenberg, J., L. A. Elsner, and C. Knischewski. Dynamics of the Spatial Distribution of  
32 Hubs in Groupage Networks – The Case of Berlin. *Journal of Transport Geography*, No. July,  
33 2018, pp. 1–10. <https://doi.org/10.1016/j.jtrangeo.2018.07.004>.
- 34 11. Heitz, A., and A. Beziat. The Parcel Industry in the Spatial Organization of Logistics Activities  
35 in the Paris Region: Inherited Spatial Patterns and Innovations in Urban Logistics Systems.  
36 *Transportation Research Procedia*, Vol. 12, No. June 2015, 2016, pp. 812–824.  
37 <https://doi.org/10.1016/j.trpro.2016.02.034>.
- 38 12. Choubassi, C., D. P. K. Seedah, N. Jiang, and C. M. Walton. Economic Analysis of Cargo  
39 Cycles for Urban Mail Delivery. *Transportation Research Record*, Vol. 2547, No. 1, 2016, pp.  
40 102–110. <https://doi.org/10.3141/2547-14>.
- 41 13. Arnold, F., I. Cardenas, K. Sörensen, and W. Dewulf. Simulation of B2C E-Commerce  
42 Distribution in Antwerp Using Cargo Bikes and Delivery Points. *European Transport*  
43 *Research Review*, Vol. 10, No. 1, 2018, pp. 1–13. [https://doi.org/10.1007/S12544-017-0272-](https://doi.org/10.1007/S12544-017-0272-6/FIGURES/6)  
44 [6/FIGURES/6](https://doi.org/10.1007/S12544-017-0272-6/FIGURES/6).
- 45 14. McLeod, F. N., T. J. Cherrett, T. Bektas, J. Allen, A. Martinez-Sykora, C. Lamas-Fernandez,

- 1 O. Bates, K. Cheliotis, A. Friday, M. Piecyk, and S. Wise. Quantifying Environmental and  
2 Financial Benefits of Using Porters and Cycle Couriers for Last-Mile Parcel Delivery.  
3 *Transportation Research Part D: Transport and Environment*, Vol. 82, 2020.  
4 <https://doi.org/10.1016/J.TRD.2020.102311>.
- 5 15. Conway, A., C. Kamga, J. Cheng, P. Eickemeyer, Q. Chen, A. Singhal, C. C. of N. Y. of the C.  
6 U. of N. York, U. T. R. Center, N. Y. S. E. R. and D. Authority, N. Y. S. D. of Transportation,  
7 and F. H. Administration. Freight Tricycle Operations in New York City. No. 14, 2014, p.  
8 192p.
- 9 16. Dablanc, L., and D. Rakotonarivo. The Impacts of Logistics Sprawl: How Does the Location of  
10 Parcel Transport Terminals Affect the Energy Efficiency of Goods' Movements in Paris and  
11 What Can We Do about It? No. 2, 2010, pp. 6087–6096.
- 12 17. Rème-Harnay, P. *Evolution Des Stratégies de Gestion de La Main d'œuvre Du Dernier*  
13 *Kilomètre à l'ère Des Plateformes Numériques : Impact Sur Le Marché Du Travail et La*  
14 *Précarité*. 2021.
- 15 18. Llorca, C., and R. Moeckel. Assesment of the Potential of Cargo Bikes and Electrification for  
16 Last-Mile Parcel Delivery by Means of Simulation of Urban Freight Flows. *European*  
17 *Transport Research Review*, Vol. 13, No. 1, 2021, p. 33. [https://doi.org/10.1186/s12544-021-](https://doi.org/10.1186/s12544-021-00491-5)  
18 [00491-5](https://doi.org/10.1186/s12544-021-00491-5).
- 19 19. Koning, M., and A. Conway. The Good Impacts of Biking for Goods: Lessons from Paris City.  
20 *Case Studies on Transport Policy*, Vol. 4, No. 4, 2016, pp. 259–268.  
21 <https://doi.org/10.1016/j.cstp.2016.08.007>.
- 22 20. Melo, S., and P. Baptista. Evaluating the Impacts of Using Cargo Cycles on Urban Logistics:  
23 Integrating Traffic, Environmental and Operational Boundaries.  
24 <https://doi.org/10.1007/s12544-017-0246-8>.
- 25 21. de Mello Bandeira, R. A., G. V. Goes, D. N. Schmitz Gonçalves, M. de A. D'Agosto, and C.  
