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Which parts of their transport chain can carriers and shippers shift to decarbonized modes ?

Antoine Robichet

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Université Gustave Eiffel

École Doctorale Ville, Transport et Territoires

Laboratoire SPLOTT – AME

**WHICH PARTS OF THEIR FREIGHT TRANSPORT CHAIN CAN CARRIERS AND SHIPPERS SHIFT
TO DECARBONIZED MODES?**

Antoine ROBICHET

Thèse de doctorat en Transport

Thèse dirigée par François Combes et sous l'encadrement de Patrick Nierat

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Abstract Summary

On a French scale, road freight transport accounted for 17% of CO₂ emissions in 2018. In fact, road transport is the predominant mode and represents 88% of total flows in 2018 (in t.km). In order to make a successful transition to a low-carbon economy, a sustainable solution is to transfer part of these flows to other modes with little or no carbon emissions.

To study this, a monograph of a actor: DB Schenker, with case studies on certain points from other actors (carriers and shippers), has been conducted to analyze its entire transport chain. This work is based on operational databases that make it possible to explain the global system with precision and then to evaluate the impact of a modal shift for a actor. Two solutions were studied: cargo bikes for the first and last kilometers, on the one hand, and railways for the long distance, on the other.

The study of a carrier's operations shows that the bundle of operations is not just about the link between long-haul networks and the first and last mile. It is a complex bundle in which each element is intertwined: within the long-distance network, routings are scheduled to allow a parcel to take several connections in one night; on the first and last mile side, carriers implement a strategy of polycentrism to operate in large areas resulting in optimal locations of platforms on the outskirts of cities.

The study on the location of the platforms having underlined the interest of locating them on the outskirts of the center, the use of cargo bikes relies, therefore, on the establishment of micro-hubs. However, this real estate cost must be compensated by the lower operational cost of cargo bikes compared to trucks, provided that the density is high. In a way, this work provides a link between the literature on vehicle fleet choices and the one on logistics real estate. This being said, the use of cargo bikes does not mean the end of trucks in the city: they will still be necessary to supply micro hubs as well as to operate parcels that cannot be operated by a cargo bike.

The two-stage study of combined transport shows, first of all, a mismatch between the current offer in France and the expectations of a parcel service, both from an organizational point of view and from the point of view of spatial coverage. Leaving aside the economic constraint, it would be possible to transfer only 0.2% of daily trips. In a second step, the study

of a consortium of 9 companies (shippers and carriers) has highlighted the need for mutualization to allow the trains to be fully filled. This makes it possible to increase the flows on the axes and thus to increase the number of rotations, so that the manufacturers do not have to modify the organization of their supply chain. However, it has been shown that pooling can lead to a win/lose situation when viewed at the level of the actor from an economic point of view, even though the operation is interesting overall.

Overall, this work on freight transport highlights the value of adopting a actor-by-actor approach for a more detailed understanding of certain situations in order to remove the obstacles to collective benefit. It therefore provides a complementary vision to studies based on public statistics and global views. Without contradicting them, it can sometimes drastically modify the conclusions, demonstrating that a global optimization can lead to a deterioration for one of the actors to be mobilized and thus allowing the identification of the points to be addressed in order to meet the challenges of decarbonization.

Résumé court

A l'échelle française, le transport routier de marchandises représente 17% des émissions de CO2 en 2018. En effet, ce dernier est le mode prédominant de transport et représente 88% des flux totaux. Pour réussir la transition vers une économie décarbonée, une solution durable consiste à transférer une part de ces flux vers d'autres modes peu ou pas carbonés.

Afin d'approfondir ce point, la monographie d'un acteur majeur du secteur : DB Schenker a été réalisée permettant d'analyser l'ensemble de sa chaîne de transport. Certains points ont été approfondis *via* l'étude d'autres transporteurs et chargeurs. Ce travail s'appuie sur des bases de données opérationnelles importantes (millions d'envois) qui permettent d'explicitier le fonctionnement global avec précision puis d'évaluer de manière précise l'impact d'un report modal pour chaque contributeur. Deux solutions ont été approfondies : le vélo cargo pour les premier et dernier kilomètres, d'une part ; et le ferroviaire pour la longue distance, d'autre part.

L'étude montre que la chaîne d'un transporteur, ne peut se résumer au lien entre réseaux de longue-distance et premiers et derniers kilomètres. Il s'agit d'opérations complexes et multiples entremêlant plusieurs éléments : au sein du réseau de longue-distance, les routages sont organisés en segments connectés permettant à un colis de prendre plusieurs connexions en une nuit ; du côté du premier et dernier kilomètres, les transporteurs mettent en place une stratégie de polycentrisme en optimisant un réseau de plateformes localisées en périphérie des villes lorsqu'elles sont importantes.

L'étude sur la localisation des plateformes ayant souligné l'intérêt de les localiser en périphérie du centre, l'utilisation de vélo cargo suppose, de ce fait, de compléter ce dispositif par des micro-hubs. Cette logique a un coût, notamment foncier, qui peut-être compensé par le coût opérationnel plus faible des vélos cargo en comparaison à l'utilisation de camions, sous réserve d'une forte densité d'opérations. Ainsi, ce travail permet de faire le lien entre la littérature traitant des choix de flottes de véhicules et celle portant sur l'immobilier lié à la logistique urbaine. Ceci étant, l'utilisation des vélos cargo ne signifie pas la fin des camions en ville : ils seront toujours nécessaires pour approvisionner les micro hubs ainsi que pour opérer les colis rencontrant les limites de taille et de poids pour un transport par vélo cargo.

L'étude, en deux temps, du transport combiné montre, tout d'abord, une inadéquation entre l'offre actuelle en France et les attentes d'un messenger tant d'un point de vue organisationnel que de couverture spatiale. En ne prenant en compte que les contraintes temporelles, il n'est possible de transférer que 0.2 % des trajets quotidiens.

Dans un deuxième temps, l'étude d'un consortium de 9 entreprises (chargeurs et transporteurs) a permis de mettre en lumière la nécessaire mutualisation pour remplir pleinement les trains. Cela permet en effet d'augmenter les flux sur les axes et ainsi d'augmenter le nombre de rotations afin que les industriels n'aient pas à modifier l'organisation de leur supply chain. Cependant, il a été mis en évidence que la mutualisation est globalement intéressante mais peut se traduire, à l'échelle d'un seul acteur, comme une dégradation de sa performance économique. Un jeu de gagnant/perdant à l'échelle des acteurs se met en place pour une opération globalement intéressante.

Dans son ensemble ce travail, portant sur le transport de marchandises, met en avant l'intérêt d'adopter une approche par acteur pour une compréhension plus fine de certaines situations afin de lever les freins au bénéfice collectif. Elle apporte donc une vision complémentaire aux études s'appuyant sur des statistiques publiques et des regards globaux. Sans s'y opposer elle peut parfois en modifier drastiquement les conclusions démontrant qu'une optimisation globale peut induire une dégradation pour un des acteurs à mobiliser et permettant ainsi d'identifier les points à lever pour répondre aux enjeux de décarbonation.

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INTRODUCTION

As a result of the climate emergency, decarbonization is one of the main challenges for freight transport and requires a radical reduction in greenhouse gas (GHG) emissions. It is in this context that the objective of carbon neutrality in 2050 was determined at the European level and then applied at the national level (*Projet de la stratégie nationale bas-carbone*, 2020). In France, road transport (passengers and goods) is the sector emitting the most CO₂ with 38% of French emissions in 2018 before the crisis COVID-19 (INSEE, 2019). While most of these emissions are caused by private cars, 45% are caused by road freight transport. In fact, the mode share of road freight transport has been stable at around 89% of t.km since 2010 (excluding oil pipeline and light commercial truck traffic, i.e. vehicles with a loaded weight of maximum 3.5t). Over the same period of time, despite a slight rebound in 2015, the mode share of rail hovers around 10%. However, the transport of goods is an essential activity for the proper functioning of a country. Without freight transport, factories are no longer supplied with raw materials, goods are no longer transported to cities, etc.

In order to achieve this ecological transition, the French government recently launched a 100-billion-euro strategy for rail transport (passenger and freight). In the announcement speech¹, the French Prime Minister, Elisabeth Borne, described freight transport as a sector that "represents a significant share of emissions". To decarbonize it, she announced "decarbonization through the modernization of the rail network [...], but also investments for the regeneration of the waterway network, for the modernization of the major ports and by facilitating connections between the different networks". The proposed actions for decarbonization of freight transport focus on the supply side of transport and presents freight

¹ <https://www.publicsenat.fr/actualites/politique/le-plan-ferroviaire-a-100-milliards-d-euros-est-accueilli-avec-vigilance-au>, translation from the author

transport as a single entity, without any subdivisions. This speech is part of a broader vision of freight transport that suggests that to reduce its ecological impact, it would be enough to increase the loading rate of trucks, to develop rail and waterway supply to increase the modal share of the latter, to encourage actors to pool their flows, to slow down the pace of production lines, etc. (Fisher *et al.*, 2022). However, this vision overlooks the fact that freight transport is first and foremost an interaction between actors with different objectives evolving under multiple constraints in a complex and constantly changing environment. If the focus is on carriers, they do not develop randomly, they will seek to optimize the size and vehicles of its fleet as well as the number and location of its platforms to best meet the requirements (size of packages, transport time) of its customer portfolio. Based on its fleet and infrastructure, a carrier will then design and implement a transport plan, again with the objective to meet the requirements of its customers. Thus, by construction, carriers will specialize in certain types of goods and customer locations adapted to his organization.

More generally, freight transport is an activity that consists of moving an object from point A to point B. This simple definition hides the complexity of the different components that make it up: operational constraints, economic cost, the chain of outsourcing, the different modes that can be used and the environmental cost. In addition, the economic situation (demand increasing faster than the capacity of carriers to increase their transport capacity) is currently favorable for the freight transport sector, which traditionally suffers from structurally strong competition. Thus, the price of transport increased by 3% in 2019 in France (CGDD, 2019; Faibis, 2020). This situation, temporarily favorable to private investments – despite the operational difficulties due to the Covid19 crisis, was then challenged by the energy crisis that has affected France since the end of 2021 (with the effect of a significant increase in the price of fuel), which directly reduces the margin of carriers.

From the carriers' standpoint, the additional costs that these trends generate can be partially absorbed by consolidation, i.e., the possibility of transporting together, as much as possible, different shipments with distinct origins and destinations and thus using large vehicles to transport a set of small quantities over a part of the journey. It is in fact a long term, even constant strategy of freight carriers to transport distinct shipments together, as much as possible, to achieve cost efficiency. However, consolidation requires platforms to perform load breaking, sorting and reloading. Therefore, the location and number of these

platforms contribute, among other things, to the objective of organization and consolidation (Stephan and Boysen, 2011). Too many platforms will limit the possibility of massifying flows but will increase proximity to customers, and vice versa. In addition, there is the issue of modal choice, as the location of the platforms must allow for the use of the chosen mode. For example, in France, the choice of road transport allows carriers to set up fine grid, with different platforms linked by direct road routes. The rail and inland waterways modes do not have the same spatial coverage; and both need important flows to reach cost efficiency, as their vehicle capacity is much higher than that of trucks. These thresholds have a strong impact on the potential for these modes to supply the entire territory. In addition, the high pressure on real estate in certain areas can make it difficult to choose the location of these platforms, especially near major cities (Hesse and Rodrigue, 2004; Verhetsel *et al.*, 2015). Therefore, the question of the location of the platforms network is intimately linked to modal choice issues.

Finally, in the current context of reducing GHG emissions, it is essential to understand the opportunities and obstacles to modal shift, as it presents an interesting path in several respects. First of all, alternative modes with little or no carbon emissions exist for all parts of the transport chain: for example, rail for long distance, and cargo bikes for the last mile. Secondly, from an operational point of view, these solutions are feasible (some actors already use them). Nevertheless, these underlying trends and issues must be carefully considered when public policy issues are addressed. As explained earlier, these issues are significant and difficult to address. In fact, there are many instruments for regulating freight transport (not exhaustively: taxation, transport and traffic regulations, local authorities' powers over roads and land, etc.). Yet, the doctrine regarding where and how these instruments should be implemented is generally based on public statistics that are aggregated, or on models calibrated with these statistics, when quantitative analyses have been used in the elaboration of said public policies. Most of these works completely omit the presence of actors, the complexity of transport segmentations or the existence of operational constraints (Fisher *et al.*, 2022). Few studies actually seek to understand what are the concrete implications (from an operational and financial point of view) of transferring road flows to a low-carbon mode at the level of an actor. As a consequence, the possibility that this body of knowledge misestimates the potential for decarbonation of freight transport, or incorrectly determines what are the barriers to that potential and the ways to overcome those, is

unfortunately very real. This research aims at addressing this issue. In other words, this work seeks to understand **the possibilities for carriers or shippers to shift part of its transport chain to decarbonized modes.**

The methodological backbone of this work is to conduct a monograph of a prominent European parcel carrier: DB Schenker, and to complement it with a number of case studies. In all cases, these analyses are based on large operational datasets extracted from the operation systems of private firms. The approach allows us to analyze the whole transport chain with case studies on some points (carriers and shippers). The considerable advantage of this approach over classic statistical analyses or models is that it allows to account thoroughly for the operating process and the operating constraints of the actors of the freight transport system. Moreover, compared to fieldwork, operational data allows access to large datasets that cannot be collected by hand. While standard fieldwork does provide a very useful basis to understand the actors' operations, constraints and objectives, it is limited in the capacity to have a full and fine knowledge of the whole set of their operations, to identify what those shares in common, or how and by how much they differ from one another.

To the author's knowledge, no other study has had access to such a large amount of information (millions of shipments) on flows with this precision and with diverse sources (different companies) in freight transportation research. It allows to explain the global functioning of a carrier with precision, and then to evaluate its potential and impact of a modal shift from its standpoint. It makes it possible to identify the actual obstacles preventing an actor from transferring part of its transport chain to low-carbon modes and as such, is a basis for elaborating ways to lift those obstacles, when possible and relevant. This is not in opposition to studies based on public statistics. Those provide an overall, statistically representative view of freight transport, whereas the study by actor aims at providing a complementary and precise view of certain issues.

Two solutions are studied in detail in this thesis: the first one consists in substituting cargo bikes to light commercial trucks for the first and last miles of parcel transport. The second one consists in shifting part of the long-distance network to combined transport at both the national and European scale for a consortium of companies.

The manuscript is divided into four chapters. A summary of the contents is present at the beginning of each chapter. The manuscript is organized as follows:

- Contextualization: this chapter provides the basic elements of road freight transport necessary for the rest of the manuscript as well as a literature review.
- Spatial organization: this chapter focuses on the understanding of the location of cross-docking platforms and the interactions between them at the national and local levels.
- Modal shift: from trucks to cargo bikes: this chapter studies the possibility for a carrier to use a cargo bike to operate in an urban environment
- Modal shift: from trucks to combined transport: this chapter examines the possibility of carriers and shippers using combined transport for long-distance transport.

Each chapter includes its own conclusion. The manuscript ends with a general conclusion.

CONTEXTUALIZATION

This introductory chapter aims to provide the necessary context for understanding the entire manuscript. It is divided into three parts:

- Part 1: Road freight transport in France sets out the author's vision of road freight transport in France, and clarifies the definitions chosen for the rest of the manuscript (first and second part of this section). The third part describes the different possibilities for a carrier to organize its long-distance network. The fourth part of this section explores related concepts that are not directly related to road freight transport but are necessary;
- Part 2: Review of literature allows to make a state of the art on the various subjects covered in the manuscript: cargo bikes for the first and last mile, localization of platforms and combined transport;
- Part 3: Data is, first, a quick review of the state of the art of public data available in France today and then in a second part a brief summary of the different databases used for this work.

Each sub-section of this chapter is independent.

1. Road freight transport in France

1.1. Different transport chains

Road freight transport is a heterogenous activity. Different carriers generally implement different processes, and use different resources. The objective of this first section is to provide a brief and simple presentation of the processes generally met in road freight transport. Note that this presentation is mostly relevant to monomodal freight transport. Indeed, road freight transport is also involved as a part of many multimodal transport operations, notably the intercontinental ones. Those are not discussed here. For a more complete and detailed presentation of freight transport, please refer to *Le transport de marchandises*, Michel Savy (2017).

