First and Last Miles by Cargo Bikes: Ecological Commitment or Economically Feasible? The Case of a Parcel Service Company in Paris

Antoine Robichet¹, Patrick Nierat¹, and Francois Combes¹

Abstract
Urban logistics is a key step in distribution chains. It implies the use of trucks in congested areas, and generates numerous externalities (congestion, noise, pollution, etc.). Supply chain configurations and consumer behaviors are undergoing deep changes, with a significant increase in the intensity of urban logistics and a diversification of delivery channels within cities. This is an important challenge for city sustainability, as urban logistics is an essential economic activity, and yet the source of intense negative externalities. Numerous directions are currently being explored to rethink urban logistics, such as drones, cargo bikes, crowd logistics, and so forth. However, the economic and environmental relevance of these technologies is not yet perfectly clear. This paper focuses on the conditions for the financial sustainability of cargo bikes compared with electric light commercial vehicles (LCVs). The analysis is based on real data, provided by the parcel service company DB Schenker. The dataset consists of 600,000 operations made in Paris over two months. Operations with electric LCV are assumed to be identical to conventional LCV; the cost comparison is based on a total cost of ownership approach. Operations with cargo bikes assumes that eligible shipments are first brought to micro hubs within the city by electric LCV, then delivered by cargo bike. The numbers and locations of micro hubs are optimized. Results show that a cargo bike solution can be more cost-efficient than electric LCV with a few micro hubs located where the demand is densest, but they can only be relevant financially in those conditions.

Keywords
freight systems, city, city logistics and last mile strategies, street use, delivery, freight facility location and land use

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

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

However, micro hubs are costly (rent, additional managers needed, etc.). With a high density of pick-up and delivery operations, it is possible that the cost of the

¹SPOPT – AME, Gustave Eiffel University, Champs-sur-Marne, France

Corresponding Author:
Antoine Robichet, antoine.robiçhet@univ-eiffel.fr
micro hub is more than compensated by savings on transportation costs (12–14). On the other hand, the high cost of land is a key limitation in the implementation of these new solutions (15). For instance, in Paris, land pressure is extremely high and platforms are driven to the periphery (16).

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

- Lower vehicle costs (purchase, maintenance, and insurance);
- Fast and reliable movement in dense areas (less delayed by traffic jams);
- The possibility to park close to delivery/shipping points (14);
- Less road and parking space consumed because of the smaller size of the vehicle;
- Cleaner and fewer and less serious negative externalities than most other modes of transportation (especially trucks) (13, 14, 19–22).

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

This study addresses the possibility of delivering by cargo bikes shipments which are traditionally delivered by trucks. To compare two low emission solutions, delivery by cargo bikes will be evaluated against a fleet of electric LCVs (light commercial vehicles). Conventional thermal trucks are not considered because their costs are not comparable with (i.e., much cheaper than) the two solutions mentioned above. The originality of this study is that it is based on an operational dataset of DB Schenker’s activities during two months in the Ile-de-France region (dataset of 600,000 operations) in a sector where lack of data can be problematic (18, 28–30). DB Schenker is the second largest parcel company in France after the Geodis group and is principally oriented to business-to-business (B2B), which consists of transactions between companies, as opposed to B2C (business to consumers) operations (31). Using the dataset, it was possible to conduct an economic analysis to compare the current costs with those of a cargo bike delivery system by estimating the fleet needed in both scenarios. In the scenario using cargo bikes, micro hubs are needed. Two methods for implementing micro hubs are studied: by district or by minimizing the distance between the delivery/pick-up points and micro hubs (facility location problem).

This study is based on the same dataset as that used in Robichet and Nierat (9). The latter study discussed the geographical implementation of DB Schenker’s terminals with regard to the logistics sprawl at the scale of the Paris metropolitan area. In comparison, this study focuses on Paris intramuros and the possibilities for a green last mile.

