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CONSEQUENCES OF LOGISTICS SPRAWL: ORDER OR CHAOS? - THE CASE OF A PARCEL SERVICE COMPANY IN PARIS METROPOLITAN AREA

Antoine Robichet¹ & Patrick Nierat¹

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Abstract

Logistics sprawl is the phenomenon driving warehouses and freight terminals further and further away from city centers, for reasons that are mostly dependent on urban planning, field price and economies of scale. In the past, studies have already described logistics sprawl in Paris Metropolitan area. These studies have concluded that logistic facilities far from Paris city center increased the distance traveled, and by extension, CO₂ emissions. This study does not question logistics sprawl in Paris metropolitan area but questions its consequences.

This study presents a point of view on the location of cross-docking terminals. One main parcel service carrier was studied through a database strong of 600,000 inputs including pick-ups and deliveries for two months in the Paris metropolitan area. This study is not intended to be representative of all merchandise flows but makes it possible to understand the running of one significant actor. This project aims at determining the optimum terminals location according to two criteria: minimization of the total distance as calculated by the Euclidean distance (as the crow flies) between terminals and points of pick-up/ delivery, and the number of authorized terminals. The number of terminals is modified to study its relationship with the spatial distribution of its clients.

Interestingly, we found that optimized locations for this parcel service carrier are located outside of Paris city center. Those locations minimize the total distance to the clients, and thus, are the best places to limit pollution. The reason is that the carrier manages this perimeter through a polycentric organization. Paris Metropolitan area is viewed as several sectors and not as a whole for this carrier. It is therefore unknown how the carrier's performance has evolved over time, but its current organization is close to the optimal situation.

Keywords: Logistics sprawl, cross-docking terminal, distance traveled, polycentric organization, parcel service, Paris metropolitan area

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Abstract

Logistics sprawl is the phenomenon driving warehouses and freight terminals further and further away from city centers, for reasons that are mostly dependent on urban planning, field price and economies of scale. In the past, studies have already described logistics sprawl in Paris Metropolitan area. These studies have also concluded that logistic facilities far from Paris city center increased the distance traveled, and by extension, CO₂ emissions. This study does not question logistics sprawl in Paris metropolitan area but questions its consequences.

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1. INTRODUCTION

Cross-docking terminals are a key step in the transport chain. Indeed, these terminals improve the performance of transporters by increasing the load factor of the trucks and display a link between the long distance and the last kilometer (Stephan and Boysen, 2011). The location of the terminals is an important issue. Should they be located on the outskirts to facilitate access for long-distance trucks, or close to urban centers to improve the delivery side? What factors should be taken into account when defining the optimal location for terminals? Some of these questions have been addressed in the literature under the theme "logistics sprawl".

Logistics sprawl is defined as "the spatial deconcentration of logistics facilities and distribution centers in metropolitan areas" (Dablanc and Rakotonarivo, 2010). This deconcentration has been observed in many cities such as Paris (Dablanc and Andriankaja, 2011), Atlanta (Dablanc and Ross, 2012), Los Angeles (Kang, 2018a), Seattle (Dablanc et al., 2014), Berlin (Hesse, 2004), Toronto (Woudsma et al., 2016), Tokyo (Sakai et al., 2015), Brussels (Strale, 2019) and Gothenburg (Heitz et al., 2018). Interestingly, few cities do not experience logistics sprawl such as in the Katowice conurbation, where anti-sprawl logistics is taking place because of its political history (Krzysztofik et al., 2019).

Logistics sprawl raises the question of the evolution of the location of logistics facilities over time. To address this question, most reports use the calculation of the average distance of terminals to the centroid of the terminals, the study of the evolution of the centroid, average distance Gini coefficient and location mapping. These methods have been summarized by He *et al.* (He *et al.*, 2018).

Logistics sprawl is mainly due to: land costs, which decrease with distance from the urban center (Hesse and Rodrigue, 2004; Verhetsel *et al.*, 2015), urban policies that do not encourage logistics companies to locate in city centers (Meitzen *et al.*, 2012) and the willingness of companies to achieve economies of scale by relying on mega hubs on the outskirts of town (Krugman, 1991). A majority of these points are grouped together in a literature review (Aljohani and Thompson, 2016; He *et al.*, 2018). A more recent study showed the influence of good category (Sakai *et al.*, 2018).

Paris metropolitan area has been the subject of several studies about logistics sprawl (Dablanc and Andriankaja, 2011; Dablanc and Rakotonarivo, 2010; Heitz and Dablanc, 2015). Logistics sprawl has been demonstrated multiple times in Paris metropolitan area and is not the object here. However, the studies conclude, among other things, that this sprawl causes an increase in the distance travelled and, by extension, an increase in CO₂ emissions due to delivery (Dablanc and Andriankaja, 2011; Dablanc and Ross, 2012). Studying the locations of logistic facilities using the evolution of the distance to the centroid (barycenter) over the years, the authors indeed concluded that the distance travelled has increased to deliver the center of Paris. They made the assumptions that all terminals deliver Paris' center and did not take into account the fact that a carrier can operate from multiple terminals in such a territory, each one with its own territory. However, several studies showed that the relationship between logistics sprawl and distance travelled is much more complex (Kang, 2020, 2018b, 2018a; Sakai *et al.*, 2019). Furthermore, demand is not taken into account, generally speaking, few studies are based on data from companies because they are rare (Kang, 2020). This study examines the relevance of positioning the terminals on the outskirts of the Paris metropolitan area and is based on the activity of one of the main couriers in this area. Based on its activity, it is possible to establish, via models, where its terminals would be optimally located.