Starting from a simple definition - the transport of goods is an activity that consists in moving some goods from a point A to a point B - we end up with a transport chain similar to that of Figure 1. Then, from the point of view of one carrier, there are two possibilities to organize the transport process:

- The quantity of goods to be transported from point A to point B is sufficient to fill the truck. In this case, the transport is done directly (Figure 1);

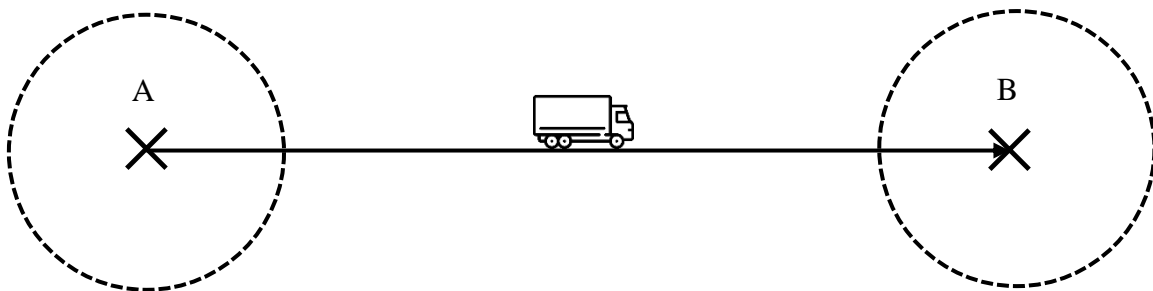


Figure 1 – Scheme of a direct transport chain, author's realization

- The quantity of goods to be transported from point A to point B is not sufficient to fill the truck. In this case, in a logic of profitability and efficiency, the carrier will generally try to fill the truck with other goods to be transported between points A' and B' near points A and B (Figure 2).

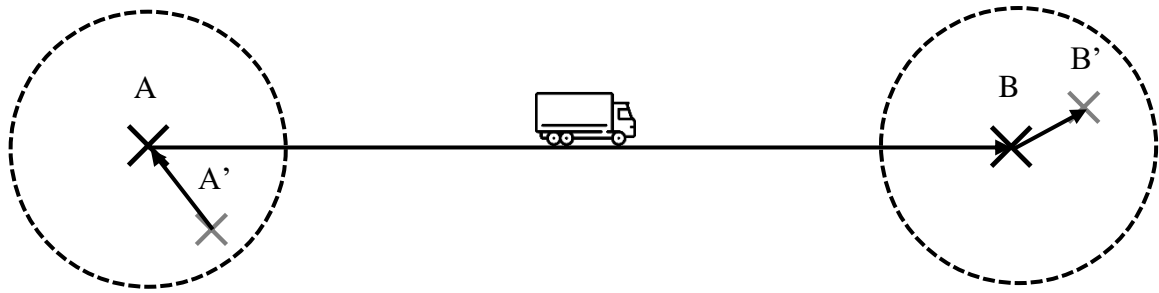


Figure 2 – Scheme of a direct transport chain with groupage, author's realization

In the second scenario represented in Figure 2, two situations should be distinguished. In the first one, locations A and A' (respectively B and B') are located close to one another. Consolidation, where the shipment from A to B fills, say, 60% of the truck's capacity and the shipment from B to B' fills 35% of the truck's capacity, is feasible. In this first situation, goods do not need to go through a cross-docking platform for the vehicle to be reasonably well filled.

There is another situation, where the carrier would like to transport many shipments together, because those shipments are much smaller than the capacity of the vehicles in its fleet. In addition, those shipments do not go only from one area to another (Figure 2) but from a multitude of areas to a multitude of areas (Figure 3). To transport these shipments, some carriers (mainly the larger ones, but not only) rely on an organization which separates the transport chain into two categories of operations: the first and last miles, and the long distance. These two parts are connected by crossdocking platforms. These platforms are the transloading places where the goods are transferred from one vehicle to another (it is also possible to transfer them from one mode to another). The network covering the first and last miles will be referred to as the local network, while the network connecting platforms over long distances will be referred to as the long-distance network.

Within such a scheme, where two networks coexist, each shipment goes through the following sequence of operations: they are first collected via rounds and transported to cross-docking platforms. From there, they are transported to another platform by heavy goods vehicles making long-distance connections (long hauls, or tractions). Some parcels may transit through a number of intermediate platforms before reaching the last one. At this stage, the parcels are integrated into rounds to be delivered to their recipients. Deliveries and pick-up are integrated in same rounds. This sequence of operations is summarized in Figure 3.

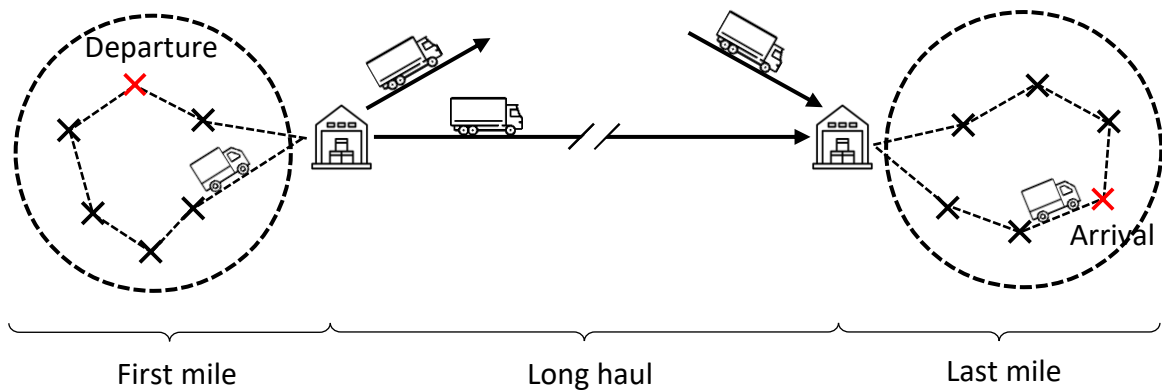


Figure 3 – Scheme of a transport chain with consolidation and deconsolidation of the flows, author's realization

In the case of an organization with a first and a last mile network and a long-distance network, the delivery and collection rounds are typically carried out during the day, while the long-distance network is mainly operated at nighttime, thus allowing a parcel collected a given day to be routed via the long-distance network during the night and to arrive in time for delivery the following day. This strategy, which allows to use large vehicles at high loading factors while providing short lead times to customers, is used by most express and parcel service companies.

The two networks (local and long-distance) must be seen as complementary. The local network provides a catchment area service around the cross-docking platform terminal, while the long-distance network connects various platforms across a national or larger territory, operated by the carrier. The relative sizes and characteristics of each network are determined so as to balance the need for local service and to have enough shipments in order to consolidate between platforms. With too many platforms, local movements are shorter and faster, but this comes at too high a cost in terms of the optimization of the long-haul truck movements which must connect those platforms together. Conversely, without enough platforms, the advantage of having relatively less long-haul movements is more than offset by the much-increased cost of local delivery service. The goal for a carrier is to find the optimal balance between these two costs.

Examples in Figure 1 and Figure 3 show two extremes of freight trucking organization:

- Figure 1 shows a configuration where the demand is such that a direct path system, without any consolidation, is spontaneously efficient;

- On the contrary, Figure 3 illustrates a network system with a process of consolidation - deconsolidation (or break-bulk) which interfaces the long distance and the local networks.

There is a variety of options between those two extremes. No solution is better than another, they simply serve different goals.

This section addresses the question of the choice of the organization chosen according to the activity of a carrier. Two additional elements are worth mentioning. The first one is the choice of vehicle, in particular the choice of the size (therefore cost, and capacity) of the trucks. In close relationship with its choice of organization, a carrier will determine the size of its fleet as well as its composition in order to adapt it to its demand. The second one is the fact that carriers operate in a competitive environment. Every decision taken by a carrier depends directly on that environment including its organizational choices.

1.2. Segmentation of road freight transport

Road freight transport is a heterogenous market. It can be segmented in several different and complementary ways. Two very commonly seen segmentations are, first, by type of goods (general cargo, dry or liquid bulk, chemicals, temperature-controlled, etc.); second, by package weight. Segmentation by type of good is notably relevant because transporting, say, liquid bulk, or refrigerated goods, requires specific equipment. Segmentation by package weight is relevant because different segments require different organizations. In this thesis, weight segmentation is the main focus.

It goes without saying that the organization required to transport a 1-ton shipment differs from that of a 1-kilogram shipment. The vehicles required, the equipment to handle the shipments on the platforms (forklifts for one, automatic sorting chain for the other), etc. differ according to the weight of the transported packages. As a matter of fact, it is classic in the industry to segment road transport of goods as in Figure 4.

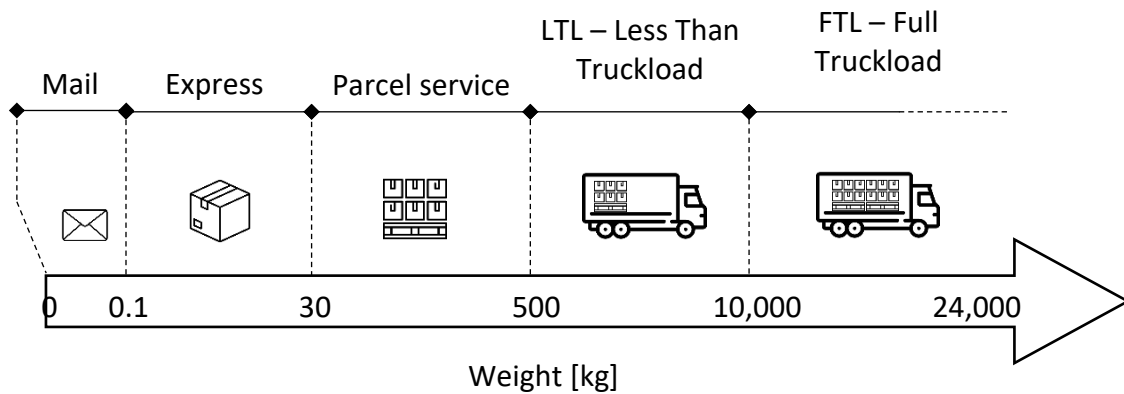


Figure 4 – Segmentation of road freight transport, author's realization

Figure 4 represents the different segments of the road transport. The mail represents the courier. This segment is almost exclusively dedicated to the transport of letters. The express segment is centered on parcels weighting from 0.1 to 30 kilograms; in addition, it also offers express services for letters (less than 24 or 48 hours depending on the distance). Both the mail and express services use mostly automatic lines for sorting in platforms.

Parcel service is centered on shipments weighting from 30 to 500 kilograms. One important difference between express and parcel services is that a shipment eligible to express transport can be handled without material aids² (such as a trolley), which is generally not the case for parcel service. In other words, express services are organized around the fact that manual handling is possible, while all operations in the parcel segments are managed around the fact that handling must be done with a pallet jack.

Let us now have a look at larger shipments. In fact, parcel service and LTL. The distinction between parcel service and LTL is mainly economic in nature. From a certain quantity, it is more economical to use LTL. From the point of view of a carrier, in the case of parcel service

² The law in France regulates the maximum weight that a worker can lift without help, which is 55kg (with a recommendation not to exceed 25kg). Anything heavier must be handled with a pallet jack.

just like LTL, he will try to pool the flows with other customers to optimize the filling rate of its trucks. Some carriers (such as *DB Schenker*) offer both parcel service and LTL.

The Full Truck Load (FTL) segment is, theoretically, made up of shipments which fill trucks by themselves, requiring no consolidation at all (Figure 1). In practice, some smaller shipments can be considered as FTL, and two can be carried together in the same vehicle with a very simple consolidation process (Figure 2). Some carriers call that type of operation PTL (Partial Truck Load). From a certain perspective, FTL can be seen as a subcategory of LTL in which the quantity of goods is sufficient to fill the truck completely and does not require pooling with another flow (i.e. Figure 1 and Figure 2).

The weight limits defining the segments in Figure 4 are not set in stone. Nevertheless, companies operating on a given segment will tend to focus their operations on said segment: once the fleet and the operations are organized to a particular segment, shipments will be all the more problematic to squeeze in the operations as their characteristics are far from those the company organized itself to handle efficiently and in masse. Take the example of an express company handling a 100 kg package: if the company takes the package, either they will have to mobilize a specific organization, or they will have to subcontract the package to another carrier as the organization is not set to carry those type of shipments.

The same is true between the boundaries of the next segments. Finally, on a long-distance trip between two sorting platforms, a courier or express carrier performs FTL. One can also consider that a courier performs LTL during the rounds to deliver or retrieve packages. Whatever the case, despite being debatable, this classification allows us to give the major separations of road freight transport.

In the rest of the manuscript, a limited selection of those segments is actually examined. The research done in this PhD thesis, built on datasets from private firms, is focused on general cargo, requiring no specific equipment, and going without handling constraints others than those of size and weight. The following segments have been investigated:

- A parcel service carrier – *DB Schenker*;
- Two express carriers (which operate worldwide);
- Industrials that used FTL services.

1.3. Long distance organization

Some segments of road freight (mostly express to LTL) transportation focused on small shipments overwhelmingly rely on platforms to consolidate shipments at the local level. All carriers then face an important decision: how to connect those platforms to one another for long haul operations? Note that this question is not specific to road freight operation; it is in fact an issue transversal to most transport segments, freight and passenger, inland and intercontinental alike.

This is an issue of network structure, which is by nature a complicated one. A simplified way to present it is to state that the 'solution' (the problem needing solved being, to a certain extent, specific to each firm) lies somewhere between two polarly opposed configurations: the point-to-point structure, and the hub-and-spoke structure.

In the point-to-point structure, the shipments are transported directly from their origin platform to their destination platform without intermediate operations. In the hub-and-spoke structure, goods are collected at each platform, sorted and consolidated at a central hub before being dispatched to their destination platforms. The two organizations are presented in Figure 5.

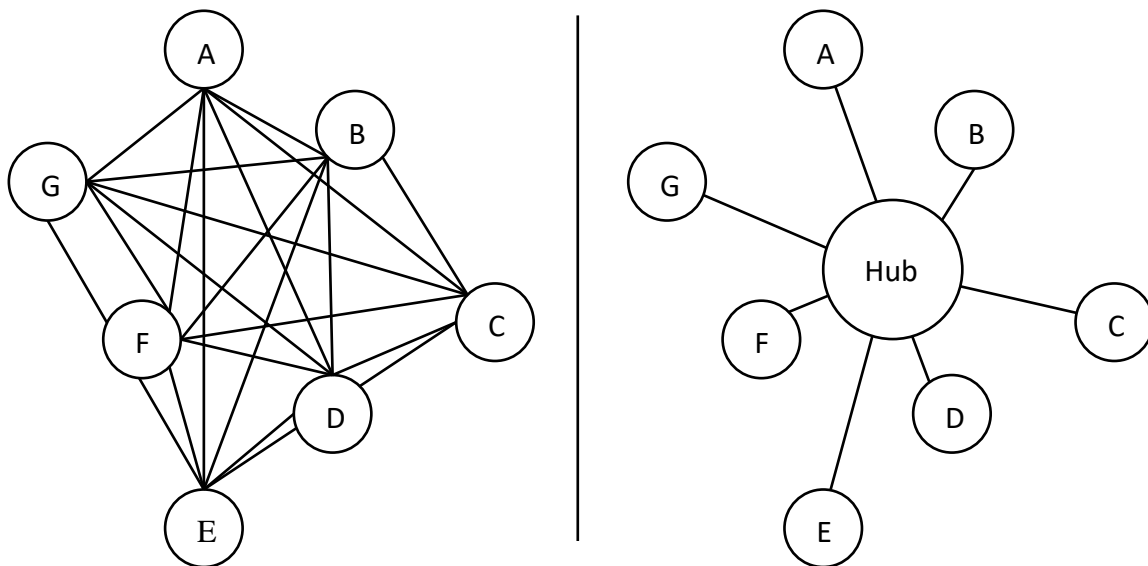


Figure 5 – Point-to-point organization (left) and hub and spoke organization (right), author's realization

Both structures have their advantages and disadvantages and the choice between the two often depends on the specific needs and characteristics of the firm operating the

transportation network. The point-to-point structure offers the advantage of a faster transit time between the different platforms (all transport operations are direct). In addition, an incident on one link (such as an unpredicted delay) has limited consequences as only the shipments in the vehicle are impacted. However, this leads to high transport costs (a lot of transport operations are necessary to connect each platform to each other at a high frequency) and, if the volume is not sufficient to fill the trucks between each platform while maintaining a high enough level of service, the whole structure may be very inefficient. Note that, as already hinted at previously, this question of structure is closely dependent to the question of choice of vehicle size.