**Model Presentation**

**Territory Studied**

Paris has a population of 2,175,601 inhabitants in an area of 105.4 km², which corresponds to a density of 21,000 inhabitants/km² (32). The city of Paris is part of an urban area of 12,475,808 inhabitants and is located in the center of the Paris metropolitan area, a region that generates 30% of the gross domestic product of France.

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

**Running of Parcel Service Carrier**

Parcel service is a specific segment of freight transport. Goods are transported from the sender to the recipient under the supervision of a single company (which may deal with subcontractors). Transported goods generally weigh between 1 kg and 500 kg. The average weight of parcels in Paris city is 88 kg, according to the dataset (Table 1). In volume, shipments are generally limited to
three pallets; beyond that, it is generally more attractive to use a less-than-truckload (LTL) service.

As shown in Figure 2, parcels are collected via rounds and transported to cross-docking terminals. From there, parcels are carried to the final terminal by heavy goods vehicles making long-distance connections (tractions). There may be additional transshipments between the first and the last terminals. There, the parcels are assigned to rounds to be transported to the recipients. Deliveries and pick-ups are integrated in the same rounds.

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

The aim of this study is to compare two scenarios by their greenhouse gas emissions for the last mile. The first case consists in keeping the traditional organization and substituting the thermal LCV by electric LCV. Rounds being relatively short in dense areas such as Paris, they are rarely more than 80 km long, a distance that can be achieved with the autonomy of an electric LCV. This is scenario S1. The second scenario (S2) is based on the use of cargo bikes. As the operating area of a cargo bike is smaller than that of a LCV, supplementary hubs, called micro hubs, are set up in dense areas. Micro hubs support the national hubs at the local level (they are not directly connected to the national network). Cargo bikes operate in a radial pattern around a micro hub. The number of operations per round is limited by their payload (200 kg). In addition to cargo bikes, electric LCVs provide, firstly, the connection between terminals and micro hubs, and, secondly, operations for parcels over 200 kg and parcels more than 2 km away from the micro hubs. These operations are summarized in Figure 3.

**Data**

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

The average weight of parcels (deliveries and pick-ups) in the Paris area is 88 kg (Table 1), which is lower than the average weight for the whole Ile-de-France region (105 kg). Furthermore, 91% of these parcels weigh less than 200 kg, which is the limit for operation by cargo bike. This high percentage encourages research into the feasibility of cargo bikes from an economic point of view. Furthermore, in comparison with the literature, the share of parcels that can be carried by cargo bikes (91%) is much higher than the 55% announced by Llorea and Moeckel (18). However, the weight limit in that study was 10 kg, much lower than the 200 kg limit in this study.

### Table 1. General Information on DB Schenker’s Activity in Paris Metropolitan Area over Two Months

<table>
<thead>
<tr>
<th></th>
<th>Paris city</th>
<th></th>
<th>Paris metropolitan area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deliveries</td>
<td>Pick-ups</td>
<td>Deliveries</td>
</tr>
<tr>
<td>Average weight (kg)</td>
<td>91</td>
<td>71</td>
<td>112</td>
</tr>
<tr>
<td>Median weight (kg)</td>
<td>53</td>
<td>35</td>
<td>54</td>
</tr>
<tr>
<td>Share with a weight &lt;200 kg</td>
<td>90%</td>
<td>93%</td>
<td>87%</td>
</tr>
<tr>
<td>Stock</td>
<td>31,536</td>
<td>5,098</td>
<td>271,293</td>
</tr>
<tr>
<td>North terminal</td>
<td>21,912</td>
<td>3,702</td>
<td>na*</td>
</tr>
<tr>
<td>South terminal</td>
<td>9,624</td>
<td>1,396</td>
<td>na*</td>
</tr>
</tbody>
</table>

*na = not applicable.
(some cargo bike trailers can also move, as a cart or dolly, packages weighing more than 50 kg).

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

Geographical Distribution

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

Figure 4 shows the density of DB Schenker’s operations (deliveries and pick-ups) within Paris for the two months. The scale is linear from zero to 800 operations per square kilometer, except one cell with a much higher density (1,216 operations/km²), colored black.