It is to note that the models developed to analyze the location of terminals can be divided into two main categories. First, theoretical approaches aim at determining the influence of different parameters (warehouse cost, distance to the center, transport cost) (Combes, 2019). Secondly, decision support models are using genetic resolution methods (Bermúdez *et al.*, 1999), or fuzzy logic (Mousavi and Vahdani, 2016). However, these computer models for decision support system (DSS) require specific variables as delivery time slot, round scheduling, shipment size. Because we do not have time slot in this study, we chose the P-median model (Hakimi, 1964) which offers quality results (Rosing and Hodgson, 2002; Serra and Marianov, 1998).

The originality of this study lies in its approach: studying the location of the carrier's terminals from its demand. This study is based on the carrier's demand to determine the location of its terminals instead of studying the location of terminals without any information (only assumptions) on demand. In a second time, we compared results from the model with the current organization. To this end, we took advantage of the abundance of data from one of the main players in the French parcel delivery industry, *DB Schenker*. Analyzing a database of its activity in the Paris metropolitan area made it possible to define where terminals should be ideally located to optimize freight transport in Paris area.

2. MODEL PRESENTATION

This section provides a brief presentation of the Paris metropolitan area and the parcel service business. Then, the geographical distribution of the company's activity is analyzed. Finally, the selected model and assumptions are explained.

2.1. Paris metropolitan area

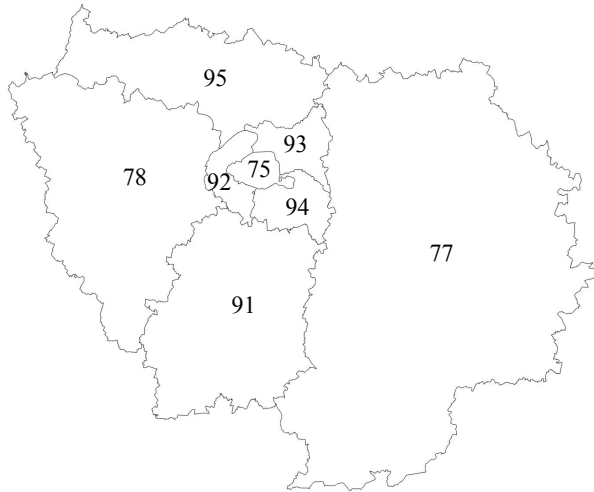


Figure 1 – The departments of Paris metropolitan area, MATLAB

Paris metropolitan area is the most populated region in France (12 million inhabitants) and has the particularity of containing the capital, Paris. 30% of the French Gross Domestic Product are generated in this region.

The region is composed of 8 departments: Paris (75), Essonne (91), Hauts-de-Seine (92), Seine-Saint-Denis (93), Seine-et-Marne (77), Val-de-Marne (94), Val-d'Oise (95) and Yvelines (78) (Figure 1). The first ring contains the departments 92, 93 and 94. The second ring is composed of the departments 77, 78, 91 and 95.

2.2. 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 use subcontractors). The goods transported generally weigh between 1 and 500 kg. The average weight in our database is 105 kg (Table 1). As far as volume is concerned, shipments are generally limited to 3 pallets. Beyond that, it is generally more attractive to use LTL (less than truckload) service.

Parcels are collected via rounds and transported to cross-docking terminals. From there, parcels are transported to the final terminal by heavy goods vehicles making long-distance connections (tractions). It is possible to transit through different terminals before reaching the last one. Once reached, the parcels are integrated into rounds to be transported to the recipients. Deliveries and pick-up are integrated in same rounds. This operation is summarized in Figure 2.

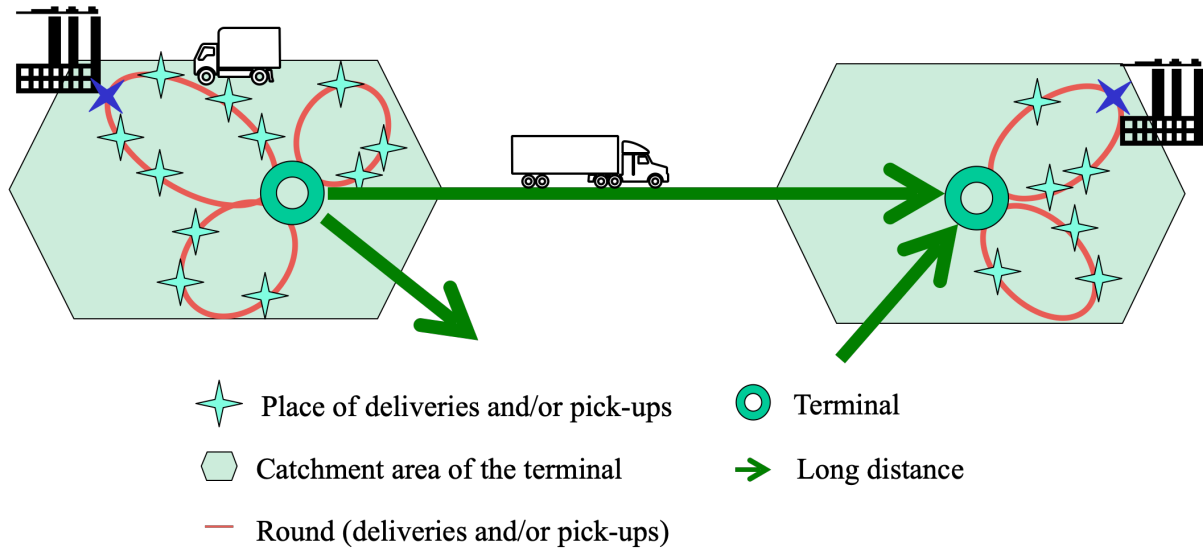


Figure 2 – Diagram of the operation of a parcel service carrier company

The following part focuses exclusively on understanding the functioning of the company studied in this paper, *DB Schenker*, which is the second largest parcel company in France after the *Geodis* group (Faibis, 2020).