For its part, the hub-and-spoke system reduces costs by reducing the number of connections (7 connections compared to 21 for the point-to-point system in the case of Figure 7), although that comes at the cost of having to implement and operate a central hub. This organization also makes it possible to double the number of rotations on an axis, if necessary, while needing fewer connections than with point-to-point. However, depending on the organization, some connections between hubs may not be made quickly, i.e. in less than 12 hours, allowing for a 1-day delivery. Moreover, the slightest delay in one of the connections has a direct impact on the whole system which is, in fact, interconnected.

When determining whether a hub-and-spoke structure is more relevant than a point-to-point one, one must adopt a global perspective. Indeed, if one transport operation is examined in isolation, a hub-and-spokes structure can seem irrational. For example, a shipment via DHL (an express carrier) from Marseille to Paris will have to go through the hub and spoke organization in Leipzig. On a micro scale this seems absurd, but considering the global organization of *DHL*, this journey is actually efficient. However, it is common for road freight carriers in the express and parcel segments to adopt a long-distance network, with a combination of the two organizations in order to optimize connection by taking advantages of both organizations.

Subsequent to this topic, the following vocabulary will be used in the following of the manuscript to describe the long-distance movement that connect the platforms/hubs:

- Axes: the link between two areas without direction (except if made explicit);

- Connection: indicates a regular directed movement (from area A to area B) of an actor between two zones;
- Trips: number of movements on a connection;
- Journey: path of a package.

In other words, it means that on an axis there can be several connections with several trips each. A journey can include multiple connections.

1.4. Additional notions

Freight transportation is a much wider system than just road freight transport. This section introduces a few notions which are either relevant to, or in close connection with, road freight transport, an which will be met regularly in the remainder of this manuscript. The following issues are briefly discussed: first, the distinction between own account and for hire transport; second, the logistic facilities typically met in the production of, or in connection with, road freight transport; third, intermodal and multimodal transport.

1.4.1. Make or buy: own account transport vs for-hire transport

Road freight transport, as many other economic activities, raise the question to make or to buy, for each firm. As summarized in the Figure 6, a number of more or less complex configurations can be made. In a very simplified way, there are two categories:

- Own-account transport: the goods are transported by the firm (shipper or loader) which produces them or owns them (the firm which produces the transport operation is not a carrier – more precisely, that firm does not sell transport to its customers, despite actually producing transport);
- Transport for hire: the firm is a freight carrier. It moves the goods of its customers, the shippers, and does not own the goods it transports. In other words, the carrier and the shipper are distinct firms. In addition, the carrier's core economic activity is to produce transport.

In the case of transport for hire or reward, the carrier is a supplier of its customer (the shipper). However, as illustrated in Figure 6, that does not entail that the carrier produces the transport with its own assets alone. Indeed, the carrier can also call on a subcontractor for a

part or the whole of the transport operation. This can go as far as to become an actual subcontracting chain.

This binary presentation – own-account versus for hire – should be considered as mostly theoretical. In real life, all kinds of intermediate configurations are met. One easily finds companies which outsource 100% of their transport activity; on the contrary, only few companies do produce 100% of their freight trips with internal resources.

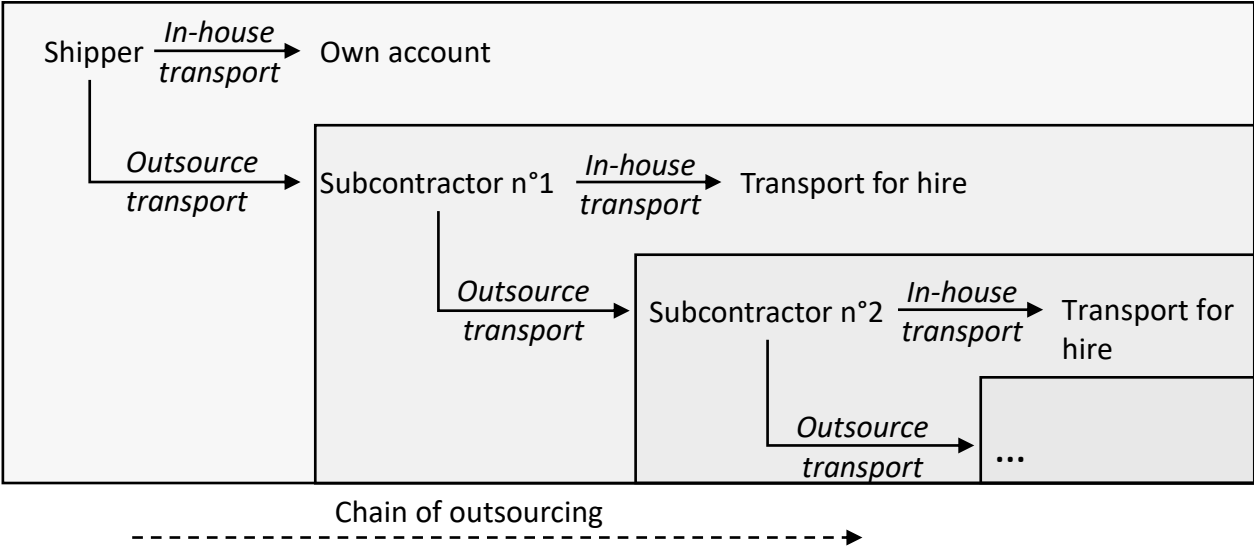


Figure 6 – Scheme of the chain of orders, author's realization inspired by P. Nierat's ENPC course

The strategies underlying whether or not a firm should outsource its transport operations, which one and why, are a complex issue warranting its own research questions. Those are not at the center of this manuscript, and the discussion remains purposefully limited on that topic. Still, it is important to note that this question is closely related to the management of uncertainty: uncertainty of demand (and the risk of being unable to use transport assets efficiently if the demand falls below their capacity), uncertainty of supply availability (and the risk of being unable to find fallback solutions if the need for transport goes above the capacity of the immediately available transport assets). Figure 7 illustrates how this uncertainty as the (somewhat) erratic evolution of the transport activity over time, and one possible strategy of a firm which is to size its own asset pool so as to be able to use all of them, all the time, and to rely on subcontracting to absorb the variable part of the activity. Of course, this strategy exposes the firm to the risk of being unable to find resources in the case of an unusual peak

of activity or lack of resources for subcontracting at a given time, but that comes with the benefit that its own resources are used very efficiently. What Figure 7 does not show is that there is a spatial dimension to that issue too, and an issue of consolidation – as discussed in Section 1.3 above (page 14).

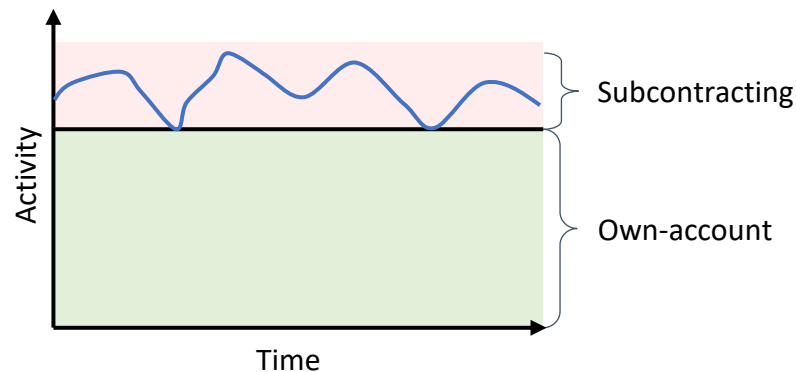


Figure 7 – Sizing of the fleet according to the evolution of the demand over time, author's realization from P. Nierat's ENPC course

In the remainder of the manuscript, the word 'actors' is in an undifferentiated way used to refer to shippers and carriers both.

1.4.2. Logistic facilities

Road freight transport does not work with vehicles and roads alone. It also involves buildings. Besides, origins and destinations of freight transport operations are overwhelmingly often buildings. Some of those buildings' main role is to allow or facilitate the operation of supply chains. Behind the apparent simplicity of the topic, relies an actual complexity, which requires clarity in the definitions. This is the objective of this section.

Logistic facilities gather various terms that we detail here:

- Cross-docking platform (or platform): facility where shipments are first unloaded from trucks, sorted by destination, and then reloaded into other trucks, without long time storage (more on that below). Very often, these places are the interface between long distance operations and first and last miles operations;
- Hub: platform where goods are dispatched. In a road freight transport, goods are unloaded from long-distance trucks, sorted by destination and reloaded into long-distance trucks. In a rail freight transport system, the wagons are sorted according

to their destination and then sent back by train to their destination. This is, most often, a mono-modal facility. It differs from a mere cross-docking platform in that the function of the hub is not too interface local operations and long-distance operations; the role of the hub is to consolidate flows so as to provide both spatial coverage, good level of service, and efficient production;

- Micro-hub: small load transfer point located in the city center, enabling goods to be transferred from trucks to cargo bikes. This transfer point is not directly linked to all the platforms on a national level but to only one local cross-docking platform. They work as satellite of those platforms. According to the discussion above, one could consider that, strictly speaking, naming them hub is misleading and that they should be called 'micro-platforms' instead;
- Intermodal terminal: facility allowing the transfer of intermodal transport units³ (ITU) between two or more modes. There are rare occurrences of trimodal terminals (rail, waterway, road.) However, in the rest of the manuscript, this term will always refer to bi-modal terminals interfacing road and rail transport operations;
- Warehouse: facility dedicated to storage, the fundamental difference between a warehouse and a platform is that when a shipment enters a warehouse, it is not undergoing a transport operation anymore. In general, it is not flagged yet to a destination and delivery time and date outside that warehouse. Whereas where a shipment enters a platform, it is still undergoing a transport operation; and even if it is stored a few hours, or maybe a few days, it is already, systematically flagged towards a destination and delivery time and date. In other words, a warehouse serves a logistics purpose, whereas a platform serves a transport purpose. This distinction is theoretical: in practice, many warehouses will serve both purposes.

³ Intermodal transport unit (ITU): Transportation container (sea container, swap body, semi-trailer, etc.) allowing the transfer from one mode to another. Thus, it allows to transfer a set of shipments together, author's definition

1.4.3. Modal shift and intermodal transport

Modal shift refers to the change from one mode of transportation to another, typically from road to rail or inland waterway, but also, in the context of urban logistics, from ICE (Internal Combustion Engine) conventional light commercial trucks to smaller, greener vehicles like cargo bikes, in order for freight transport to be more efficient, sustainable, and cost-effective. This shift is motivated by a number of objectives including: improving supply chain management, reducing congestion, and reducing greenhouse gas emissions.

Unfortunately, a strict modal shift (i.e. less trucks) proves to be extremely constraining. To cite but one difficulty, in order to fully shift a commodity flow currently transported by road onto the rail network, it is necessary, if it's not done already, that the shipping and receiving sites be connected to the rail network. This requires very expensive investments, and recurring substantial maintenance costs. One way to circumvent that requirement, is to have recourse to multimodal transport. Multimodal transport refers to the combined use of multiple modes of transportation (e.g. rail, truck, and ship) for the movement of goods from origin to destination. Combining different modes to road freight transport can provide a more flexible, efficient, and cost-effective solution compared to fully shifting a given commodity flow to a single non-road mode.

Note that it is necessary to distinguish multimodal and intermodal transport. Intermodal transport requires that the goods be contained in an ITU (i.e. container, swap body, etc.). Then, it is the ITU that is handled, and transferred from one mode to another, leaving the goods inside untouched. Whereas in multimodal transport, there is no requirement that the goods stay in the same containment unit from the origin to the destination of the transport operation.

There is a wide variety of multimodal and intermodal situations in the context of freight transport. Two cases are of specific interest to this manuscript, and are briefly presented below. The first case is the multimodal transport of goods with a combination of trucks and cargo bikes in the context of first and last miles operations. The second case is that of intermodal transport for long distance inland freight transportation, with road and rail operations.

Consider first the case of introducing cargo bikes into first miles and last miles logistics for parcel transport. Despite all its qualities, one of the most impactful limitations of a cargo bike is that its operating area is smaller than the one of light commercial trucks (LCT) due to its limited speed, payload, and range. The shipments being transported by cargo bikes typically come from a platform which is not located in the close vicinity of their origins or destinations. Therefore, supplementary locations, called micro-hubs, must be set up close to the points of deliveries and/or expeditions, so that the shipments can be carried to and from the conventional platforms. In a manner of speaking, those micro-hubs support the national platforms at the local level (they are not directly connected to the national network). Cargo bikes operate in a radial pattern around each micro-hub. In addition to cargo bikes, light commercial trucks ensure the connection between the platforms and the micro-hubs. For the freight transport segments where it is relevant, those vehicles can also directly transport the overweight (cargo-bike wise) parcels (e.g. over 200 kg) and the parcels originating from or destined to locations which are outside the catchment area of the micro-hubs (say, more than 2 km). If the carrier wants to decrease its emissions as much as technically possible, those LCTs can be electric. Those operations are illustrated by Figure 8, which is a modified version of Figure 3. On the left-hand side of Figure 8 is represented the conventional organization: a LCT starts from a platform with a load of shipments, makes a round connecting all pick-up and delivery locations, then goes back to the platform. On the right-hand side, the LCT carries a set of shipments to the micro-hub, where those are unloaded, sorted and put on cargo-bikes who bring them to their destinations, and conversely for pick-ups. The LCT also delivers overweight and out of bounds shipments (not represented here). It is the objective of Chapter Modal shift: from trucks to cargo bikes (page 89) to explore further the possibility of using cargo bikes instead of LCTs.

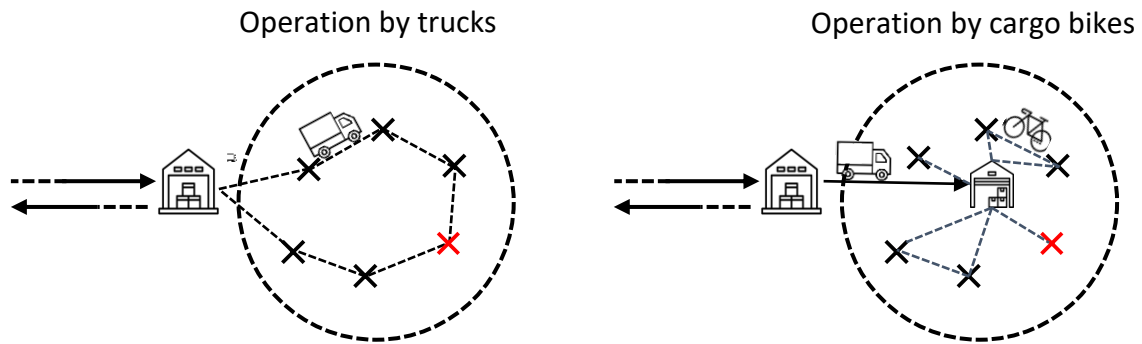


Figure 8 – Scheme of one operation for the first and last mile with truck (left) and with cargo bikes (right), author's realization

The second case is to introduce trains into long distance using combined transport. Combined transport consists of using train for a significant part of the journey. Instead of being routed directly to the final agency, the parcels are usually loaded in a swap body⁴ that is routed to an intermodal terminal (pre-haulage). There, the swap body is transferred to a train that will move the swap body (by pooling with other actors' connections) to its intermodal destination terminal. Once there, the swap body will be carried by truck to the final sorting platform (post-haulage). Those operations are summarized in Figure 9 as a modification of Figure 3. Combined transport has the strong advantage of allowing the use of rail for actors without having their production sites connected to the rail network (this connection has important costs and is rarely justified). The combined transport takes advantage of using the train which is a cheaper means of transport per kilometer and less carbon intensive than the truck, provided that the train is full. To fill the train either an actor can use the existing offer of combined transport (i.e. the offer currently on the market offered by the combined transport providers). However, if the offer does not correspond, it is also possible for an actor to try to pool his flows with one or more other actors in order to achieve the critical mass needed to fulfil the train.