The concentration of operations is high (on average 10.3 operations/km²/day) inside Paris; however, it is not uniformly distributed. Density peaks are mostly in the northern half.

Finally, the figure shows that the delivery density is heterogenous within administrative districts: it is relevant to note that this administrative partition is not necessarily the most relevant one to design a delivery operation process (see the next section, “Models”).

Models

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

Cost Models and Assumptions. The following equipment was taken as a basis to derive the cost model:

- an electric LCV with a payload of 1,420 kg (Renault Master): chosen because it is the electric vehicle with the highest payload without need for a heavy vehicle license;
- an electric LCV with a payload of 4,500 kg (Fuso eCanter): chosen because it is an electric vehicle that is already part of DB Schenker’s fleet;
Table 2. Characteristics per Vehicle

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Daily cost (%)</th>
<th>Payload (kg)</th>
<th>Number of operations per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo bike</td>
<td>80</td>
<td>200</td>
<td>17</td>
</tr>
<tr>
<td>Renault Master</td>
<td>143</td>
<td>1,420</td>
<td>22</td>
</tr>
<tr>
<td>Fuso eCanter</td>
<td>211</td>
<td>4,500</td>
<td>22</td>
</tr>
</tbody>
</table>

- an electric cargo bike with a payload of 200 kg.

The daily costs (total cost of vehicles, energy, maintenance, and driver) are available in Table 2 assuming vehicles are used 7 h/day. It is assumed that operations where the driver needs to hold a heavy goods vehicle license (total weight over 3.5 t) are costed on the basis of the wages of a heavy goods vehicle driver, while the others are paid the minimum wage.

Under scenario S1, the fleet is calculated as the minimization of the total transport cost. The fleet mixes small LCVs and large LCVs (see “Vehicle Routing Problem” subsection, below).

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

To supply one micro hub, it is assumed here that LCVs ($N_{LCV\text{supply},i}$) are required for 2 h per day (the LCV type depends on the actual load, the least expensive solution is kept).

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

$$TC_{CR,i}(p) = C_{MH} + C_{CB} \cdot N_{CR,i}(p) + \frac{2}{7} \cdot C_{LCV} \cdot N_{LCV\text{supply},i}(p)$$

(1)

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

$TC_{Fleet\text{LCV},n}$ is the per day cost of the fleet of LCVs needed to carry parcels that cannot be carried by cargo bike, that is, all the parcels that either weigh more than 200 kg and/or that are to be delivered 2 km from each of the micro hubs (see “Vehicle Routing Problem”). $TC_{Fleet\text{LCV},n}$ therefore depends on the number of micro hubs. Therefore, the total cost of S2 for $n$ micro hubs is:

$$TC_{S2,n} = \sum_{i=1}^{n} TC_{CR,i} + TC_{Fleet\text{LCV},n}$$

(2)

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

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

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

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

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

**Vehicle Routing Problem.** The vehicle routing problem problem is solved with the Matlog package (33). The objective is not to study the distances traveled but to obtain the minimal number of vehicles needed to convey a given number of parcels, considering:

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

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

**Results**

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

**Location of Micro Hubs**

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

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

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

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

In the second case, each iteration (i.e., number of micro hubs, ranging from 0 to 20), starts from a blank slate. For each iteration, the share of parcels carried by cargo bikes and the total cost (cargo bikes, micro hub rental, LCVs needed) are calculated.

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

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

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

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

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

**Impact of the Rental Cost of Micro Hubs**

The cost of renting the micro hubs is a critical limitation to the implementation of cargo bikes. To investigate
further the sensitivity of cargo bike financial profitability to real estate prices, the following was done. Consider the scenario with electric LCVs as a base case: for each share between zero and 100%, it is possible to determine the maximum micro hub rental cost per square meter such that it is possible to transport that share of shipments by cargo bikes for a lower daily cost than the base case: 100% of electric LCV. Figure 6 is built with the following input parameters from the data:

- \( S_{\text{MH}} \) = surface of the micro hub: 150 m\(^2\);
- \( N_{\text{CB}} \) = number of operations per day per cargo bike (value: 17);
- \( N_{\text{LCV}} \) = number of operations per day per electric LCV (value: 22).