At the national scale, *DB Schenker* is composed of a general management which deals with national issues and 81 local agencies spread over the French territory. An agency consists in a terminal (where logistics operations are carried out) and an office. The office ensures the correct functioning of the agency and also has a sales team whose objective is to maintain the link with existing customers and to approach new customers for the agency. The decentralisation of the sales department within the agencies reinforces the local appeal around the agencies.

2.3.Data

The database comes from an extraction of 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, date and time of pick-up, name and address of sender and recipient, 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).

	Deliveries	Pick-ups
Average weight [kg]	112	98
Median weight [kg]	54	52
Number of customers	25,095	7,707
Number of large customers (>100 shipments)	467	454
Geocoding accuracy		
address	260,024	291,349
city	11,268	20,612
Stock	271,292	311,971

Table 1 – General information of *DB Schenker* in Paris metropolitan area, geocoding via address.data.gouv.fr

In total, 39,637 shipments come from Paris Metropolitan area and go to Paris Metropolitan area. They represent 16% of deliveries and 13% of pick-ups and they appear in both tables (deliveries and pick-ups).

The first problem to be solved was geocoding. Indeed, the addresses entered by the users were not perfectly filled in. Thus, we chose to use the geocoding tool provided by the French state (address.data.gouv.fr). 95% of the addresses have been geocoded to address accuracy². When it was not possible to geocode the address, we assigned the selected point to the town hall of the city of the place of delivery or pick-up³ (5% of the cases). The excellent results obtained gave us an overview of DB Schenker's activity in the area.

Furthermore, for this study, the Euclidean distance (as the crow flies) was used. Firstly, this allowed a significant simplification of the calculations and did not induce a significant bias (Boscoe et al., 2012; Buczkowska et al., 2019). Secondly, Paris metropolitan area has an extremely dense roads' network which decreases the bias of the Euclidean distance. Moreover, Euclidean Distance was used in most of the studies dealing with logistic sprawl (Dablanc and Andriankaja, 2011; Dablanc and Ross, 2012; Heitz et al., 2019, 2018; Sakai et al., 2017, 2015).

2.4. Subject of study

In Paris metropolitan area, *DB Schenker* supplies its customers from five terminals (Figure 3). Four terminals are for national traffic and one terminal is dedicated to deliveries from abroad (E).

Figure 3 represents only the deliveries (the round ID for pick-up is not available). Even though, deliveries and pick-up are carried out in the same tour, studying Figure 3 is sufficient to understand the spatial organization of *DB Schenker* in the area.

For national traffic, each one of the four terminals manage a territory that is easily identifiable in Figure 3. It highlights the polycentric organization of *DB Schenker* in the area. The region is divided into 4 geographical sectors, each terminal having its own sector. The city of Paris is divided into two parts: north of the river Seine is handled from terminal D; south of is handled from terminal B. The rounds are organized by grouping of communes and by districts in Paris.

² A check was made by calculating the distance between the geocoded point and the town hall (use of national table). If this distance was greater than 3 km, the geocoding of the point was checked manually and if the geocoding was not considered as sufficient, the point was manually geocoded.

³ Paris metropolitan area is composed of 1,276 communes (one town hall by commune) for a total area of 12,012km². So, the average area of a commune is 9.4 km². The geocoding error at the town hall accuracy is therefore a few km maximum.