⁴ As a maritime container, a swap body can be transported by road or rail. Unlike the sea container (or shipping container), swap bodies cannot be stacked. Its dimensions are the same as a semi-trailer.

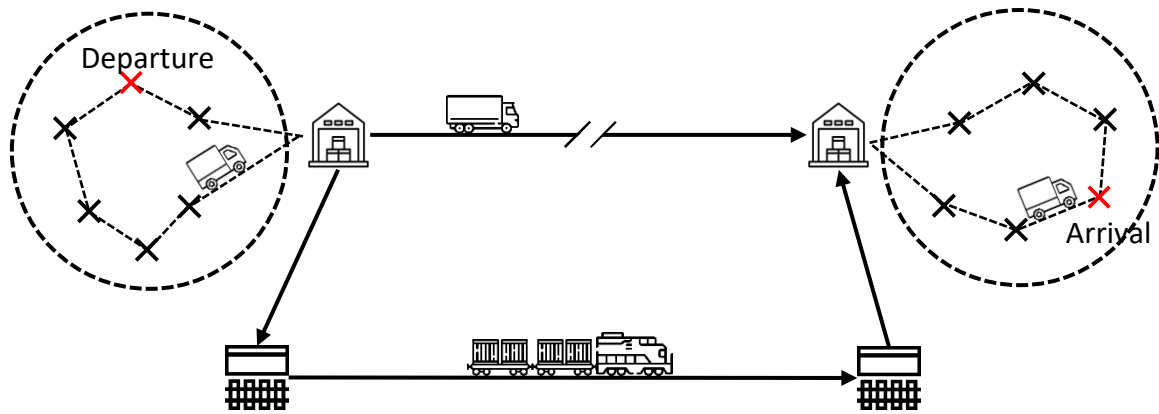


Figure 9 – Scheme of a transport chain with and without combined transport, author's realization

From an economic point of view, if the cost per kilometer of the train is lower, it must compensate for the additional cost of transshipment and pre- and post-carriage by road, which is more expensive than a long-distance trip at the cost per kilometer. It is the objective of Chapter Modal shift: from trucks to combined transport (page 111) to explore further the possibility to integrate combined transport in the long-distance network of actors.

2. Literature review

This section presents a review of the literature on four key topics related to the subject of the manuscript:

- The main strategies for decarbonizing road freight transport.
- First and last miles freight transport operations;
- Long-distance road transportation;
- The location of cross-docking platforms.

The purpose of this literature review is to provide an overview of the current research and understanding of these topics. It does not aim at exhaustiveness; it is focused instead on the key aspects upon which the remainder of the document is built.

2.1. Road freight transport decarbonization

Freight transport is facing a significant challenge of decarbonization, as it is responsible for a substantial share of global transport emissions (36% in 2019) (OCDE, 2019). With a growth forecast of 300% by 2050, it would represent 58% of the emissions of the transport field in 2050 (OCDE, 2019). In France, freight transport alone represents 14% of total CO₂ emissions in 2019 (INSEE, 2019). Moreover, when looking at the shares of freight transport modes, we notice that a large part is done by truck, and that the long-term trend is towards an increase in road transport to the disadvantage of rail transport (Figure 10).

Figure 10 shows a discontinuity in the statistics starting in 2014. This is due to a change in the methodology beginning in 2020 (the statistics were recalculated up to 2014). The main modification is the inclusion of heavy vehicles from 16 to 25 years old, which were previously excluded.

The sector has been identified as one of the most difficult to decarbonize (Guérin, Mas and Waisma, 2014). There are many causes to this state of affairs; perhaps the most important one is that the production of freight transportation is an energy intensive activity, and that energy is used by vehicles, which are mobile devices. The question of bringing energy to a mobile device is, unfortunately, one of the biggest barriers to energy transition given the fact that, at this stage, the most energetically dense, easily stored, transported and handled vector

is liquid fuel produced from fossil sources; and it is a relatively cheap energy vector too. Alternatives are hardly perfect substitute: bringing electricity inside mobile devices is difficult (it is possible for trains, although not all lines are electrified, especially in France; and it is hard for road vehicles, either because of the cost and capacity of local storage – batteries – or because of the cost of investing in a continuous electricity providing system – such as catenaries). Another aspect is that transport is dependent on other activities, transport is not produced for nothing, it responds to a demand. Moreover, in order to optimize its profits, a carrier will tend to produce the minimum amount of transport to meet the demand.

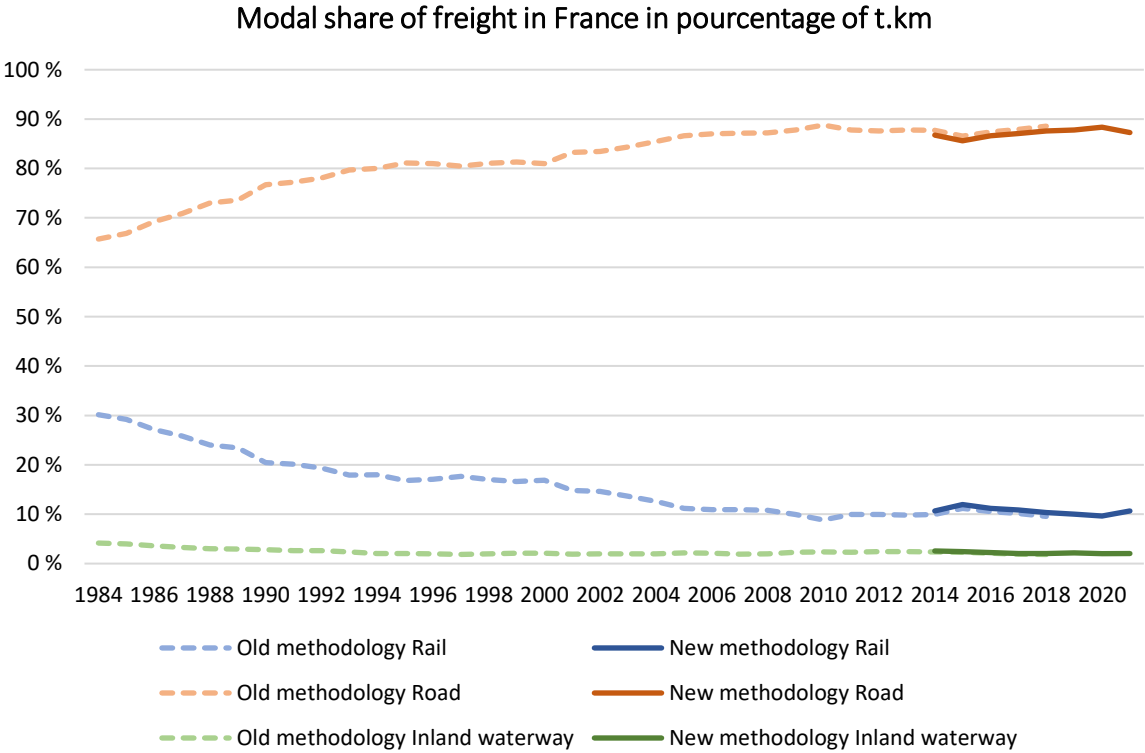


Figure 10 – Modal share of freight in France in percentage of t.km (SDES, 2021)

In France, successive governments have been implementing measures and restrictions for years with the objective of decarbonizing freight transport by developing the share of rail. The results have not met expectations. For example, the latest objectives in 2022 were to double rail freight from 9% to 18% by 2030, but given the current trends, this objective seems hardly

achievable as it stands⁵. However, there are a number of possible paths that can be grouped into 4 axes discussed below (McKinnon, 2018):

- Reduce freight demand;
- Improve transportation efficiency;
- Use of decarbonized energy;
- Shift to low-emission transportation modes.

2.1.1. Reduce freight demand intensity

The first, maybe most intuitively obvious way to reduce freight emissions is to reduce the intensity of freight. However, contemporary society is embedded in a pattern of overconsumption that seems difficult to reverse (Ivanole and Cornescu, 2013). Moreover, it is a long accepted fact that freight transport followed the same trends as GDP, although this conclusion is now being questioned and some works show a partial decoupling between economic activity and freight transport in recent years (Banister and Stead, 2003; McKinnon, 2007). This decoupling may stem from the mutation of economies in rich countries towards a digitalized economy (several sectors have indeed become partially or completely digitalized, for example music, media, etc.) (Alises, Vassallo and Guzmán, 2014; Milliot, 2016; Sisario and Russell, 2016).

Another path is the reduction of the intensity/pressure on the supply chains that allows to introduce flexibility by limiting systems such as Just In Time (JIT), as stated in some studies (McKinnon, 2016). How this relates to a decrease in freight transport is not intuitive; however, some freight movements are the direct consequence of supply chains being configured so as to provide maximal flexibility or level of service (one can think, for example, about the reverse logistics due to failed deliveries.) The issue of how the configuration and objectives of supply

⁵ <https://www.ecologie.gouv.fr/parution-du-decret-approuvant-strategie-nationale-developpement-du-fret-ferroviaire>

chains influences directly or indirectly the carbon intensity of freight transport is in fact transversal.

However, the idea that supply chain efficiency is by nature incompatible with a reduction of the carbon intensity of freight transport is not fully correct. This will be further throughout the manuscript. The intuition underlying that work can be stated as follows: carriers thanks to economies of scale, can leverage their customer basis in order to maintain cost and level of service and, at the same time, shift all or part of their operations on decarbonized alternatives. In particular, Chapter Modal shift: from trucks to combined transport (page 111) shows how through the consolidation of enough commodity flows, it is possible to shift road freight transport operations to road rail combined transport operations within just-in-time supply chains. This is precisely the added value of a carrier: to take advantage of its entire network of customers to balance the connections both geographically and temporally while implementing the most suitable transport solutions.

2.1.2. Improving transport efficiency

First and foremost, let us precise that improving efficiency is understood as finding a way to achieve the same result with less resources. It is closely aligned to the notion of cost efficiency, although not always strictly identical. As a matter of fact, in practice, the definition will depend on how one defines “achieving the same results”, as that statement is not as unambiguous as it seems. Whatsoever, improving the efficiency of freight transportation as a way to reduce the emissions of CO₂ is a widely documented path in the literature. This instrument can actually be broken down into two subtypes.

The first general way to improve the efficiency of road freight transport (or of any transport system in general) is to put more of the things which need to be transported inside each vehicle, in other words, to improve their loading rate. Some papers showed that manufacturers have been able to increase the efficiency of their transportation chain and particularly the loading ratio of their trucks, thus allowing them to move more goods without increasing the number of trucks needed (Kveiborg and Fosgerau, 2007). In particular, an econometric study shows that an increase in the cost of use of trucks resulting from higher fuel prices, would lead to an improvement of the loading ratios of trucks (Rizet, Cruz and Mbacké, 2012). However, this point needs to be interpreted with caution. As stated above, a

carrier's way to generate profit is to combine the flows of all its customers to produce transport efficiently. Stating that an increase in fuel prices would increase the efficiency of the chain entails that, were fuel prices to remain constant, carriers would have remained in an initial situation that was not optimal. In other words, that it is perfectly normal to state that carriers are not organized optimally. This statement comes at odds with the facts that, on the one hand, carriers being private firms, it is their actual objective to generate as much profit as possible (in an intertemporal way); second, that competition being quite fierce on that market, suboptimal carriers would eventually be driven out of operations. Not contradicting the fact that all firms (and probably more so the big ones) are always looking for optimizations, because there are always optimizations to find, the reaction of the sector to a modification of the price of one of its resources is not an *optimization per se* (i.e. a way to achieve the exact same thing with less resources), but rather a shift in the way to produce transport, and/or to manage supply chains, which probably alleviates part of the resource cost change, probably at the cost of something else (such as supply chain flexibility or transport level of service.)

The second general way to improve the efficiency of freight transport is to modify the limit of the payload of the trucks, allowing to load more commodities inside one vehicle. This is sometimes referred to as the idea of introducing Longer or Heavier Vehicles (LHV). The case of Great Britain has shown that the increase of the maximum load (from 41t to 44t in 2001) has allowed a reduction of vehicle-km of 134 million in the 3 years following the implementation of the measure (McKinnon, 2005). In connection with the previous point, it is in the economic interest of a carrier to try to massify its flows as much as possible. However, increasing the maximum load can only be of significant interest if carriers are already optimizing their flows. Moreover, in the case of the parcel service, the weight of the truck loads is more around 20t while the payload is 27t for a 44t LHV. The increase of the maximum load has finally a limited impact. Only certain segments of the road transport industry will benefit from it. For example, for parcel service, it can be assumed that volume is the limiting factor.

However, other papers also point out the danger that increasing vehicle capacity affects the relative competitiveness of intermodal solutions, resulting in a globally less positive, or even actually negative balance, because of the commodities that would come “back” from intermodal freight transport to monomodal road freight transport. Indeed, that modal shift

would lead to an increase in externalities (Sanchez Rodrigues *et al.*, 2015). If the adoption of HGVs were to reduce the cost of road transport by 15% to 25%, meaning that combined transport connections could be switched back to road in Belgium up for 91% of Flanders municipalities (Meers, van Lier and Macharis, 2018). The question is complex, because LHVs can also improve the competitiveness of road-rail, although probably not to the same extent as for monomodal road freight transport. It has been shown that the use of LHV can reduce the cost of pre- and post-haulage by 5 to 10% (Bergqvist and Behrends, 2011). This last point is in line with the measure taken in France in 2022 to allow⁶ 46t trucks for pre- and post-haulage since the generalization of 44t trucks in 2013 (Code de la Route, 2022).

The notion of improving freight efficiency by relaxing vehicle capacity constraints is not specific to road freight transport. As a matter of fact, it has been examined for the French railways, with a view to increasing the size of trains from 750 m⁷ to 1,500 m, with the assumption that it would reduce the transport costs per ITU (provided the train is fully utilize), with inspiration perhaps from the 3,658 m trains in the United States. This proposal raises, as for trucks, some questions. First of all, on the scale of France, is there sufficient rail traffic to fill a 1,500 m train? Would not it be more interesting to focus on demand rather than increasing supply as suggested in the literature (Nierat and Combes, 2020) ? Secondly, increasing the length of trains requires adapting all existing infrastructures (intermodal platforms, sidings, etc.), which has a significant cost. Moreover, increasing the length of trains in France seems to be at odds with the European development of rail freight: today, France is one of the countries that allow the longest trains, and developing 1,500 m trains would mean no longer allowing interoperability with neighboring countries such as Italy (600 or 730 m

⁶ Décret n° 2022-1045 du 25 juillet 2022 relatif à l'expérimentation relevant à 46 tonnes le poids total roulant autorisé des véhicules réalisant la part routière d'opérations de transport combiné

⁷ On some axis in France, it is possible to operate 850m long trains on 4 axes in 2023, mainly on the North-South axis (SNCF Réseau, 2023)

depending on the path), Spain (600 or 750 m depending on the path) or Germany (740 or 835 m depending on the path) (FIS and Kersten, 2020).

Note that the real debate is not the use of larger and more heavily loaded vehicles but the use of vehicles adapted to the corresponding trips. Allowing heavier payloads (such as done in Great Britain) enables a wider spectrum of opportunities for road transport. But it is not automatically relevant. If the vehicles get too big, their additional purchasing and operating costs may not be offset by the improved efficiency that they allow. Conversely, the fact that some big vehicles are used does not mean that all carriers will use the largest possible vehicles all the time, and that small vehicles are mechanically, systematically, out of the picture. In this context, because the constraints are very different, LCTs remain the relevant vehicles for first and last miles operations, and it may even be beneficial to replace them with even smaller vehicles such as cargo bikes, provided those are better adapted to the situation.