Thus, it is possible to define the equivalent electric LCV fleet needed to convey \( p \) parcels (\( T_{\text{LCV}_{\text{eqCB}}} \)). From Equation 1, by equalizing the costs of the two formulas (i.e., \( T_{\text{LCV}_{\text{eqCB}}} = T_{\text{CB}} \)), we deduce the maximum rent per square meter as:

\[
\text{Max. rent per m}^2(p) = \frac{T_{\text{LCV}_{\text{eqCB}}}(p) - \left( C_{\text{CB}} \times N_{\text{CB}}(p) + \frac{2}{3} \times C_{\text{LCV}} \times N_{\text{LCV}_{\text{supply}}}(p) \right)}{S_{\text{MH}}}
\]

(3)

Function Max. rent per m\(^2\) is represented in Figure 5. Given the number of operations that differ between vehicles, the curve is by plateau, according to the number of operations to realize. For example, three cargo bikes and one electric LCV for supply or three electric LCVs (similar cost) are needed to perform 41 to 52 operations per day. However, four cargo bikes and one electric LCV for supply or only three electric LCVs are required to perform 52 to 60 operations.

With the assumptions made in this study, cargo bikes are economically interesting when there is a significant number of daily operations (81 in Paris). Even if local authorities were to provide free premises or space for mobile premises, a minimum of 41 daily operations would be required for cargo bikes to be economically viable for the carriers. This underlines the importance of having a high density of operations to set up a network of micro hubs for cargo bike deliveries. In addition, it is found that while high density is necessary to implement cargo bikes, given the different number of operations per transportation mode, increasing the density does not necessarily imply a direct decrease in the operating cost per cargo bike.

**Discussion**

Results show that it is technically possible to pick up or deliver a large majority of the parcels in Paris city by cargo bike (91%). However, it is not economical to convey all parcels by cargo bikes. This confirms the hypothesis of Conway et al. (36) about the economic feasibility of delivering in Paris by cargo bikes without subsidy. The study was conducted with the data of one company, however, the method, and some results, are generalizable. On one hand, it appears that a high density of operations is necessary for cargo bike operations to be competitive. On the other hand, a higher density of operations is found in places where land prices are higher, thus compromising the competitiveness of cargo bike operations, given that those require a micro hub at close hand.
This raises the issue of pooling shipments between several operators. Consolidation has been shown to be highly advantageous through modeling, especially in the Frankfurt case (37) as it is the easiest way to increase density, but it does come with specific issues (cost of delivery, responsibility for the parcel, additional sorting points, etc.). The use of subcontractors specialized in cargo bike deliveries can represent an opportunity to pool flows.

Moreover, in this study, the condition for conveying a parcel by cargo bike is the upper weight limit (200 kg maximum). We have no information about the volume of the parcels. It would be interesting to take this aspect into account, as a cargo bike can carry a limited volume (approximately 1.5 m³).

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

## Conclusion

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

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

Moreover, as far as the location of micro hubs is concerned, it is advantageous to be free of administrative borders. Indeed, it would allow many operations (67% of daily operations) more cheaply with only three micro hubs and with a relatively small catchment area (2 km radius around the micro hubs).

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

## Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: F. Combes, P. Nierat, A. Robichet; data collection: F. Combes, P. Nierat, A. Robichet; analysis and interpretation of results: F. Combes, P. Nierat, A. Robichet; draft manuscript preparation: F. Combes, P. Nierat, A. Robichet. All authors reviewed the results and approved the final version of the manuscript.

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## ORCID iDs

Antoine Robichet [i](https://orcid.org/0000-0001-5694-5167)
Patrick Nierat [i](https://orcid.org/0000-0003-3543-1305)
Francois Combes [i](https://orcid.org/0000-0001-5658-4437)

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