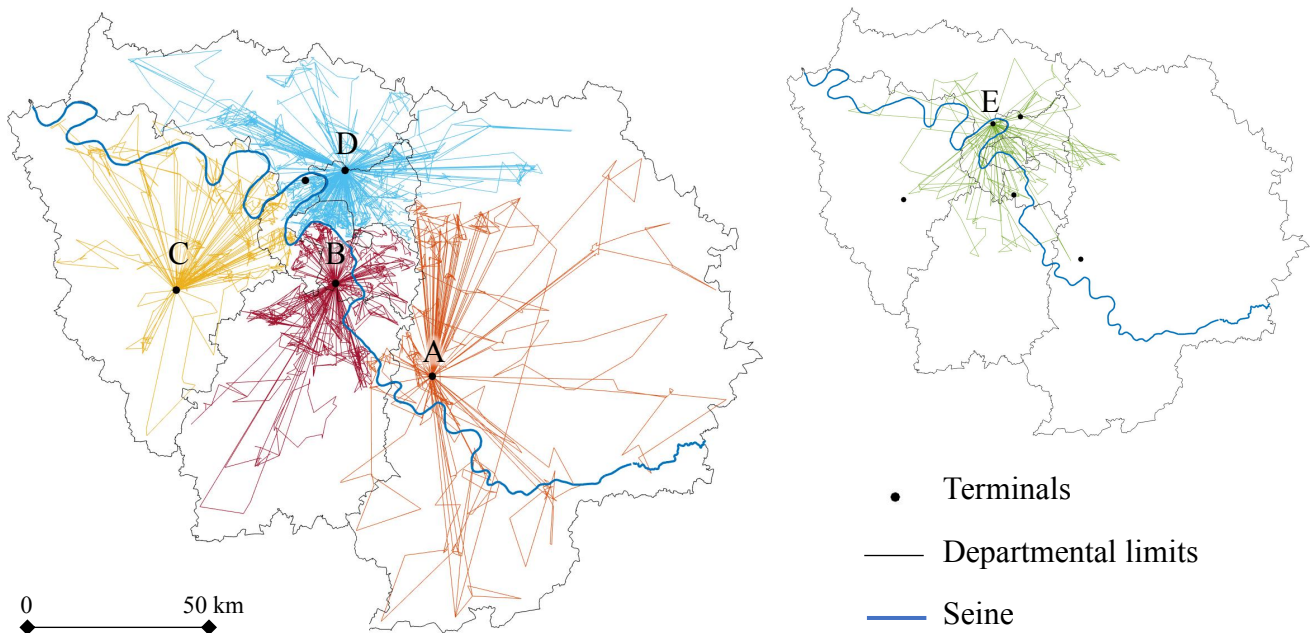


Figure 3 – Reconstruction of rounds for national (left) and international (right) deliveries on 01/23/2018 in Paris metropolitan area from the database, MATLAB

Interestingly, natural geographical divisions, as the river Seine, are tackled by polycentric organizations (Figure 3).

On average, 5,430 deliveries are everyday performed during 331 rounds (16.4 deliveries per round). The distance between 2 delivery points is 1.8 km (Euclidean distance). The time between two points is 18.6 minutes. With an average weight of 112 kg per delivery, the average load of a round is 1.8 metric tonne for deliveries. This weight can be explained by *DB Schenker's* commercial positioning, which is more B2B⁴ than B2C⁵ oriented.

Terminals	Deliveries	Pick-ups
A (77)	39,893 15%	56,079 18%
B (94)	85,124 31%	95,251 31%
C (78)	37,765 14%	45,177 14%
D (93)	92,160 34%	113,856 36%
E (92)	16,350 6%	1,608 1%
Total	271,292	311,971

Table 2 – Number of deliveries and pick-ups per terminal

In the following, we will only consider the national activity operated from the 4 corresponding terminals. This choice is justified by the fact that terminal E has a specific role (international traffic) and represents only an extremely small part of the activity, less than 6% of deliveries and 1% of pick-ups (Table 2).

Furthermore, the regional terminals are connected to the national network, which corresponds to 81 terminals in France. The network generates 1,454 long-distance tractions every day.

2.5. Geographical distribution

The spatial distribution of customers is given in Figure 4. The scale is logarithmic because the densities vary in a ratio from 1 to 30,000 operations by cell (2.5 km² grid).

⁴ Business to business covers commercial transactions between two companies.

⁵ Business to consumer covers commercial transactions between a company and a consumer

The first noteworthy observation is that pick-ups outnumber deliveries for this player in Paris metropolitan area⁶. It can be easily explained by the presence of companies sending numerous small parcels (e.g. wholesale kitchen equipment seller and publishers according to the database). The first four senders represent 22.2% of pick-ups (69,344 shipments). Comparatively, DB Schenker counts 7,707 senders over the studied period.

More broadly, pick-ups account for 311,971 points. They are spatially gathered around poles with very high densities. The particularity of these poles is that they are located in the first and second rings of the area. Those high densities are due to few companies generating significant flows. In addition, pick-ups are mostly located near major roads and more particularly at crossings.

Deliveries account for 271,292 points. Unlike pick-ups, the low density over a large part of the territory reveals a spatially dispersed demand. Within Paris, the density is significantly higher. However, this represents 22% of deliveries and only 10% of the entire activity (pick-ups and deliveries) in Paris metropolitan area.