A third way to improve efficiency is to pool flows from several shippers. This allows a better use of resources, as shown by this paper where the pooling of flows between two actors of the French retail industry allows to decrease by 14% the CO₂ emissions (Pan, Ballot and Fontane, 2013). However, pooling pools between shippers raises a host of critical question, such as sharing detailed data among competitors (which is possibly illegal, depending on the type of data, and probably quite as often not natural for those competitors), as well as waiving some control in contracting with carriers, a decision which can be seen as specifically risky for the shippers. In addition, it should not be forgotten that it is the very purpose of a carrier, to pool the flows of several to be as efficient as possible, especially in the segments focused on smaller shipments.

2.1.3. Decarbonization of energy consumption

For road freight transport, improving energy efficiency – i.e. reduce the CO₂ amount of the energy used by the vehicles – can be split into two parts. Firstly, one can imagine the replacement of conventional ICE vehicles with battery electric ones. How much carbon emissions are avoided directly depends on the energy mix of the electricity production? From that regard, transport operations in France benefits from a barely carbonized electricity, i.e. 48 g.CO₂/kWh (due to the high share of nuclear electricity in the French energy mix) (Huet, 2019). However, electric vehicles' technologies are not mature enough or cost-effective today

for the road freight transport sector to rely on them, particularly for the heavier vehicles (Mauler *et al.*, 2022). Another alternative is the use of vehicles powered by other energy sources such as Natural Gas for Vehicles (NGV): the advantage of energy density, storage and handling of the vector (although not as strong for NGV as for liquid fuel) remain, but the load of producing those vectors without emitting carbon does not disappear instantaneously, is just moves upward the energy chain.

Even if there were mature solutions today, there are 600,000 trucks in circulation in France in 2020, half of which are less than 6 years old. A complete replacement of the fleet cannot be done overnight. Moreover, in the case of a major shift to electric vehicles, this will lead to a significant increase in the demand for electricity, with a need to increase electricity production capacity accordingly (Mullan *et al.*, 2011).

2.1.4. Shift to low-emission transportation modes – modal shift

The last of the four instruments for the decarbonization of the freight transportation sector is to shift from the most polluting modes of transport, such as trucks, towards greener alternatives like rail, sea, or cargo bikes. The use of a decarbonated mode allows significant gains in terms of CO₂ emissions. Especially since the volume involved is not necessarily small, but rather the possibility of switching a significant part of road transport to combined transport for example (Craig, Blanco and Sheffi, 2013). This idea is in line with the will of political decision makers; the European White Paper aims to shift 50% of inter-urban goods trips from road to rail or inland waterways by 2050 (Kallas, 2011). This point raises several questions that will be addressed in the following chapters of this manuscript.

However, approaching the modal choice from the unique angle of decarbonization may be problematic, if it does not consider other factors that carriers consider when choosing a mode of transport. For example, trucks may pollute more than other modes, but the cost, quality of transport, reliability, and transport time can also be important factors for actors (Mostert, Caris and Limbourg, 2017). Additionally, it is important to evaluate the transportation system as a whole rather than focusing solely on decarbonization, as this can lead to unrealistic conclusions. The main criteria for a carrier when choosing a mode are cost, quality of transport, reliability and transport time : the environmental cost is therefore not one of the fundamental criteria (Flodén, Bärthel and Sorkina, 2017): this must be accounted for when

elaborating a modal shift policy, or assessing its potential. The issue of modal shift will be more widely discussed in the manuscript in the Chapter Modal shift: from trucks to combined transport (page 111).

2.1.5. Partial conclusion

The various options outlined above provide a diverse set of opportunities to decarbonize road freight transportation. However, it is highly unlikely that one of them will dominate and, alone, reach the decarbonation targets which are aimed at in 2050 (in many cases, neutral carbon balance). More realistically, to reach deep decarbonation, it will be required to use all levers intensively.

Additionally, it's important to note that transportation companies are beholden to their customers, which means that they must meet the demands of their clients (Isaksson and Hüge Brodin, 2013). For this reason, it may not always be feasible to change from one mode of transportation to another, or to always use fully loaded trucks and meet customer expectations. However, as mentioned before, the strength of a carrier is the multitude of its customers (as well as its strategy to seek new customers), which allows them to optimize the use of its trucks as well as the opportunities to shift to non-road modes (Nierat and Combes, 2020).

All solutions are interrelated; all solutions have differentiated impacts; all shippers and carriers will have distinct perspectives and preferences regarding them. Characterizing these solutions, and determining their correct mix and the timeline of their implementation, is by no means a simple challenge.

2.2. The first and last miles – local network

The last mile refers to the last step in the logistics chain, allowing the parcel to be brought from the sorting platform to the final customer⁸, when that one is located in an urban area. The problem of the last mile also includes the problem of the "first mile" or how to get the package from the sender to the platform, when the sender is in an urban area (see Figure 3). Moreover, in a desire to optimize the transport chain, pickups and deliveries are processed together when carrying out rounds (this also makes it possible to optimize the loading rate of vehicles).

This issue is particularly important in urban areas which, due to population density, public space is limited. Also, the last step of the transport chain is of critical importance regarding customer satisfaction (Murfield *et al.*, 2017). The discussion will be divided into two territories:

- High density: dense urban centers and suburbs;
- Low density: countryside.

2.2.1. High density territory

As mentioned above, the issue of first and last mile is a critical point in the delivery chain because the supply chain generates many externalities (Dablanc and Frémont, 2016). For example, in urban areas, due to the lack of public space, trucks generate numerous negative externalities such as congestion, noise, pollution, etc. (Olsson, Hellström and Pålsson, 2019; Hammami, 2020). Local authorities are willing to reduce the impact of the carriers, however, the implications of local authorities and the type of regulations differ greatly from one territory to another as regulations are for a large part locally initiated, and not necessarily coordinated (Dablanc, 2007; Dablanc, Giuliano and Holliday, 2013). This is a complex task because, first, there is no one-size-fits-all measure that will solve all the problems. Second,

⁸ By final customer one understands here the first point in urban area after the platform. For example, in the case of retail, it will not be the final customer (the buyer) but the store.

not all actors perceive an action in the same way due to the diversity of activities grouped under the freight transport label (Anderson, Allen and Browne, 2005; Stathopoulos, Valeri and Marcucci, 2012). 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 (Savelsbergh and Van Woensel, 2016): the trend is not towards a spontaneous resolution of those issues.

The proposed solutions to reduce negative externalities mainly rely on breakthrough technologies that change the current uses of delivery (a round starting from and ending at a cross-docking platform located in the urban periphery) (Szymczyk and Kadłubek, 2019). Nowadays, most of the new ideas (cargo bikes, delivery robots) require that the shipments undergo additional transfers (Boysen, Fedtke and Schwerdfeger, 2020). 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., parked container in street during the day) (Katsela *et al.*, 2022). From those micro-actors, operations are conducted on a star-shape around it (Lenz and Riehle, 2013; Gruber, Kihm and Lenz, 2014; Marujo *et al.*, 2018; Affonso and Ormond, 2019). 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 (Heitz and Beziat, 2016; Klauenberg, Elsner and Knischewski, 2018; Robichet and Nierat, 2021). This operation is summarized in Figure 8, which is an adaptation of Figure 3.

Those micro-hubs are costly (rent, additional managers, etc.) which induces a need for a minimum density of activity to make it possible (although not guaranteed) that this scheme is profitable (leaving aside the fact that with higher density often come higher rents...). Indeed, 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 (Choubassi *et al.*, 2016; Arnold *et al.*, 2018; McLeod *et al.*, 2020; Robichet, Nierat and Combes, 2022). On the other hand, the high cost of land is a key limitation in the implementation of these new solutions (Conway *et al.*, 2014). For instance in Paris, globally, platforms have moved away from urban centers in the last thirty years (Dablanc and Rakotonarivo, 2010). This movement implies the need for satellite micro-hubs in the heart of cities to allow for operations via cargo bikes (Robichet and Nierat, 2021).

The bicycle (compared to new delivery system like robots) 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, currently, 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 a given number of operations. Furthermore, the last mile is mostly done by subcontractors, which implies that big companies do not have full and direct control on how parcels are carried (Rème-Harnay, 2021). Be that as it may, 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 on the subject (Llorca and Moeckel, 2021). Amongst the important conclusions, cargo bikes offer other advantages such as:

- Lower vehicle costs (purchase, maintenance and insurance) (Sheth *et al.*, 2019);
- Fast and reliable movement in dense areas (less dependent on traffic jam) (Pedal Me, 2018);
- Possibility to park close to the delivery/shipping points and spend less time cruising for parking (Dalla Chiara and Goodchild, 2020; Dalla Chiara *et al.*, 2020; McLeod *et al.*, 2020);
- Less road and parking consumption due to the smaller size of the vehicle (Conway *et al.*, 2017);
- Cleaner and less negative externalities than most other modes of transportation (especially trucks) (Koning and Conway, 2016; Melo and Baptista, 2017; Arnold *et al.*, 2018; de Mello Bandeira *et al.*, 2019; McLeod *et al.*, 2020; Fraselle, Limbourg and Vidal, 2021).

These new technologies are implemented to anticipate new regulations which aim 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 (Dablanç, Giuliano and Holliday, 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. (Schliwa *et al.*, 2015; Choubassi *et al.*, 2016; Rudolph and Gruber, 2017). The policy objective is to constrain vehicle types to reduce negative

externalities without preventing carriers from operating. Different studies have already been made in Portland and Seattle to compare cargo bikes and electric light commercial trucks (LCT) but with a smaller sample size and over a smaller geographic area compared to the study presented in section Modal shift : from trucks to cargo bikes (Tipagornwong and Figliozzi, 2014; Sheth *et al.*, 2019)

However, even if it is possible to switch part of the flows to alternative modes, questions remain: how to supply these new breakpoints? what is the real cost for a carrier? what are the operational implications? what about flows that must be carried by trucks due to technical constraints (too big, too heavy)? There is also a need to harmonize the various regulations at the local level. From the point of view of an actor, it is easy to understand the difficulty of adapting to several local regulations. For example, there are 1,276 cities in the Paris Metropolitan area; if each of them applies a different regulation, it can become difficult for a carrier to abide by each of them considering the fact that the carrier will deliver different cities in the same round and that the platform's catchment area will include even more cities.

2.2.2. Low density territory

The theme of the last mile is less explored for the peri-urban areas, because the density required for many of the alternatives to conventional road freight transport to be viable is simply not present. Also, the negative external impacts of urban freight transport may be less intense. As a result, carriers are using the traditional methods presented at the beginning of this chapter. Despite this, there may still be opportunities for solutions such as drones, provided they have the necessary autonomy to travel several kilometers to reach their destination. This topic, which is a whole field of research and innovation in itself, is not further examined in this manuscript.

Note that it is quite often observed that, in territories with low density, carriers rely on subcontractors as the volume of parcels processed is not sufficient to have a profitable activity. These subcontractors, by grouping the flows of several carriers, reach higher densities which makes it possible to rationalize the rounds. This is interesting as it shows that carriers are able, via subcontractors and when they find an interest in it, to massify their flows between them. This point will be discussed in the rest of the manuscript.

2.3. Localization of cross-docking platforms

The location of logistics facilities plays a crucial role in the overall efficiency of the transportation chain. This section focusses specifically on the case of platforms located in densely populated urban areas. Cross-docking platforms, which are a vital component in the transportation process, greatly enhance the performance of carriers by increasing the load factor of trucks and facilitating the link between long-distance and last-mile transportation (Stephan and Boysen, 2011)

When determining the optimal location for these platforms, various factors must be considered. For example, should they be located on the outskirts to ease access for long-distance trucks or located closer to urban centers to improve delivery efficiency? Other considerations include transportation costs, delivery times, and the availability of labor and resources (Oliveira *et al.*, 2022). Furthermore, the impact of the localization of platforms on the surrounding community, such as traffic congestion and environmental impacts, must also be considered. These questions, among others, are commonly addressed in literature under the theme of "logistics sprawl", which highlights the importance of finding the best location for platforms.

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, Ogilvie and Goodchild, 2014), Berlin (Hesse, 2004), Toronto (Woudsma, Jakubicek and Dablanc, 2016), Tokyo (Sakai, Kawamura and Hyodo, 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, studies either calculate the average distance of platforms to the centroid of all platforms, the evolution of the centroid of all platforms over time, average distance Gini coefficient or location mapping. These methods have been summarized in the literature review by He *et al.* (He *et al.*, 2018). Logistics sprawl is justified in the literature by:

- Land costs, which decrease with the increase of the distance from the urban center (Hesse and Rodrigue, 2004; Verhetsel *et al.*, 2015; Kang, 2018b),
- Urban policies that do not encourage logistics companies to locate in city centers (Meitzen *et al.*, 2012)
- 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 two literature reviews (Aljohani and Thompson, 2016; He *et al.*, 2018).

Logistics sprawl has been studied for Paris metropolitan area specifically, first, for parcel service's platforms (Dablanc and Rakotonarivo, 2010), and secondly, more globally with warehouse, platforms and other spaces that support activities for transportation (Heitz and Dablanc, 2015). Studies conclude, among other things, a 11.8 km augmentation in the average distance of parcel service platforms to their centroid between 1974 and 2010. They conclude that this sprawl comes with an increase in the distances travelled to carry freight into the city center and, by implication, that CO₂ emissions due to delivery increase accordingly (Dablanc and Andriankaja, 2011).

As a matter of fact, the majority of the research mentioned above assumes that demand is fully concentrated in urban centers. However, this assumption should be challenged. With the increasing decentralization of economic activity, there is a growing body of evidence suggesting that demand for goods transportation is becoming more dispersed and not concentrated within the urban centers. This shift in demand patterns has significant implications for transportation planning and policy, as traditional models that rely on centralization are no longer adequate (Riguelle, Thomas and Verhetsel, 2007). Moreover, studies showed that the relationship between logistics sprawl (distance between platforms and their centroids) and actual distance travelled is much more complex than a simple one-to-one function. In other terms, be located close to the urban center is not always optimal depending on the type of goods (Sakai, Hyodo and Kawamura, 2018; Kang, 2020).

Finally, an overall observation is that a majority of these studies are based on platform location information, a few of them on national surveys, and none of them on actual carrier data (Kang, 2020). This implies that there is limited precise information, at the level of an

actor, on demand (that issue is discussed later on in Subsection First and last miles in urban area, page 62). This lack of data can lead to assumptions about the operational strategies of carriers. In the case of logistics sprawl, an assumption made is that all the platforms deliver urban centers while in reality a carrier will use a number of platforms to operate in a metropolitan area, but not all of them will serve the urban center (Robichet and Nierat, 2021; Katsela *et al.*, 2022; Trent and Joubert, 2022) and with the benefit of being able to develop spaces that are often under-exploited (Buldeo Rai *et al.*, 2022). This cannot be observed using the methods described above, and it challenges the impact of logistics sprawl. This point will be developed in the first chapter.

2.4. Long distance

Long-distance freight transportation is a complex issue that is transversal to various research fields and approaches. While urban logistics is seeing the emergence of new and innovative modes of operation such as cargo bikes, drone delivery, crowd logistics, etc., long-distance logistics relies on the same traditional means of transport: road, rail, inland waterway, air and sea. Today, the majority of long distance in Europe (and specially in France) is carried out by trucks. In France in 2021, trucks represents 87% of the metric tonnes-kilometers and 77 % in 2020 in Europe (on the whole transport chain) (Commission, for Mobility and Transport, 2022; SDES, 2022).

In France, the solution to decarbonizing long-distance transportation often focuses on modal shift, and particularly on combined transport (Lopez-Ruiz and Crozet, 2010). Similarly, at the European Union level, the White Paper for decarbonizing transportation includes plans to increase the use of trains for freight transportation (Kallas, 2011). More generally, combined transport is put forward as a promising solution for the successful ecological transition of freight transportation (World Bank, 2012; Mostert, Caris and Limbourg, 2017; Pinto *et al.*, 2018). In the case of France, rail freight has two major advantages in the context of decarbonization. To begin with, a significant part of the network is electrified (59%) (Ministère de la Transition Ecologique, 2021). Secondly, the French energy mix, largely dominated by nuclear power, supplies very low carbon electricity, i.e. 48 g CO₂/kWh (Huet, 2019). Therefore, on average, a train emits 17 g.CO₂e/tkm while a diesel truck emits 92 g.CO₂e/tkm (CGDD, 2019; Michel *et al.*, 2020).

