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► To cite this version:

Antoine Robichet, Patrick Nierat, Francois Combes. Comparison of the social cost of cargo bikes, electric and thermal commercial trucks for urban deliveries. Transport Research Arena, Nov 2022, Lisbonne, Portugal. 8p. hal-04100018

HAL Id: hal-04100018

<https://hal.science/hal-04100018v1>

Submitted on 17 May 2023

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Transport Research Arena (TRA) Conference

Comparison of the social cost of cargo bikes, electric and thermal commercial trucks for urban deliveries

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Abstract

Road transport is a major contributor to greenhouse gas emissions on a global scale. In addition, in urban areas, other negative externalities must be considered, such as congestion, noise, etc. Freight transport is responsible for a significant part of these externalities which companies are not, today, financially charged. To address these issues, one solution is to operate the city in a more sustainable way.

In this study, we compare the social cost (cost of ownership and environmental cost) of three technologies (Light Commercial Trucks – LCTs, electric LCTs and cargo bikes) in the case of Paris City. The main results indicate that it is worthwhile to use cargo bikes up to a certain point, the optimum being a mixed fleet. The originality of this study is that it is based on an operational database of one carrier's activities during two months in the Ile-de-France region.

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Peer-review under responsibility of the scientific committee of the Transport Research Arena (TRA) Conference
Keywords: Cargo bikes; environmental costs; Light commercial vehicles; Last mile; Urban good movement; Micro-hub

1. Introduction

Urban logistics is a key point in the delivery chain. The use of trucks in crowded areas such as city centers generates numerous negative externalities (congestion, noise, pollution, etc.) (Hammami, 2020; Olsson et al., 2019). 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) (Szymczyk and Kadłubek, 2019). Nowadays, most of the innovative ideas (cargo bikes, delivery robots) are based on the presence of additional

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transfers. These transfers imply additional smaller platforms, often referred to as micro-hubs, which can have a fixed location (e.g., a small warehouse in a building), or a variable one (e.g., parked container in street during the day). The 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 (Klaunberg et al., 2018).

However, micro-hubs are costly (rent, wages etc.). With a high density of pickup and delivery operations, it is possible that the cost of the micro-hub is more than compensated by savings on transportation costs (Arnold et al., 2018). On the other hand, the high cost of land is a key limitation in the implementation of these new solutions.

Among these solutions, the bicycle has the advantage of being already technically mature as well as being already present in the urban environment (by the previous presence of cyclists). Furthermore, using bikes is possible under current regulation (which isn't true for drones, for example). The possibility to use electric cargo bikes allows to transport important loads (up to 200 kg) with no major difficulty. A review of the literature was done by Llorca & Moeckel (2021). 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 dependent on traffic jam);
- The possibility to park close to the delivery/shipping points;
- Less road and parking consumption due to the smaller size of the vehicle;
- Cleaner and less negative externalities than most other modes of transportation (especially trucks) (Koning and Conway, 2016; McLeod et al., 2020).

These new technologies are implemented to anticipate new regulations which 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 in order to diminish negative externalities (Dablanc et al., 2013). In the case of cargo bikes, cities can play a crucial role via the creation of cycle lanes, zero-emission zones, reduction of drive-through traffic, etc. (Choubassi et al., 2016). The policy objective is to constrain vehicle types to reduce negative externalities without preventing carriers from operating.

In this study, we address the possibility to deliver by cargo bikes shipments which are traditionally delivered by trucks. Delivery by cargo bikes will be evaluated against a fleet of thermal LCTs (Light Commercial trucks) and a fleet of electric LCTs. The originality of this study is that it is based on an operational database of DB Schenker's activities during two months in the Ile-de-France region (600,000 data) in a sector where the lack of data is problematic (Llorca and Moeckel, 2021). DB Schenker is the second largest parcel company in France after the Geodis group and is principally oriented B2B (Faibis, 2020). From there, it was possible to conduct an economic analysis to compare the total social costs of those three scenarios. In the scenario using cargo bikes, micro-hubs are needed. We have studied two methods to implement micro-hubs by district or by minimizing the distance between the delivery/pickup points and micro-hubs (facility location problem).

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

2. Scenario presentation

In this section, the two scenarios studied and the data used for the study are presented.

2.1. Running of parcel service carrier

In this study, we aim at comparing the total social cost of three scenarios for the first and last miles. The first case (S0) consists in keeping the traditional organization (thermal LCTs). The second scenario (S1) consists of substituting the thermal vehicles by electric vehicles. The third one is based on the use of cargo bikes. As the operating area of a cargo bike is smaller than the one of a LCT, 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 micro-hub. In addition to cargo bikes, electric LCT 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. This is scenario 2 – S2. Those operations are summarized in Figure 1.