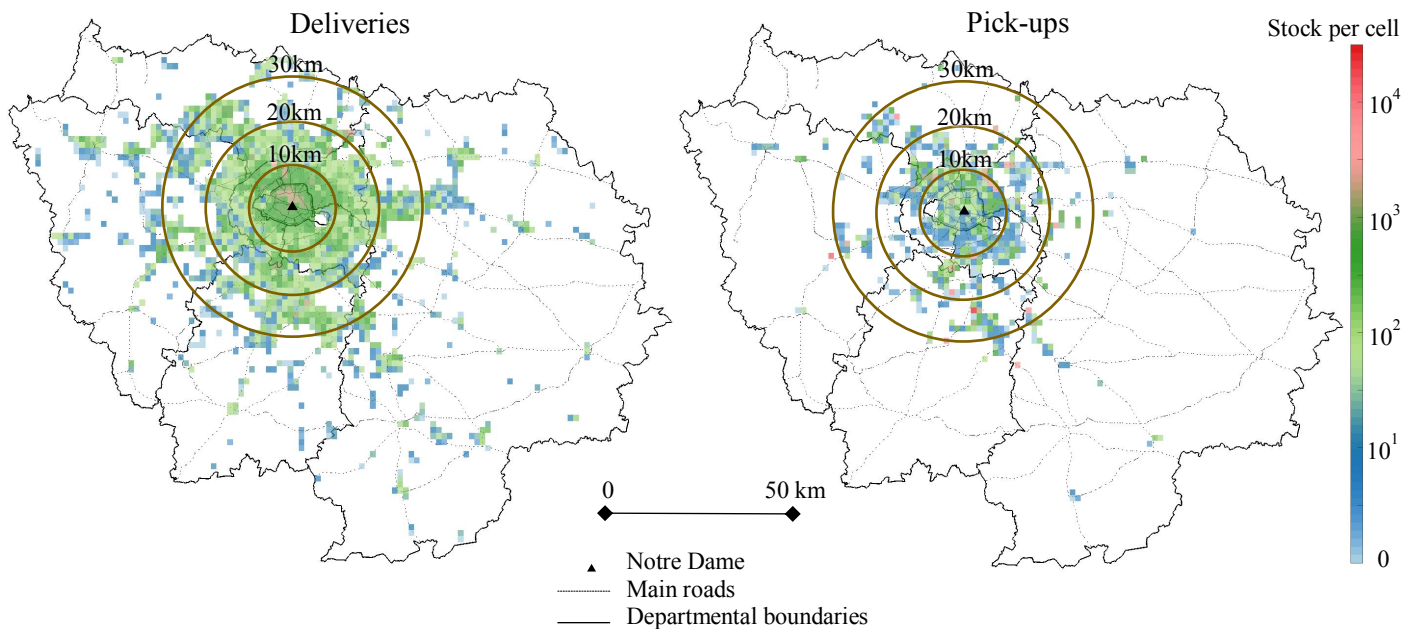


Figure 4 – Density of deliveries (left) and pick-ups (right) for two months, 2.5 km² grid, MATLAB

Figure 5 gives the distribution of deliveries and pick up depending on the distance to the center of Paris (Notre-Dame). For deliveries, Paris and the inner suburbs account for a significant proportion of the activity, which then decreases with distance. For pick-ups, activity is low within Paris. It increases to peak up to 20-25 km and then decreases.

⁶ Other studies showed a lower share of movements for pick-ups (33%) than deliveries (56%) and 11% combined (Toilier et al., 2016). Movements are stops of vehicle whatever the number of shipments. For us the unit is the shipment. Results are not in opposition but come from two different methods of observation.

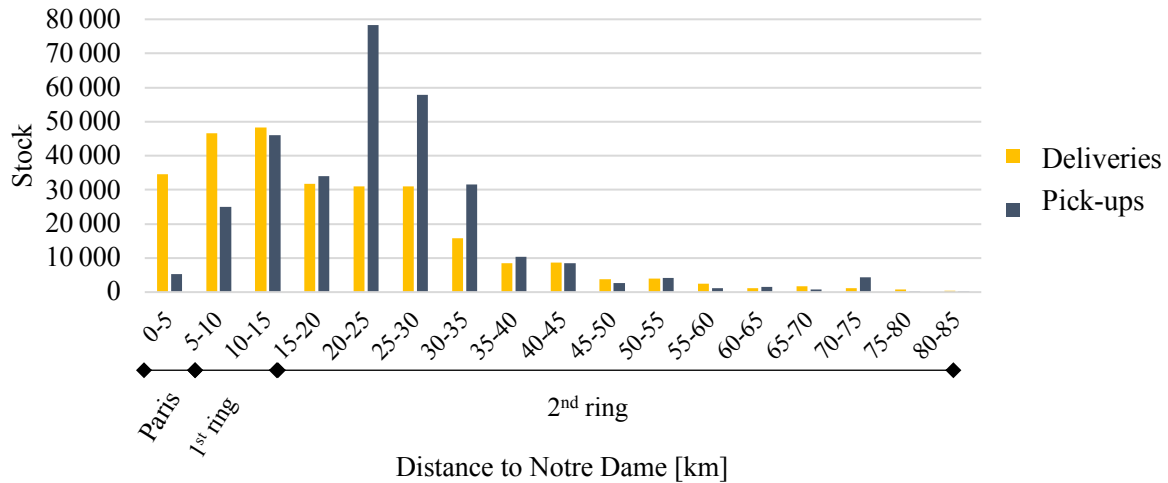


Figure 5 - Number of deliveries and pick-ups according to the distance to Notre Dame

2.6.Model

Knowing the carrier's activity, the question is whether or not it would be possible to optimize the location of its terminals. The model used to find these locations was the one developed by Kay in the Matlog package (Kay, 2016). The algorithm is based on the P-median Model (Hakimi, 1964). It is a discrete model for finding optimum locations by minimizing the sum of the distances between the terminals (variable) and the deliveries as well as pick-up points (input parameters). The following assumptions have been retained:

- Euclidean distance;
- Land price ignored;
- Existing infrastructures and buildings not taken into account;
- No construction of the rounds in the minimization (congestion ignored).

This model was chosen over other more complex models because, firstly, we did not have all necessary information to implement them (among the missing information, the delivery and pick-up time slots). Secondly, the P-median handle easily large number of data.

Optimized locations were calculated considering all points (delivery and pick-up). We were not able to take in consideration rounds as we did not have access to the necessary information required to rebuild the rounds. For example, we did not have the time slots that are very constrained for some customers (both for deliveries and pick-ups); besides, building unrealistic rounds does not make sense

To ensure that the set of locations found was the global solution and not a local solution, the algorithm was run 20 times for each set of parameters. Other studies have used a similar approach (Euclidean distance and P-median model) to define optimal locations (Rosing and Hodgson, 2002). One applied study using the same model was for the determination of optimum localization of fire places in Barcelona (Serra and Marianov, 1998).