It should be kept in mind that combined transport is but one way to put freight on railroads. As a matter of fact, there are three main possibilities to operate rail freight transport (Nierat, 2011):

- Block train: a train goes from a point A directly to a point B (comes back to the Figure 1 but with a train instead of a truck). This requires that points A and B are both physically connected to the railway network and that the flow is sufficient – this market segment, which is mostly relevant to heavy industry and raw material commodity flows, is not discussed in the following;

- Wagonload service: the idea is to pool flows from several actors: in that case, each shipper must be equipped with its own railway infrastructure, in order to be able to receive wagons and handle the goods in the wagon (directly in the wagon or by disconnecting the container and the wagon according to what makes the most sense. In a way, it is the equivalent for rail freight transport of parcel transport for road transport: the objective is to fill vehicles (in this case train) while allowing customers to send “small” shipments (in this case a few wagons) thanks to a consolidation process. Wagonload service also requires that the origin and destination be physically connected to the railway network. The cost and efficiency balance of this kind of service is, unfortunately, not always in favor of the railway when compared to road transport and shows a decline in Europe in recent years (Guglielminetti *et al.*, 2017);
- Combined transport: this type of operation consists in running a full train between two intermodal terminals (first solution) in combination with road transport to connect shippers and receivers (pre and post haulage by trucks as described in section 1.4.3). In that case, the origin and destination of the freight needs not be physically connected to the railroad network. This is the solution which will be explored in the following of this section and manuscript.

This section focuses on two modes: road (the main mode currently) and combined transport (rail option chosen). Inland waterways, by nature, is limited by the geography of the waterways network. This is particularly true in France, notably due to the lack of facilities and network. Railway does not have the same physical limitation. In many countries, railway has been the main transport mode for freight in the past. This is the case in France, where a developed and mostly electrified rail network have been built over years. If the network is already present, which means that shifting back freight from road to railway does not start from scratch, all paths are not necessarily adapted to current trains: weight limits too low, slope too steep, tunnel too small, etc. (for example, the line between St Jean de Maurienne and Modane, connecting France to Italy, does not allow to support trains of more than 1,500t). In other words, if the case of France allows us to rely on an existing network, in the case of a strong development of rail, it will be necessary to invest massively to adapt the network to the demand for freight (Tyler Von Brown, 2011; Chong and Hopkins, 2016). The goal of this

section is not to cover all the sub topics link with long distance but to focus on some important themes for the comparison of trucks and trains:

- Operational constraint;
- Flexibility;
- Cost;

2.4.1. Operational constraint

One of the main advantages of using truck transportation over rail transportation is operational ease. Trucks have the ability to use a much more extensive and well-developed road network compared to the railway network (more than 1,100,000 kilometers of roads for trucks compared to 27,000 km of railways for trains), making it easier to navigate and access an enormously wider range of destinations. As a direct consequence, all sites of production in France are connected to the road network, which is not the case with the rail network. In France, there are about 3,000 railway sidings in 2019, however, 62% of them had no freight traffic at that time (Cerema, 2019). The 3,000 railway sidings⁹ must be compared with the more than 11,000 railway sidings present in France in 1970. As a basis for comparison, a study in Germany (where 19% of freight transport was done by train in 2014 in t.km) shows that only 6.4% of the German logistics locations are directly connected to the rail network (Rolko and Friedrich, 2017; Eurostat, 2018).

While combined transport offers flexibility for a carrier, there are still constraints: First, the time constraints of the train (fixed time of use of the train path) (Flodén, Bärthel and Sorkina, 2017). Secondly, the use of combined transport is constrained by the existence of a service between the two desired intermodal platforms. In France there are only 186 combined transport connections. For a carrier to choose combined transport, there must at least be a

⁹ Access track to a main line allowing to connect a facility (which can be a logistic facility) to the global railway network.

service on the desired axis and the timetables must be compatible (Robichet, Nierat and Combes, 2023).

2.4.2. Flexibility

In the event of a 5-minute delay interfering with the process, in the worst case, the truck would arrive 5 minutes late at its destination. In the case of an intermodal solution, a 5-minutes delay can mean missing the train, and it would be necessary to take the next train, which could be several hours or even the following day, resulting in a significant delay in the transportation chain (Nierat, 2002, 2011).

Furthermore, truck transportation also offers greater flexibility in terms of scheduling and routing, making it more adaptable to changes and unforeseen events. This is particularly important for businesses that need to ensure timely delivery of goods to customers. More generally, combined transport is more complex and offer less flexibility over road transport (Frémont and Franc, 2010).

Finally, the first and last miles (or kilometers) are generally done by road. Transporting over long distances by road means not having to multiply the modes of the global chain. Overall, when looking at the operational ease and flexibility, many companies would choose truck over intermodal as it is a more practical choice.

2.4.3. Cost

Finally, the cost of long-distance transportation is a crucial factor for companies. It is through consolidation over long distance that actors make a margin (Faibis, 2020).

According to several studies, combined transport is more cost competitive than road freight transport above a given threshold which varies with the authors, ranging from 300, 500 km or longer (Arnold, Peeters and Thomas, 2004; Janic, 2007; Hanssen, Mathisen and Jørgensen, 2012; Meers, Vermeiren and Macharis, 2014; Zgonc, Tekavčič and Jakšič, 2019). This can be explained by the fixed costs of rail transportation, such as the cost of railcars, locomotives, pre and post haulage are spread over a smaller number of miles, making it less cost-effective for shorter hauls. However, determining the relevance of combined transport only from the distance to be covered totally ignores the questions of geographical and economic context around the two intermodal platforms which are decisive for the relevance

of combined transport. The theory of market areas addresses all these factors (Nierat, 1997). The theory also enables to show that the competitiveness threshold distance depends on the spatial density of demand around the departure and arrival terminals, indirectly explaining, perhaps, the lack of consensus in the academic literature. The higher the demand density is, the shorter the minimal distance needs to be. Other studies have also looked at the impact of pre- and post-haulage on the economic feasibility of combined transport highlighting that the key distances from which the combined transport is more interesting is extremely dependent on the drayage (Nierat, 1997; Carboni and Dalla Chiara, 2018).

Consistently with this discussion, let us insist on the fact that this distance of 500 km does not correspond to a minimum distance for rail. In the case of a need between two places connected by rails and under condition of sufficient flow (volume or weight), the rail transport can be competitive although the distances can be widely lower than 500km (Nierat *et al.*, 2009). With respect to distance, the work of Craig *et al.* (2013) applied market area theory to the issue of emissions in the United States (Craig, Blanco and Sheffi, 2013). This question is less relevant in France, where the train is much less polluting in terms of CO₂ emissions compare to trucks due to the electrification of railways (59% in France compared to less than 3% in the US). This is, for example, not the case than in the United States where trains are mostly not electrified.

Furthermore, the economic model of the train is based on consolidation. Railway can only be competitive, with respect to road, if the train is almost full (in general, a train in France can transport 80 TEUs, that is to say 40 swap bodies) per train. The conditions where this is feasible are not easy. For example, it is rare that a single actor has the necessary volume to have its own train dispatched every day from a given origin to a given destination. The use of combined service requires to mutualize the flows of several shippers from an intermodal terminal A to an intermodal terminal B. This idea is similar as the one used for the development of a barge network (Groothedde, Ruijgrok and Tavasszy, 2005).

It has been shown that rail transport (as well as inland waterway transport) is much more price-sensitive than road transport. The latter is hardly responsive to the costs of alternative modes (Vierth *et al.*, 2017). This can be explained by the fact that road transport needs to

maintain a high level of service quality to have a competitive advantage, which may not be easily offset by price cuts from competing modes (Maier, Bergman and Lehner, 2002).

2.4.4. Partial conclusion

Finally, the use of heavy trucks allows for resiliency to be built into the transportation chain while offering a responsiveness unmatched by other modes. The advantages of trucking are best expressed in the study by Maier et al. (2002), which shows that in some cases firms are willing to pay more for trucking than using rail, and Pfoser (2022), which shows the limits from the point of view of the logistics providers of relying on multimodal transport (Maier, Bergman and Lehner, 2002; Pfoser, 2022).

However, the conditions where combined transport is more competitive than road transport are not always well understood. This is a critical question, as under free market conditions, shippers and carriers will only shift from a road-only solution to a combined transport solution if that goes with reduction of costs, improvements of level of service, or a suitable combination of both. Classic transport economics approaches, based on the limited datasets produced by public institutions and ministries, examine the domain of competitiveness of combined transport through a classic generalized cost approach which, although consistent with the structure and quality of the data, does not bring the full light on what it means, in practice, for a firm (shipper or carrier alike) to shift from road transport to combined transport (Tavasszy and Jong, 2013). Specific papers address this gap; this is the case of the market areas theory that makes it possible to define the geographical areas of economic relevance of combined transport vs. road (Nierat, 1997).

3. Data

This section begins by examining the open access data available in the literature (mainly at the scale of France). The aim is to provide an overview (but not exhaustive) of the current state of accessible data for freight in France and the implication of using them. In the second part of this section, the thesis will be situated in relation to the existing literature, with the objective to identify any gaps or opportunities for further research

3.1. Traditional data sources

This section proposes a short presentation of the databases available to academic research in France and the implications for the models based on them. The following databases will be presented:

- ECHO
- ETMV
- Transit – CAFT
- SitraM-I
- SIRENE

3.1.1. ECHO

The ECHO survey, designed and first conducted in 1988, analyzes freight transport at the shipment level in France. It is one of the few Commodity Flow Surveys (CFS) realized in the world. It consists of asking a sample of shippers about the characteristics of three shipments out of the twenty last shipments they dispatched at the time of the survey. For each shipment, variables regarding the shipment characteristics, the shipper-receiver relationship, the freight transport operation (or sequence of operations) and the contractual relationships between all the firms which participated in the production of the transport operation. Two large waves were conducted in 1988 and 2004. Since 2016, smaller scale surveys are conducted annually. Those simpler surveys do not look at packages under 1kg anymore, and examine much less variables.

The 2004 ECHO survey includes a sample of 2,935 shippers (with a total population of 69,256 shippers) and a sample of 10,462 shipments from these shippers (with an estimated total annual population of 738 million shipments for 984 million tons)¹⁰.

One of the main results of the survey is the importance (in terms of quantity) of small shipments, which weighs little in global statistics when analyzed in terms of tons and t.km. The survey has made it possible to conduct other various studies, such as the influence of the activity on the organizational choice of a carrier, namely how to predict the choices of location and organization (hub and spoke or point-to-point) of the transport operation, according to some characteristics of the shipper and of the shipper-receiver relationship (Combes and Tavasszy, 2016). The survey also allowed to validate in a French context results obtained in a German context on the relationship between the choice of shipment size, on one hand, and other characteristics such as the conditioning and handling constraints on the other hand (Piendl, Liedtke and Matteis, 2017; Piendl *et al.*, 2022).

3.1.2. ETMV

The ETMV survey (Enquêtes Transport de Marchandises en Ville – Urban Freight Transport Surveys) focuses, as its name suggests, on urban freight transport. It is intended to complement the TRM survey (described below), which provides information on interregional flows but does not allow for a detailed analysis at the level of a metropolitan area (see below). The unit of study is the vehicle movement (i.e., what happens between two consecutive stoppings of the vehicle; several operations can be performed during a movement). This survey is intended to be highly descriptive and to provide a broad view of freight transport in an urban area, but this implies a significant cost. The survey was conducted in two phases:

- 1995 – 1997 in Bordeaux, Dijon and Marseille ;
- 2010 – 2013 in Bordeaux and Paris metropolitan area.

¹⁰ splott.univ-gustave-eiffel.fr/fileadmin/redaction/SPLOTT/documents/ECHO/ECHO_synthese_resultats.pdf

For the Paris metropolitan area ETMV survey, Data collection took place over 2 years and includes: 1,200 facility forms, 5,000 operation forms and 900 driver forms.

Aside from providing direct knowledge about urban freight transportation, the ETMV datasets were designed to input the Freturb model, which simulates the occupation of the roadway by freight transport and the impact of the implementation of governance on it. When used for simulation, FRETURB uses SIRENE (presented below) like databases as input (Toilier *et al.*, 2018).

3.1.3. Transit – CAFT

This survey conducted by the Ministry of Ecological Transition provides information on international road flows in France. The scope of the study is all transit road traffic (without a stop in France) or international exchange traffic (origin or destination in France) for trucks over 3.5 tons (MTECT, 2018). This survey was conducted in 1992/1993, 1999, 2004 and 2010. Since 2010, it has been replaced by the CAFT - Cross Alpine Freight Transport - which provides information on cross-border trade at the European level by trucks and trains. The unit of study is the weight and number of trucks.

This database is based, for the French perimeter, on road flows from road managers (tunnels and highways) and on rail operators for rail flows¹¹.

3.1.4. SITRAM

The SITRAM database provides a broad view of freight transport in France and is used to supply global public statistics. It covers all modes of transport except pipelines: road (via TRM, see below), rail and inland waterways. The units of study are: the weight and the t.km.

¹¹ transport.ec.europa.eu/system/files/2020-07/2020-alpine-traffic-observatory-key-figures-2019.pdf

For rail, the information is collected directly from the 13 operators authorized to operate rail freight in France. For inland waterways, the data is collected from VNF, manager of the inland waterways network¹².

Also included is the customs file, which allows the integration into SITRAM of the flows of foreign trade, excluding the transit, and above a certain threshold. Firms which engage in international trade from or towards France have to declare the nature and value of the traded goods, when the value of the transaction is higher than a given threshold. The nature of the declaration and the thresholds depend on the commodity type and on whether the trade is inside or outside the European union. Without entering into too much detail, customs data can provide useful information about transport, but it is not a transport dataset per se.

3.1.5. TRM

This survey, conducted by the Ministry of Ecological Transition, provides global public statistics on road freight transport. The scope of the study is all national road freight traffic in France and road freight transport abroad under the French flag of trucks over 3.5 tons and less than 15 years old (MTECT, 2018). The unit of study is weight and t.km. It is a compulsory survey, and all countries of the European Union must do them. The survey methodology is managed by Eurostat. This survey is based on vehicles: carriers are required to declare the movements of their trucks, and their loads, over one week. By construction, this survey provides no direct information on the shippers and receivers of those freight movements. However, it gives a statistically representative information about the nature and geography of freight flows in France, and works as one of the main data sources for standard freight modelling.

In 2018, the sample size is 71,504 trucks for a total population of 540,646 trucks.¹³

¹²statistiques.developpement-durable.gouv.fr/sites/default/files/2018-11/sitram-metadonnees.pdf

¹³statistiques.developpement-durable.gouv.fr/sites/default/files/2019-07/rapport%20qualite%20TRM2018.pdf

3.1.6. SIRENE

The SIRENE database describes the type of activity and the location of all economic establishments as well as their size (number of employees in France). It is regularly used in conjunction with the previous databases because they are complementary. This dataset has been made open source in France a few years ago.

3.1.7. Critical analysis

The databases presented above constitute the set of public data (public meaning that the data is produced by the public sector, which does not automatically entail that the data is publicly available) currently produced in France. These databases observe different aspects and different levels of freight transport in France, and they can be combined to get a global vision of the sector. However, two limits must be underlined, which impact greatly the exploitation which can be made.

First of all, each database is meant to be complementary to the others - to provide information on a blind spot of the others. However, each survey has its own methodology that is not harmonized. For example, the observation unit is not universal, which makes it difficult (sometimes considerably) to integrate those databases. For example, the unit of study of ETMV (vehicle movement) is not the same than TRM (weight and t.km) limiting the possibilities of synergy between the databases.

Secondly, the absence of the actor concept in all the databases is a significant limitation for a detailed analysis of a company's situation, although it does not affect national-level analyses. This limitation hinders the adjustment of the databases since assumptions must be made and prevents the consideration of the fact that each actor deploys a strategy based on its own network strengths and weaknesses, as well as operational choices. For example, a carrier will prefer customers that are geographically closer or complementary to its business. He will rarely take a customer that is not in such locations. That same customer may be well located for another carrier. The parallel can be made for the type of shipment, a carrier adjusts its chain to a type of parcel, for example a carrier adapted to do mail is not adapted and will not seek to have parcels of 200 kg in his network. The existence of a segmentation of road transport is natural (see Figure 4). Consider the example of an express carrier: its whole structure, fleet and organization is designed to transport efficiently light shipments. For this

carrier, taking care of a heavy shipment is a problem, as its production toolset is not adapted to such a transport operation. It is from this perspective that one can state that the segmentation of the freight transport market is, in a way, natural. These statements can hardly be derived from the public datasets described above. Given how those datasets are produced, they give little information about market structure, and even less about the strategies and constraints of firms within.