26 M. de Oliveira. Electric Vehicles in the Last Mile of Urban Freight Transportation: A  
27 Sustainability Assessment of Postal Deliveries in Rio de Janeiro-Brazil. *Transportation*  
28 *Research Part D: Transport and Environment*, Vol. 67, 2019, pp. 491–502.  
29 <https://doi.org/10.1016/J.TRD.2018.12.017>.
- 30 22. Fraselle, J., S. L. Limbourg, and L. Vidal. Cost and Environmental Impacts of a Mixed Fleet of  
31 Vehicles. *Sustainability 2021, Vol. 13, Page 9413*, Vol. 13, No. 16, 2021, p. 9413.  
32 <https://doi.org/10.3390/SU13169413>.
- 33 23. Dablanc, L., G. Giuliano, and K. Holliday. *Best Practices in Urban Freight Management :*  
34 *Lessons from an International Survey*. 2013.
- 35 24. Schliwa, G., R. Armitage, S. Aziz, J. Evans, and J. Rhoades. Sustainable City Logistics -  
36 Making Cargo Cycles Viable for Urban Freight Transport. *Research in Transportation*  
37 *Business and Management*, Vol. 15, 2015, pp. 50–57.  
38 <https://doi.org/10.1016/j.rtbm.2015.02.001>.
- 39 25. Rudolph, C., and J. Gruber. Cargo Cycles in Commercial Transport: Potentials, Constraints,  
40 and Recommendations. *Research in Transportation Business & Management*, Vol. 24, 2017,  
41 pp. 26–36. <https://doi.org/10.1016/J.RTBM.2017.06.003>.
- 42 26. Tipagornwong, C., and M. Figliozzi. Analysis of Competitiveness of Freight Tricycle Delivery  
43 Services in Urban Areas. *Transportation Research Record*, Vol. 2410, 2014, pp. 76–84.  
44 <https://doi.org/10.3141/2410-09>.
- 45 27. Sheth, M., P. Butrina, A. Goodchild, and E. McCormack. Measuring Delivery Route Cost  
46 Trade-Offs between Electric-Assist Cargo Bicycles and Delivery Trucks in Dense Urban  
47 Areas. *European Transport Research Review*, Vol. 11, No. 1, 2019, p. 11.



- 1 <https://doi.org/10.1186/s12544-019-0349-5>.
- 2 28. *A Concept for a National Freight Data Program: Special Report 276*. 2003.
- 3 29. Chow, J. Y. J., C. H. Yang, and A. C. Regan. State-of-the Art of Freight Forecast Modeling:  
4 Lessons Learned and the Road Ahead. *Transportation*, Vol. 37, No. 6, 2010, pp. 1011–1030.  
5 <https://doi.org/10.1007/S11116-010-9281-1/TABLES/4>.
- 6 30. Outwater, M., C. Smith, K. Wies, S. Yoder, B. Sana, and J. Chen. Tour Based and Supply  
7 Chain Modeling for Freight: Integrated Model Demonstration in Chicago. No. 5, 2013, pp. 55–  
8 66.
- 9 31. Faibis, L. La Messagerie et Le Fret Express. *Xerfi*, 2020, p. 288.
- 10 32. Insee. Dossier Complet - Département de Paris (75). No. 75, 2019, pp. 1–35.
- 11 33. Kay, M. G. Matlog: Logistics Engineering Using Matlab. *Mühendislik Bilimleri ve Tasarım*  
12 *Dergisi*, Vol. 4, No. 1, 2016, pp. 15–20–20. <https://doi.org/10.21923/mbtd.60558>.
- 13 34. Caggiani, L., A. Colovic, L. P. Prencipe, and M. Ottomanelli. A Green Logistics Solution for  
14 Last-Mile Deliveries Considering e-Vans and e-Cargo Bikes. No. 52, 2021, pp. 75–82.
- 15 35. Hakimi, S. L. Optimum Locations of Switching Centers and the Absolute Centers and Medians  
16 of a Graph. *Operations Research*, Vol. 12, No. 3, 1964, pp. 450–459.  
17 <https://doi.org/10.1287/opre.12.3.450>.
- 18 36. Conway, A., P.-E. Fatisson, P. Eickemeyer, J. Cheng, and D. Peters. Urban Micro-  
19 Consolidation and Last Mile Goods Delivery by Freight-Tricycle in Manhattan: Opportunities  
20 and Challenges. 2012.
- 21 37. Elbert, R., and C. Friedrich. Urban Consolidation and Cargo Bikes: A Simulation Study. No.  
22 48, 2020, pp. 439–451.
- 23