3. RESULTS

The simulation provided two types of results: the relationship between the average distance and the number of terminals as well as the best location.

3.1. Relevance between the number of terminals and the average distance

Figure 6 shows the results of the modelling (P-median algorithm). The current situation of DB Schenker for national traffic (4 terminals) is called S0. The optimized situation (current terminals with points reallocation) is called S1. A change in the allocation of points to the terminals would reduce the average distance by 2 km. Finally, the model outputs are grouped together under the name Model. The calculations were made for 1 to 10 terminals.

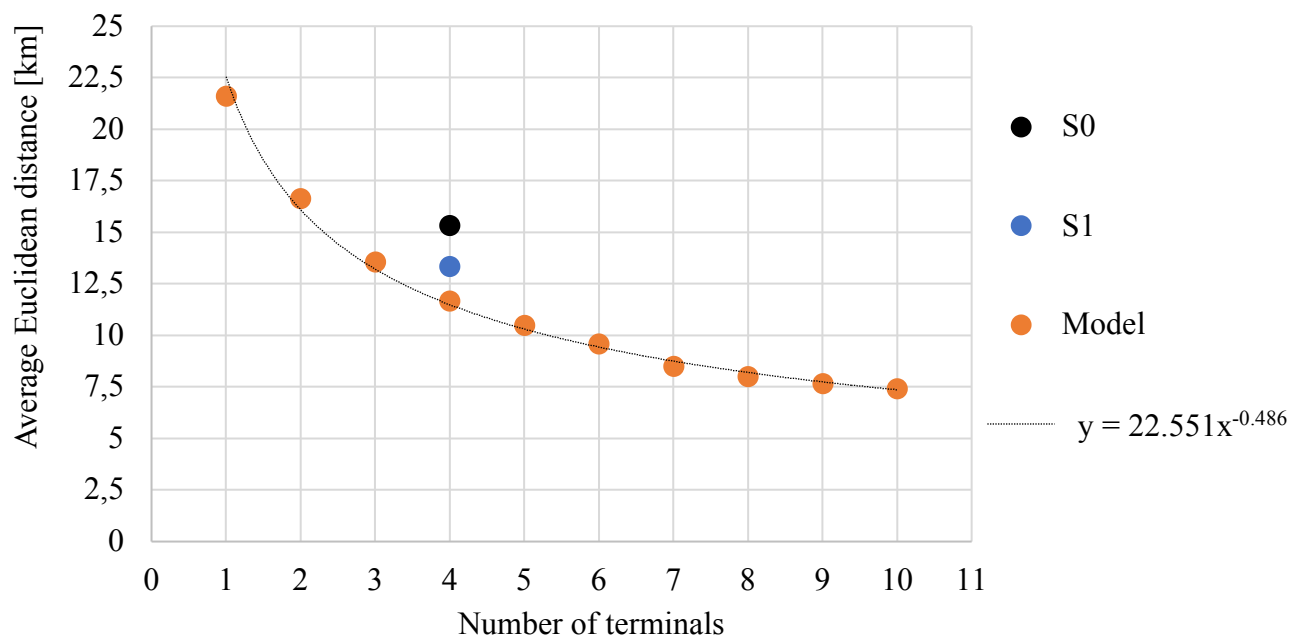


Figure 6 - Average distance (Euclidean distance) between the terminals and the delivery and pick-up points determined by the P-Median model

The average distance tends towards an asymptote. From 5 terminals, the average distance decreases by less than one kilometer when one terminal is added.

Moreover, scenario S1 gives results close to the model (1.6 km difference) which confirms the good location of the current terminals.

The results for deliveries and pick-ups are quite the same. With the same model, ideal locations for only deliveries and only pick-ups were determined. Table 3 shows that studying the activity as a whole or the two activities separately has little effect on the results. Moreover, an optimization oriented towards pick-ups or deliveries does not greatly reduce the distance. These results incense the strength of the overall results.

Number of terminals	4	5
Current situation (S0)	15.3	-
Reorganisation with same terminals (S1)	13.3	-
Global model	11.7	10.5
Pick-ups	11.2	10.0
Deliveries	12.2	11.1
Optimized for pick-ups only	11.0	9.2
Optimized for deliveries only	11.9	10.8

Table 3 - Average distance [km] between terminals and delivery and pick-up points under different criteria

3.2. Location of terminals

The optimal location of the terminals is given in Figure 7. As the current organization includes 4 terminals, the model has been used for 4 and 5 terminals.

With 4 terminals, the model does not provide a terminal within Paris. The second ring hosts 3 terminals out of 4.

Moreover, 3 of the 4 theoretical terminals are close to those of *DB Schenker*. The 4th is located east of Paris. *DB Schenker* opened a new terminal in Serris (77) close to this theoretical location in summer 2019 which may lead *DB Schenker* to give up the terminal A (south east).