This observation has important implications regarding modeling. Many simulations rely on notions of randomness or equal distribution among hypothetical actors as a way to turn around the fact that datasets are very incomplete. This neglects the above-mentioned points and, depending on the question of interest, can lead to substantially erroneous assessments of the situation. The point here is not that all models are irrelevant, but when the models go beyond their area of relevance or when they are based on false assumptions, they can yield erroneous conclusions. By zone of relevance, the author of this manuscript means the field in which a model is relevant.

The previous discussion is illustrated in the work of Hintjens *et al.* (2020) on the possibility of using intermodal transport from the ports of Zeebrugge and Dunkirk (Hintjens *et al.*, 2020). Simplifying assumptions on the distribution of flows from public statistics, simplifying modelling for the first and last miles of combined transport, and poor economic modelling lead to erroneous conclusions on the beneficial impact of a cooperation between the two ports as it has been proven afterward. Depending on the chosen hypotheses of the authors, results highlights that the overall situation is more interesting using combined transport, however, this is not the case individually for the two ports. As a result, the port (for which it is not interesting) will not get involved in the project which means that the whole operation is not interesting anymore since there is no longer any mutualization between the two ports' flows (Nierat, 2022).

Other studies such as the one conducted in Bordeaux on the use of urban consolidation centers also highlight the points discussed above (Dupas *et al.*, 2023). The use made of the ETMV survey in Bordeaux completely overlooks the existence of actors with different characteristics and objectives. This leads to the use of ratios that do not correspond to any segment of road freight transport. For example, for the calculation of vehicle fleets, the

authors assume a Light Commercial Truck (LCT) capacity of 15 parcels (of an average of 4kg). They also assume that an actor will tend to maximize the use of a vehicle to maximize his profit. This does not correspond to a time constraint to complete a round (a parcel service carrier does on average 20 to 25 pick-up or delivery operations per round; an express operator does more than a hundred per round), nor to a weight constraint (an LCT easily has a payload of 800kg or a limit of 200 parcels in our case). In view of the figures, it seems that time is the limiting constraint. A low limit of 20 operations per round implies that the study has increased the fleet by at least 33% (meaning to increase from 15 to 20 operations per tour). With an average weight of 4kg, it corresponds to more express parcels which are on average more than 100 points per round in urban areas. In this case, this leads to an over evaluation by the authors of the fleet of more than 560% putting in doubt all the economic or environmental evaluations which result from it (meaning to increase from 15 to 100 operations per tour). This illustrates the importance of considering the actor.

The two examples above are but isolated illustrations of an important point: classic datasets are useful to give a representative idea of the sector's activity, and are a sound basis for *some* models. However, as models aim at representing how the sector would react to some stimuli (most often, said stimuli come from the implementation of public policy instruments which are designed to improve the socio-economic and/or environmental balance of the transport system), they always imply, whether it is made explicit or not, a behavioral component. Behaviors are at the level of the actors. For them to be correctly modelled, it is necessary (and not sufficient) for the datasets to be precise enough, or for the errors, gaps and lack of accuracy of the datasets to be irrelevant to the questions being modelled. In addition, it implies that if actors are to change their behavior (e.g. adopt a new solution or organization – whether it is sustainable or not) they have to be better off of it, it is never a sufficient condition that the global balance is positive. The research developed in this manuscript was built on the basis of these two principles.

3.2. Data used for this work

The work presented in this manuscript is based on a method that is not widely used in the literature: the exploitation of operational data from actors (carriers and shippers). The author of this thesis had the opportunity to obtain access to different data sets from different freight transport actors, both on the demand and on the supply side. Those datasets cannot provide a statistically representative global vision of transport. However, what they lack in term of coverage, they compensate by allowing a fine analysis of the strategies and constraints of some important actors. This allows to understand the mechanism and operational strategy implemented by different actors as well as a complete analysis of the transport chain without having to supplement the gaps of public statistics datasets with assumptions on the nature and distribution of the lacking data.

Each chapter is based on different data sets that will be fully described in each chapter:

- Chapter 1: DB Schenker (~1,200,000 shipments) and two express carriers (~1,100,000 shipments);
- Chapter 2: DB Schenker;
- Chapter 3: DB Schenker and 9 shippers including 5 members of the CAC 40 (~6,000 connections representing 8.9 t.km over one year).

This thesis is therefore complementary to the rich field of studies based on national or international databases. Although not comprehensive, this work hopes to provide a more detailed understanding of freight transport in France. This work also hopes to contribute to the field of modeling.

SPATIAL ORGANIZATION

This chapter integrate elements adapted from the article published in:

Robichet, A., Nierat, P., 2021. Consequences of logistics sprawl: Order or chaos? - the case of a parcel service company in Paris metropolitan area. *J. Transp. Geogr.* 90, 102900. <https://doi.org/10.1016/j.jtrangeo.2020.102900>

This chapter focuses on the notion of spatial organization of an actor in relation to his activity, this notion has already been presented and discussed in the sections 1.3 et 0. For this purpose, we will study the implementation of three companies (DB Schenker and two express carrier) at various scales. First, we will look at the national scale for its long-distance network (DB Schenker only). Secondly, we will look at the local service with the regional implementation in the Paris metropolitan area for DB Schenker in 2018 and 2022. A complementary study has been carried out on two express carriers with data from 2019.

This chapter discusses the difference between theoretical (point-to-point or hub and spoke) and real organizations for long distance. For the first and last miles, the question of spatial organization to operate a metropolitan area is discussed. This allows us to understand the phenomenon of logistics sprawl from the point of view of the location of the carriers' activity and raise the question of polycentrism to operate metropolitan area. The two parts are independent.

1. Long distance organization at national scale

First of all, the question of the national organization of a carrier is addressed. The objective is to understand which strategies are retained, to identify the trade-offs between a hub and spoke or point to point organization. To do this, we will use the organization of the carrier DB Schenker in 2022.

1.1. Description of the operation and general data

At the national scale, DB Schenker is composed of a general management which deals with national issues and 80 local agencies¹⁴ spread over the French territory. An agency consists in a platform (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 decentralization of the sales department within the agencies allows to reinforce a local establishment. Customers close to the platforms can send the goods later in the day without increasing the delivery time, which gives an advantage in terms of supply. The long-distance network is provided by a fleet of semi-trailers.

To conduct this study, we had access to two databases:

- The list of 80 platforms;
- The routing of long-distance trucks over a week between platforms with departure and arrival times end of January 2022 (~2,000 daily trips).

¹⁴ The term agency is used inside DB Schenker to call what has been called platform earlier

1.1.1. Organization: hub and spoke or point-to-point?

A first analysis of the connections¹⁵ allows us to see that not all platforms have the same weight in the network, the best-connected platforms have a maximum of 57 daily connections (where a theoretical maximum is 79 connections if connected to all platforms), while the less well-connected ones have only one as shown in Figure 11. Thus, there is a three scale of platforms:

- The high-connected platforms (connected to more than 65% of the network), three of them are clearly more connected than the others, which structure the connections on a national scale;
- The middle-connected platforms (connected to 20% to 56% of the network), these platforms form a finer network in support of the structural triangle;
- The low-connected platforms (connected to less than 17% of the network), these platforms mainly connected to the middle-connected platforms allows a fine service of the territory.

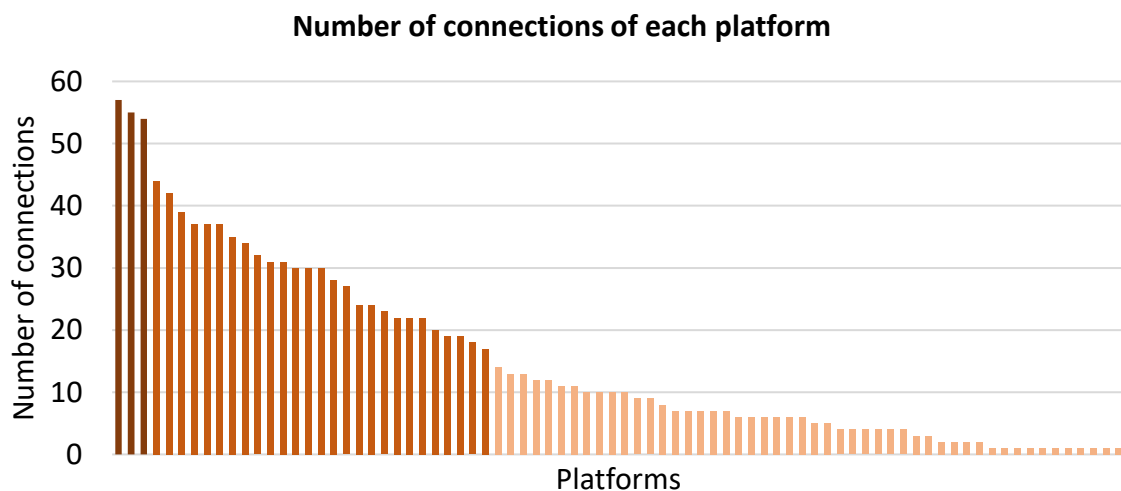


Figure 11 – Number of connections of each platform at the scale of France for DB Schenker

¹⁵ A connection is the link between two platforms, it is possible to have several trips on a connection, the routing is the set of trips

Finally, in a comparison to a one-point theory approach as presented in section 1.3, there would be 6,320 connections (80×79). In a hub and spoke organization there would be one hub with 79 connections and the others with only one connection. In reality, there are 1,437 connections for a total of 2,097 daily trips (by trip we mean the route made by a truck, a connection can have several trips). This shows a first example between theory and practice and the fact that the theoretical "rules" do not necessarily represent usage.

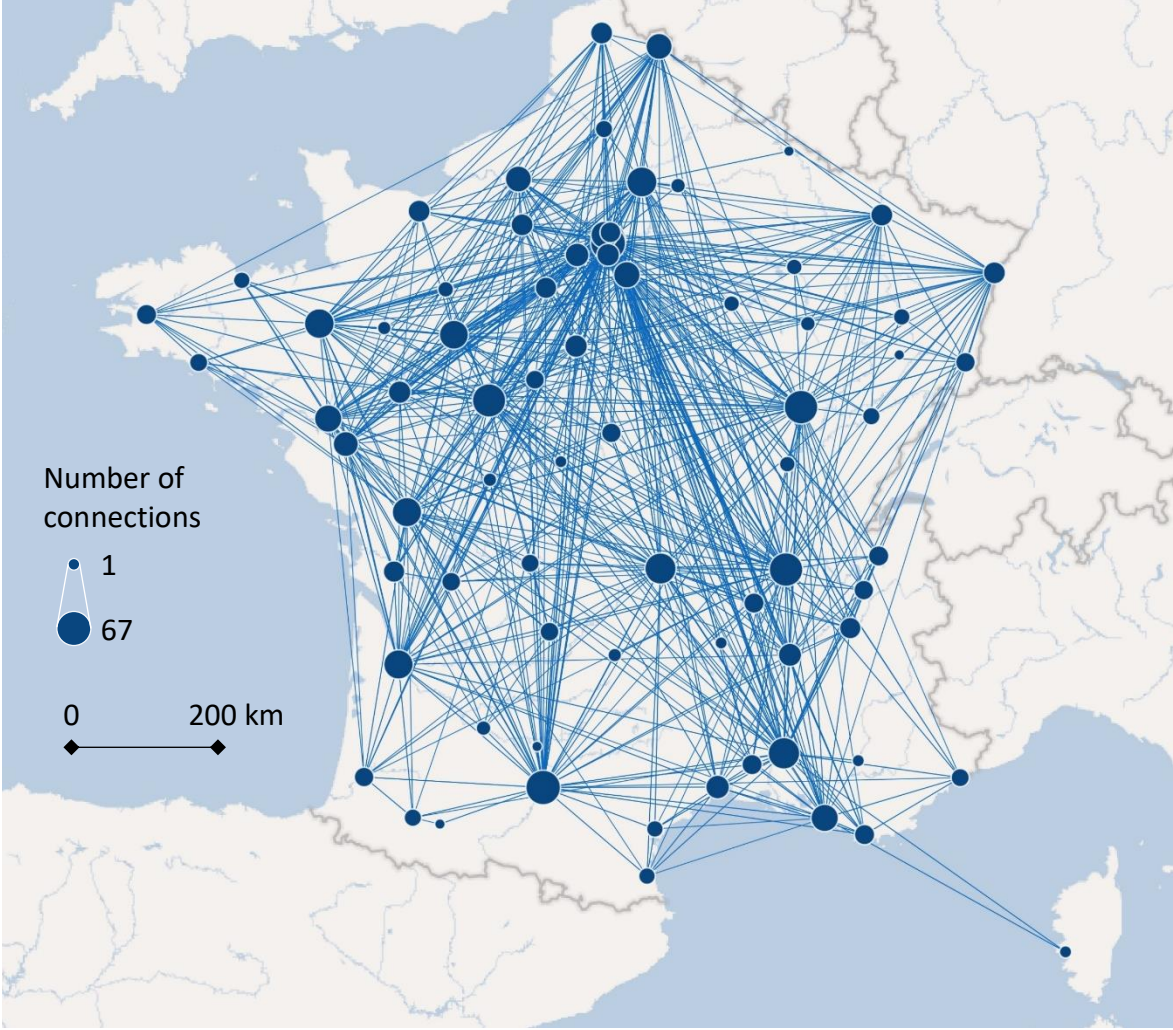


Figure 12 – Map of DB Schenker's daily long-distance network, the scale of the connections per platform is purposely hidden, author's realization

Figure 12 shows that the geographical distribution of platforms provides maximum coverage of the territory. However, if high and middle connected platforms are distributed throughout the country, there is an over-representation of platforms on the Paris-Nantes axis and few platforms on the empty diagonal – diagonal of low densities is a convenient and schematic representation of territories that are less densely populated than the French

average, forming a band crossing the country from the Northeast to the Southwest¹⁶. This can be explained by the history of DB Schenker, which relies mainly on the messenger network of the company Joyau (acquired in 2005). The latter has its historical headquarters in Vendée and has expanded from the west of France.

1.1.2. Integration of the long-distance network in the global chain

One of the specificities of the parcel business of DB Schenker is that most parcels are delivered within 24 hours. This requires that long-distance trucks leave after the rounds (deliveries and pick-ups) have been completed and all the parcels have been sorted by destination and that the trucks arrive at the arrival platform early enough to have time to sort the parcels by final destination before the rounds leave. In the current DB Schenker transportation plan, more than 82% of trucks leave the platforms between 7pm and 3am and 81% arrive between 9pm and 6am (Figure 13).

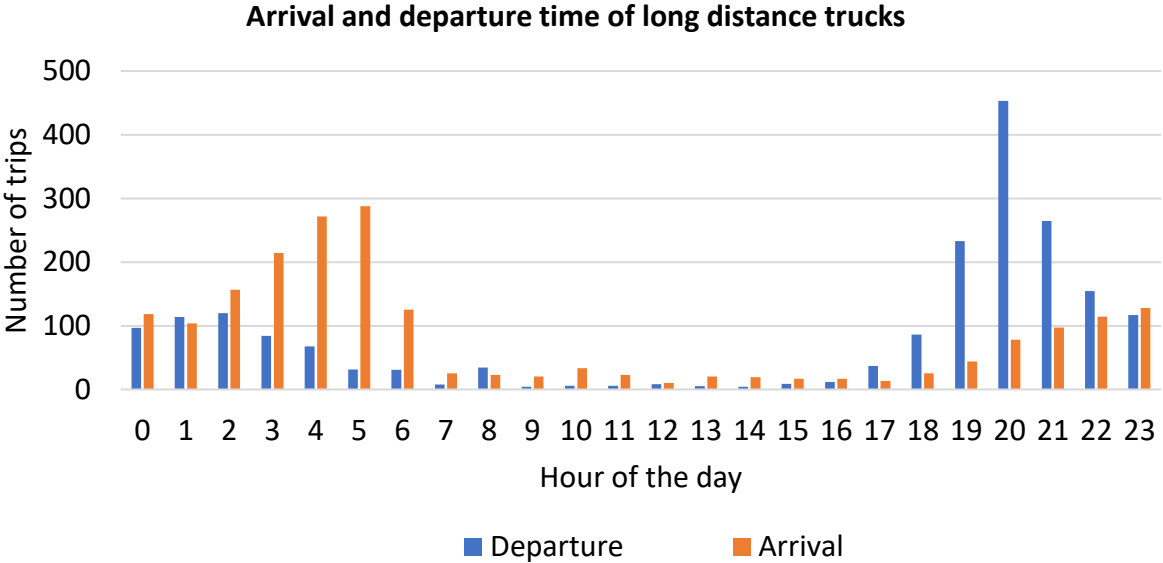


Figure 13 – Arrival and departure time of long distance trucks according to the routing of DB Schenker

¹⁶ geoconfluences.ens-lyon.fr/glossaire/diagonale-faibles-densites, author’s translation

These early (long distance) departures allow for regional hub and spoke operations, i.e. flows are massified on a major axis before being redispached to other connections during the night. These strong operational constraints are explained by the model offered to the customer, the majority of the parcels are delivered in 24h and sometimes in 48h.