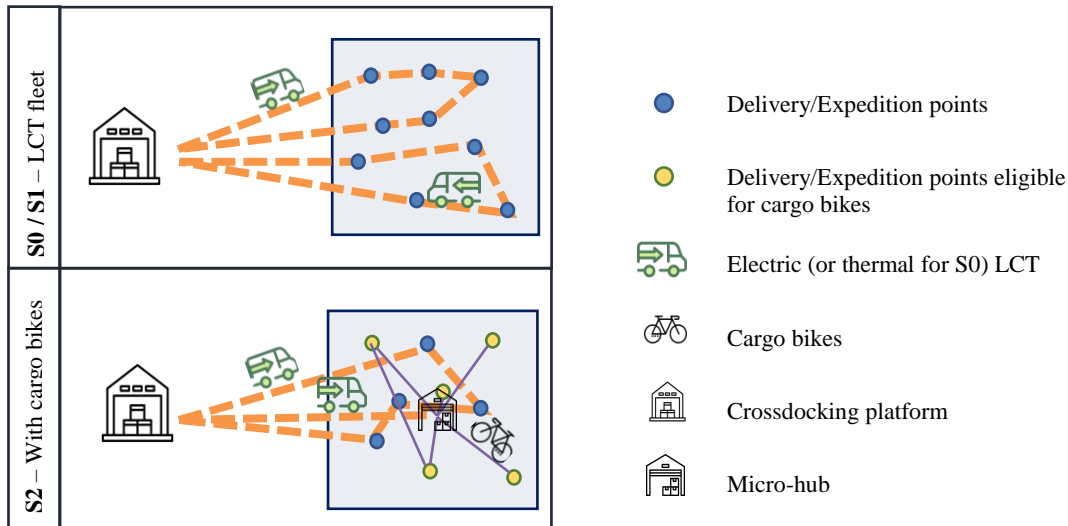


Fig. 1. Current situation with electric LCT and the scenario studied with the use of cargo bikes

2.2. Data

The database has been acquired by extracting all DB Schenker's parcel activities in Paris metropolitan area over the period January to February 2018. It is composed of two tables: deliveries and pick-ups. One record represents one consignment, it can be composed of one or several parcels. For both tables, each record has 19 variables including an ID (identification's 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 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 to be operated by cargo bikes. This high percentage encourages to study the feasibility of cargo bikes from an economic point of view. Furthermore, in comparison to the literature, the share of parcels that can be operated by cargo bikes (91%) is much higher than the 55% announced by Llorca *et al.* (2021) but with a weight limit of 10 kg compared to the 200 kg limit in this study.

3. Model

In this section, the cost models of the different scenarios as well as the two algorithms (facility location and vehicle routing problem) used for this study are described. The P-median algorithm is used to solve the facility location problem and was used for the territorial splitting 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 (Kay, 2016).

3.1. Cost models and assumptions

In order to carry out the economic study, cost models were developed for three reference vehicles. The daily costs (vehicle, energy, maintenance, driver) are available in Table 1 assuming vehicles are used 7 h/day.

Table 1 – Characteristics per vehicle

Vehicle	Cost [€]	Payload [kg]	Deliveries/ pick ups per day
Cargo bike	80	200	17
Renault Master	129	1,420	22
Renault eMaster	143	1,420	22
Fuso Canter	183	4,500	22
Fuso eCanter	211	4,500	22

For S0 and S1, the fleet is calculated as the minimization of the total cost with the two LCTs in Table 1 (see *Vehicle Routing Problem*).

For S2, additional costs come from micro-hubs and vehicles to supply them from the Parisian hubs. Each micro-hub has a fixed rental cost (C_{MH}) that is calculated from the average commercial actual estate prices for a 150 m² space (around 310 €/day). This cost is added according to the number of micro-hubs studied.

To supply one micro-hub, we assume one or two LCTs ($N_{LCTsupply,i}$) are required for 2 hours per day (the chosen LCT varies according to the load to be transported, the least expensive solution is chosen).

From these micro-hubs, the cargo bikes can operate p parcels up to 2 km around (this figure was chosen after the implementation of cargo bikes in other French cities by the same operator and in accordance with the data available in the literature (Sheth et al., 2019)).

Finally, the total cost for the micro-hub i with cargo bikes delivery ($TC_{CB,i}$) is:

$$TC_{CB,i}(p) = C_{MH} + C_{CB} * N_{CB,i}(p) + \frac{2}{7} * C_{LCT} * N_{LCTsupply,i}(p) \tag{1}$$

C_{CB} and C_{LCT} are respectively the daily cost of a cargo bike and an LCT in Table 1. For the cost of the LCT, it depends on the fleet needed, it will be either a Renault Master or a Fuso eCanter.