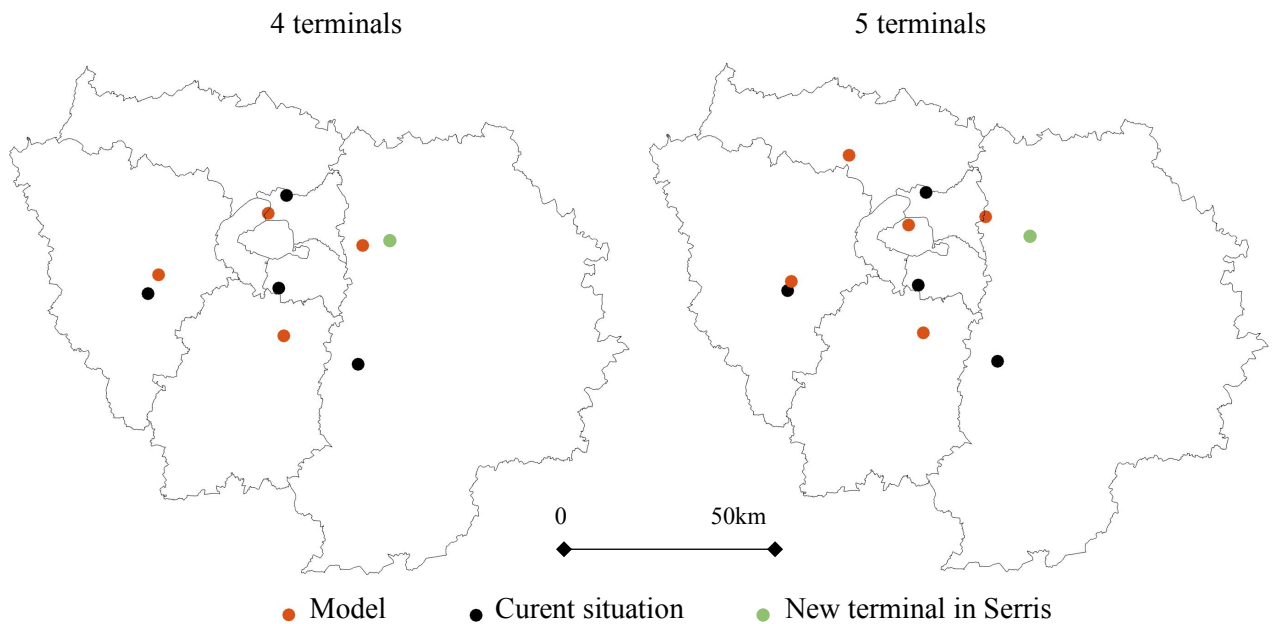


Figure 7 – Current location of terminals (black) and optimization results (orange) for 4 and 5 terminals, MATLAB

With 5 terminals, there is one terminal on the northern border of Paris and the others are located in the second ring.

An examination of the optimal locations, distinguishing between deliveries and pick-ups, shows a more contrasted situation (Figure 8). To the south and the east, the terminals are close to the global optimum; to the west, the optimal location for pick-ups is close to the global optimum, but the optimal location for deliveries is furthest north; to the north, the optimal solution for deliveries is within Paris, while the optimal solution for pick-ups is shifted

northwards. Generally speaking, the optimum terminals for deliveries are closer to the center of Paris (Notre-Dame) with an average distance of 16.5 km, whereas the optimum location for pick-ups is further away (22.7 km). For the global optimization, the distance is 20.6 km.

Then, the location of terminals is dependent on deliveries/pick-ups, but the carriers cannot have separate terminals for processing activities separately.

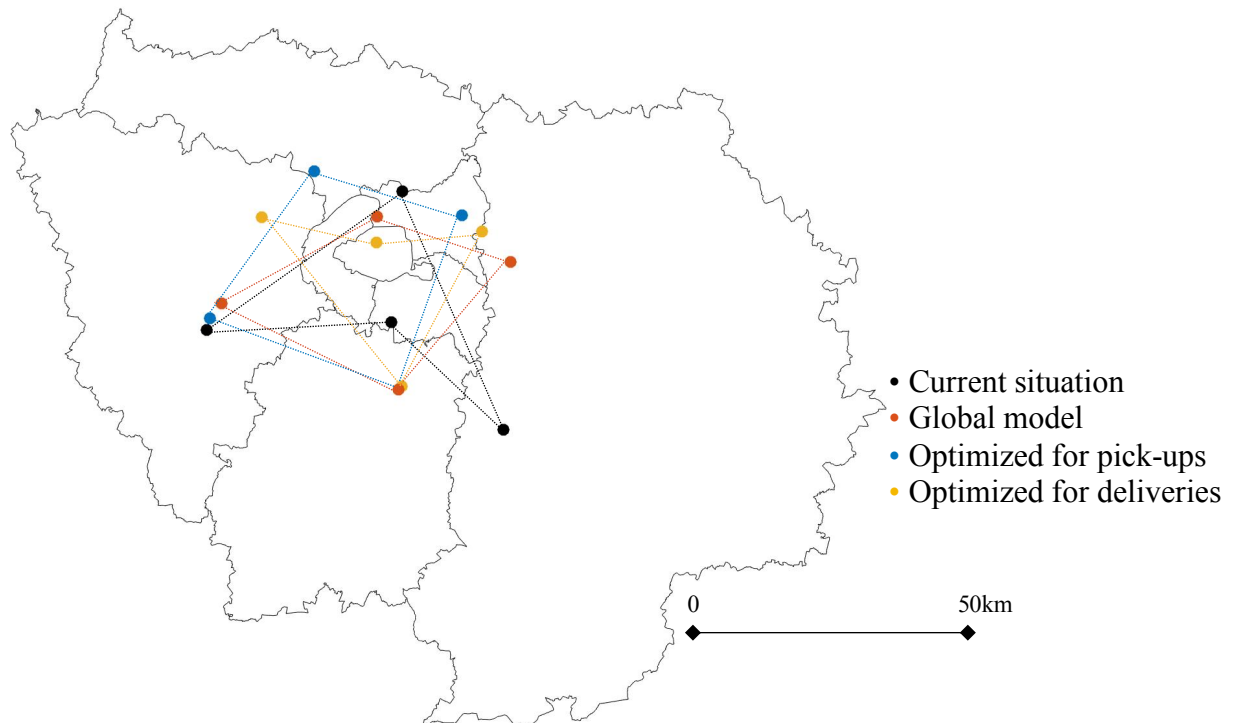


Figure 8 - Current location of terminals (black), global results (yellow), optimized for deliveries (orange) and optimized for pick-ups (blue) for 4 terminals, the lines are here to allow a better reading MATLAB

Thus, for *DB Schenker*, the location of the terminals corresponds to the minimization of the total distance. These results do not take into account the land price for the terminals. To go further, we would have to compare the cost of the terminals to the savings achieved by being closer to customers. We would also have to integrate long-distance service. This last point also impacts the decision on the number of terminals in a Parisian area. Having a large number of terminals in the Paris metropolitan area would result in more tractions to connect them to the national network.

4. DISCUSSION

Logistics sprawl is an important phenomenon that is profoundly changing the major metropolises on a global scale. The results for *DB Schenker* give rise to discussions on three levels: the relevance of the model's results to the company's current location; the influence of activity on the location of terminals and a new perspective on the consequences of logistic sprawl.

The first major result is the coherence between the company's organization and the model's outputs. The current locations of the terminals are close to the ones calculated. This underlines the fact that a company adopts an organization optimized for its activity. One

important aspect of the organization is polycentrism. To serve the Paris Metropolitan area, the carrier uses several terminals, each with its own territory. The greater the number of terminals, the closer the customers are. However, the number of terminals is limited by their cost. If there were only deliveries, the terminals would be closer to the center, but with the whole activity (pick-ups and deliveries), the terminals move away from the center of Paris. In addition, we observe that an optimized allocation of the delivery and pick-up points to the existing terminals allowed a gain of 2 km (S1) and a relocation allowed an additional gain of 1.6 km (S2). However in a tour of 16.4 deliveries (average number of deliveries per tour), the gain for S1 is not 32.8 km (16.4×2 km) but only 2 km for the first leg and 2 km for the last one of the tour. Thus, there is a real consistency between the outputs of the model and the current situation.

Secondly, many clients (especially large customers) are located close to terminals. Geographic proximity gives an advantage over competitors (e.g. a later pick-up time). In addition, the presence of a sales team in each terminal emphasizes this process and highlights the strategy of local implementation. This explains why pick-up peaks are close to terminals. Deliveries do not lend themselves to the same control, which explains their dispersion.

Finally, for parcel service carriers, Dablanc and Rakotonarivo (2010) have shown that the terminals are moving away from the center of Paris (their barycenter moves from 11 km) and that they are more numerous. These authors concluded that this induces longer distances to serve customers leading to increased pollution, which is presented as a form of chaos. In reality, their calculations⁷ only concern the servicing of the center of Paris, assuming that all the 90 terminals, identified by Dablanc and Rakotonarivo, serve Paris, even if they belong to 16 companies (Dablanc and Rakotonarivo, 2010). We have shown that when the organization of carriers is polycentric, only some terminals serve the center of Paris. Then, taking into account that the aim of a carrier is to optimize its activity for the whole territory and not only for Paris, it is not certain that logistic sprawl worsens the situation. However, this study does not refute the previous studies but provides an alternate perspective.

5. CONCLUSION AND FURTHER WORK

The novelty of this study is based on the activity of a carrier, DB Schenker. The spatial distribution of its activity (pick-ups and deliveries) allowed to test the localization of its terminals. We have shown that the current organization appears to be close to the results of the situation with a reduction in the total distance between its customers and the terminals. For the carrier, the current organization is near to minimize the access to its clients and therefore its CO₂ emissions. This is due to the polycentric organization.

The centroid (barycenter) method used to assess the consequences of logistic sprawl does not take into account two characteristics: the polycentric organization of parcel carriers nor the spatial distribution of demand. Our study does not allow us to measure an evolution over time, but it underlines the importance of these two characteristics.

When the carrier has four terminals, none would optimally be located within Paris. There would be one if only deliveries were considered, but since there are deliveries and pick-

⁷ The calculation takes into account the emissions emitted by the average fleet of round trucks to travel twice (round trip) the increase in the distance to the barycenter to deliver central Paris.

ups, the optimal terminals are located outside Paris. This does not mean that the carrier does not need a facility in Paris, but only one that cannot be a large terminal directly connected to all other national terminals. It could be a satellite terminal connected only to some terminals around Paris which would then organize the last mile by cargo bike for example.

To complete this work and calculate the optimal number of terminals for the company, it would be necessary, on the one hand, to compare the cost of adding a terminal with the savings associated with bringing customers closer together and, on the other hand, to integrate the cost of long-distance tractions, which increases with the number of Parisian terminals.

This work is based on the situation of *DB Schenker*. The other major parcel companies (*Géodis*, *Heppner*, etc.) operating national traffic also have several terminals around Paris and present the same characteristics (own spatial distribution of pick-ups and deliveries, optimization of their activity, etc.). As a consequence, some of our conclusions may apply to their situations (i.e. coverage of the territory via a polycentric organization, the importance of pick-up on the terminals' network, presence of pick-ups peaks in each company's clientele and logistics sprawl does not always worsen the situation). Further work would be needed to verify this.

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