$TC_{FleetLCT,n}$ is the fleet of LCTs needed to operate parcels that cannot be operated by cargo bike, i.e. parcels over 200 kg and/or parcels more than 2 km from the micro-hub (see *Vehicle Routing Problem*). Hence, $TC_{FleetLCT,n}$ depends on the number of micro-hubs.

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

$$TC_{S2,n} = \sum_i^n TC_{CB,i} + TC_{FleetLCT,n} \tag{2}$$

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.

3.2. Externalities cost

Externalities have been estimated using the recently updated French Handbook on the external costs of transport (CGDD, 2020) and are resumed in the Figure 2. The following externalities have been considering:

- CO₂ emissions;

- Local pollutants;
- Noise;
- Congestion;
- Insecurity;
- Infrastructure;
- Tax revenue (income).

For the CO_2 , eq emission factor for electricity production, the French annual average over 2021 was used, i.e. 53gCO_2 , eq/kWh.

Regarding congestion, it has been assumed that cargo bikes travel in the dedicated bike lanes and therefore do not create congestion. Furthermore, emission related to micro-hubs are not considered in this study.

Figure 2 highlights the important share of CO_2 and local pollutants in the social cost of a vehicle. Tax revenue correspond to the tax on fuel (called TICPE) that applies to conventional LCTs but is not applicable for electric vehicles currently in France (electricity is not included in the TICPE's perimeter). For the cargo bike, there is no criterion to integrate its insecurity, its share in congestion (use of bicycle lanes), its impacts on infrastructure nor its noise.

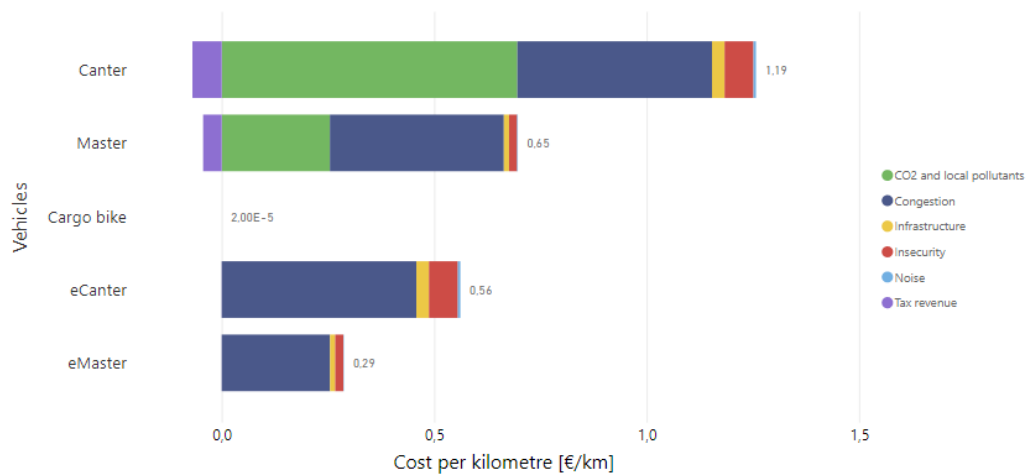


Fig. 2. Social cost per kilometer according to the type of vehicle

3.3. 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 (Hakimi, 1964). This discrete optimization model finds optimal locations for the terminals by minimizing the sum of the distances between these terminals (variable) and the delivery as well as pick-up points (input parameters).

In order to respect DB Schenker's current organization (i.e. operations in the north when compared to 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 territories (North and South) to find the optimal locations for the micro-hubs. 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.

3.4. Vehicle Routing Problem (VRP)

The VRP problem is solved with the Matlog package (Kay, 2016). The objective is not to calculate the distances traveled but to obtain the minimal number of vehicles needed to operate a given number of parcels, considering:

- The payload of the vehicles;

- The weight of the parcels;
- The number of operations per round (Table 1).

The fleet optimization is performed separately for cargo bikes and LCTs. 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. For LCTs, the calculation is made at the Paris scale. Parcels not handled by cargo bikes are grouped into two territories: North and South of the Seine. From these two territories, the optimal number of LCTs is calculated. This spatial division corresponds to the current organization of DB Schenker to operate in Paris.

4. Results

Figure 3 shows the evolution of the social cost and the share of parcels operated by cargo bikes of all scenario as a function of the number of micro-hubs and the social cost of operating with a fleet of thermal or electric LCTs.

First of all, it is not interesting to deliver all the parcels of Paris area by cargo bikes. The social cost would be greater than any type of LCTs fleet due to the total cost of ownership that increase with the number of micro-hubs.

The second result is that the social cost of a thermal LCTs fleet is 7% more expensive than the total social cost of an electric LCTs fleet.

The third result is that it is possible to set up a network of 4 micro-hubs (optimal location) performing 73% of the daily operations for a similar cost to the one with a 100% electric LCTs fleet. With more than 4 micro-hubs however, the network of micro-hubs and cargo bikes is more expensive than a traditional organization with a fleet of electric LCTs.

If we want to maximize the share of operations done by cargo bikes (with optimal location), beyond 10 micro-hubs, the gain of parcels operated by cargo bike for each new micro-hub becomes less than 2%. A network of 10 micro-hubs optimally located is sufficient. However, this results in a daily social cost increase of 20% compared to a fleet with 100% electric LCTs.

The final result is that the less expensive social cost is to operate with two micro-hubs that allow to operate 53% of the point by cargo bikes.

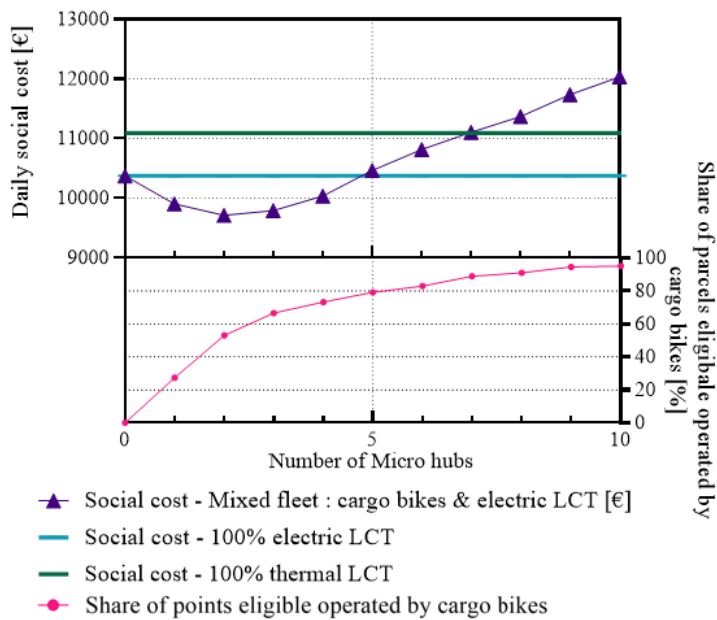


Fig. 3. Comparison of the daily cost of operating a solution with and without cargo bikes according to the number of micro-hubs

5. Discussion

This study shows that it is possible to operate a majority of parcels by cargo bike, and that it is feasible for carriers to operate a much larger share. However, trucks are still necessary within the city, either to supply the micro-hubs or to operate parcels that are too heavy for cargo bikes.

Secondly, this study emphasizes, once again, the importance of considering externalities, which considerably modify the social cost of each mode. An important result is that, when comparing social cost, the cheapest solution is to have 2 micro-hubs that allow to operate 53% of parcels deliver by cargo bikes. Furthermore, it is more economically interesting to have 3 micro-hubs than to deliver all parcels with any fleet of LCTs. However, the development of cargo bikes requires the provision of premises for micro-hubs in spaces that are currently saturated.

Moreover, in this study, the condition to operate a parcel by cargo bikes is the weight (200 kg max). 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).

6. Conclusion

The objective of this study is to compare the social cost within Paris of three different scenarios for the last mile:

- A fleet of thermal LCTs;
- A fleet of electric LCTs;
- Cargo bikes and electric LCVs fleet.

This study is based on DB Schenker's operating data. The first important result is that, when comparing social costs, it is cheaper to operate a part of the parcels via cargo bikes but not all of them, this result is in line with the study of the comparison of the operational cost (Robichet et al., 2022).

The social cost of electric LCTs is cheaper than thermal LCTs, however, when comparing the total cost of ownership, it is the opposite. This raises, once again, the question of a tax on polluting vehicles or an incentive for electric vehicles to help transporters switch to fewer polluting vehicles.

Concerning cargo bikes, it is interesting to note that their social cost and total cost of ownership are lower than those of LCTs. Moreover, their presence in the urban transport landscape is increasing. However, it seems that the availability of space for micro-hubs is low, which limits the development 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 to, first, supply the micro-hubs and, second, pick up and deliver oversize or overweight packages.

7. Acknowledgments

The authors especially thank Tariel Chamerois, Head of Sustainability - France & Maghreb - for DB Schenker for his supporting and trust in this project.

The authors would like to sincerely thank two anonymous referees for their useful comments.

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