1.2. In-depth analysis

From the different data it was possible to conduct some further analysis. First, it was possible to reconstruct the paths between all the platforms and to calculate the number of intermediate platforms to get from point A to point B. All this is summarized in the Table 1.

Duration of the trip	Number of daily trips		Number of intermediate platforms
d+1	4,672	74.9%	0.9
d+2	1,346	21.6%	1.8
d+3	221	3.5%	2.2
d+4	2	0.0%	3.0

Table 1 – Accessibility of each platform and number of intermediate platforms

Table 1 indicates that the organization allows to efficiently connect the majority of the platforms in one night (d+1) while limiting the direct path. Indeed, on average, for d+1, each parcel passes through 0.9 intermediate platforms. The same conclusions can be applied for d+2. Overall, 96.4% of journey through several connections can be completed in two days maximum in France.

Looking at the sum of the daily trips, it is not equal to 6,320 (80*79) because one of the platforms (low-connected platform) is only connected to the network for the shipment, no route for the delivery of the parcels is given (this platform is the one of a partner and not DB Schenker's own). The assumption can be made that this is due to the fact that the routing is for one day only, at that date no deliveries from this platform were scheduled. This point also shows the flexibility of the 100% truck solution to change the routing according to the needs.

When looking at the distances covered on each trip, the average is 335km and the median is 270km. This means that all trips tend to be relatively short (as a reminder, Lille - Marseille ~ 1,000km).

Finally, we observe that the chosen organization is neither a hub and spoke nor a point to point but a mix of both. The objective is to coordinate the long-distance network in order to

be able to carry out consolidations, which can be seen in the fact that few journeys are carried out in direct route, but the majority of parcels arrive in d+1. In fact, the organization is similar to a hub and spoke but with three hubs. The multitude of connections (1,437) does not seek to create a point-to-point organization but corresponds to this multitude of hubs (which explains the number of intermediate platforms).

1.3. Conclusion

This section has identified that the long-distance network set up by DB Schenker is relatively complex and responds to a system of many hubs allowing an efficient network. This makes it possible to quickly transport a parcel across France based on relatively short long-distance connections (more than 50% are less than 300 km long) by carrying out several connections during one night. The parcel will stop once or several times during the journey with few direct route connection (on average, a truck will pass through 1.1 platforms to complete its journey).

Moreover, this network fits perfectly into DB Schenker's global chain. The long-distance network operates at night, while the first and last miles network operates during the day.

Finally, this network is exclusively operated by trucks, which allows for total flexibility. The network studied is that of the end of January 2022. The choice of the 100% truck mode allows to adapt the network according to the seasonality but also in a very punctual way as we have seen before. Therefore, it is possible to add new connections or trips according to the needs. The only limit is the size of the platforms, which cannot be modified. However, the flexibility of the road system allows transit flows to be transferred to another platform in the event of saturation of one of them.¹⁷

¹⁷ Based on an interview with a platform manager.

2. First and last miles in urban area

This section deals with the organizational strategies of a carrier to operate in a megalopolis (Paris Metropolitan area). This section examines the impact of logistics sprawl and seeks to explore the reasons why carriers locate on the outskirts of large metropolitan areas. This section is based on the article cited in the beginning (Robichet and Nierat, 2021), however the 2022 database is added to the 2018 database allowing to question the stability over time. Both databases correspond to all operations in January and February in Paris metropolitan area (for each year).

An additional work on two express carriers is presented afterwards. It enables to study the stability of the results on another segment of the road freight transport.

2.1. Description and 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 to calculate optimal platforms localization and assumptions are explained.

2.1.1. Paris metropolitan area

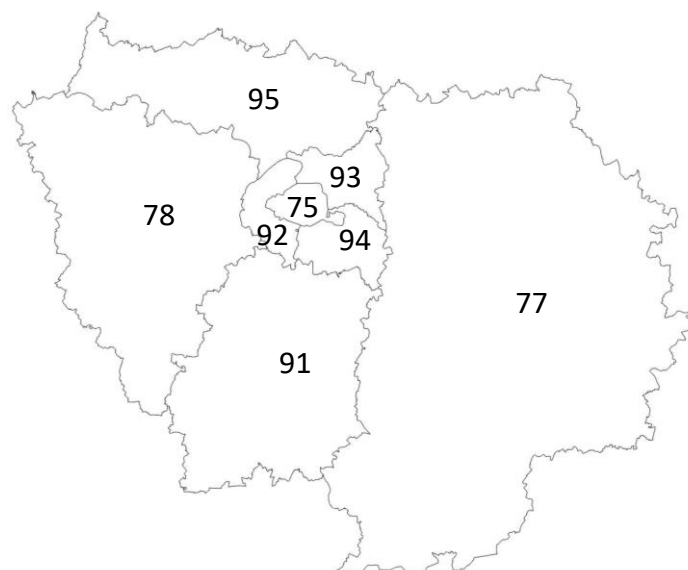


Figure 14 – The departments of Paris metropolitan area, author's realization

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 (Insee, 2019).

The area 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 78, 95, 77 and 91.

2.1.2. Running of parcel service carrier

DB Schenker's operations are as explained in Figure 3.

The following part focuses exclusively on understanding the running 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 80 local agencies spread over the French territory. AS mentioned before, an agency consists in a platform (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 decentralization of the sales department within the agencies reinforces the local appeal around the agencies.

2.1.3. 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 and January to February 2022. 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 platforms, date and time of delivery and the round ID of delivery (the round ID of pick-up is not available). For the 2022 dataset, the number of packages per shipment was also mentioned.

Table 2 summarizes all the information on the two databases over the two months of observations. Firstly, a 3% increase in both deliveries and shipments is observed between 2018

and 2022, which results in a shift from 583,864 operations in 2018 to 601,016 operations in 2022. The slight imbalance between shipments and deliveries is constant over time.

Secondly, in 2018, 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). In 2022, 77,586 shipments come from Paris Metropolitan area and go to Paris Metropolitan area. They represent 28% of deliveries and 24% of pick-ups and they appear in both tables (deliveries and pick-ups). Therefore, there is a strong increase in intra-Paris metropolitan area flows.

	2018		2022	
	Deliveries	Expeditions	Deliveries	Expeditions
Stock	271,293	311,971	278,868	322,148
Average weight[kg]	112	98	124	101
Median weight[kg]	54	52	56	50
Share of packages with a weight <200 kg	87%	88%	86%	88%
Geocoding accuracy				
address	260,024	291,349	267,713	312,483
city	11,268	20,612	11,155	9,665
Number of packages per shipments				
Average	-	-	5	5
Median	-	-	1	1

Table 2 – General information of DB Schenker in Paris metropolitan area in 2018 and 2022, geocoding via address.data.gouv.fr

Regarding the distribution of shipment weights, the shipment weights remain similar. Table 2 shows an increase in the average weight of shipments for 2022 compared to 2018 from 112kg to 124kg (+10%). Concerning the median for deliveries, the increase is less obvious going from 54kg to 56kg (+4%). For the expeditions, a +3% increase of the average can be observed (from 98 kg to 101 kg) but a decrease of 4% of the median (from 52 kg to 50 kg). Globally, the expeditions are lighter than the deliveries with a gap that tends to accentuate over time. Moreover, the share of packages under 500 kg remains stable. Figure 15 shows that there is a decrease of shipments between 0 and 24 kg and a strong increase of shipments between 25 and 49 kg. This explains the increase observed above. The other categories are relatively similar, with a slight increase in parcels over 500 kg (less significant than the change explained above).

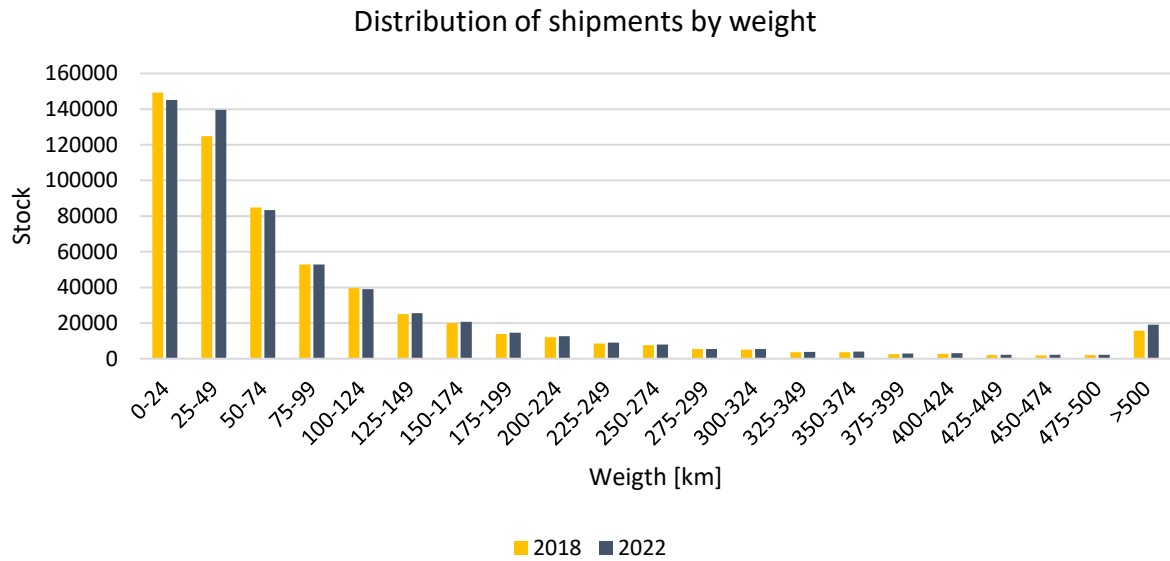


Figure 15 – Evolution of the distribution of parcels by weight

In order to work on the localizations and search for the optimal localization of the platforms, it has been necessary to geocode the addresses. Indeed, the addresses entered by the users were not perfectly filled in. Thus, the geocoding tool provided by the French state has been chosen (address.data.gouv.fr). 95% (for the 2018 database) and 97% (for the 2022 database) of the addresses have been geocoded to address accuracy¹⁸. 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-up¹⁹ (4% of the cases). The excellent results gave us a good 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, Henry and Zdeb, 2012; Buczkowska, Coulombel and de Lapparent, 2019). Secondly,

¹⁸ 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.

¹⁹ Paris metropolitan area is composed of 1,276 communes (one town hall by commune) for a total area of 12,012 km². 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.

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 (Dablan and Andriankaja, 2011; Dablan and Ross, 2012; Sakai, Kawamura and Hyodo, 2015, 2017; Heitz *et al.*, 2018; Heitz, Launay and Beziat, 2019).

2.1.4. Subject of study

In Paris metropolitan area, DB Schenker supplies its customers from five platforms. Four platforms are for national traffic and one platform is dedicated to deliveries from abroad (platform E in figure 16).

Figure 16 represents only the deliveries (the round ID for pick-up is not available) in 2018. Even though, deliveries and pick-up are carried out in the same tour, studying Figure 16 is sufficient to understand the spatial organization of DB Schenker in the area.

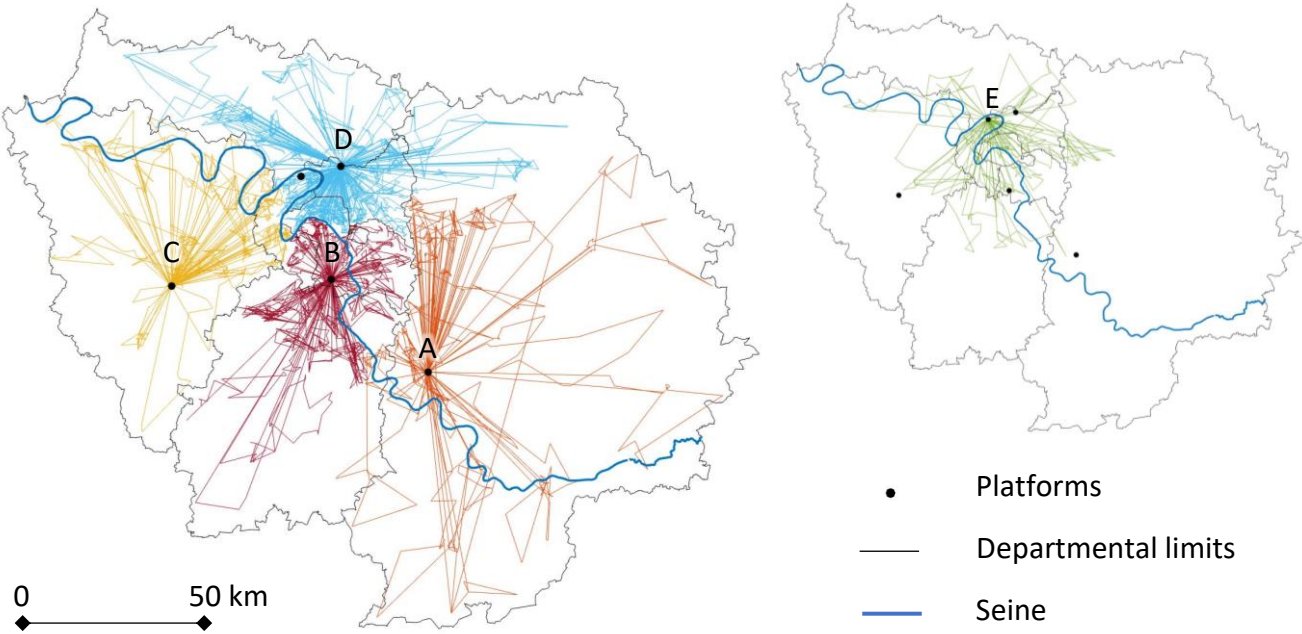


Figure 16 – Reconstruction of rounds for national (left) and international (right) deliveries on 01/23/2018 in Paris metropolitan area from the database, author’s realization

For national traffic, each one of the four platforms manage a territory that is easily identifiable in Figure 16. It highlights the polycentric organization of *DB Schenker* in the area. The region is divided into 4 geographical sectors, each platform having its own sector. The city of Paris is divided into two parts: north of the river Seine is handled from platform D; south of

the river Seine is handled from platform B. The rounds are organized by grouping of communes and by districts in Paris.²⁰

Interestingly, natural geographical divisions, as the river Seine, are tackled by polycentric organizations (Figure 16).

On average in 2018, 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 B2B²¹ than B2C²² oriented.

Platform	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 3 – Number of deliveries and pick-ups per platform in 2018

In the following, we will only consider the national activity operated from the 4 corresponding platforms. This choice is justified by the fact that platform 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 3).

²⁰ A fifth platforms opened between 2018 and 2022 in eastern Paris, see Figure 20

²¹ Business to business covers commercial transactions between two companies.

²² Business to consumer covers commercial transactions between a company and a consumer

2.1.5. Geographical distribution of deliveries and expeditions

The spatial distribution of activity is given in Figure 17. The scale of stock per cells is logarithmic because the densities vary in a ratio from 1 to 30,000 operations by cell (2.5 km² grid).

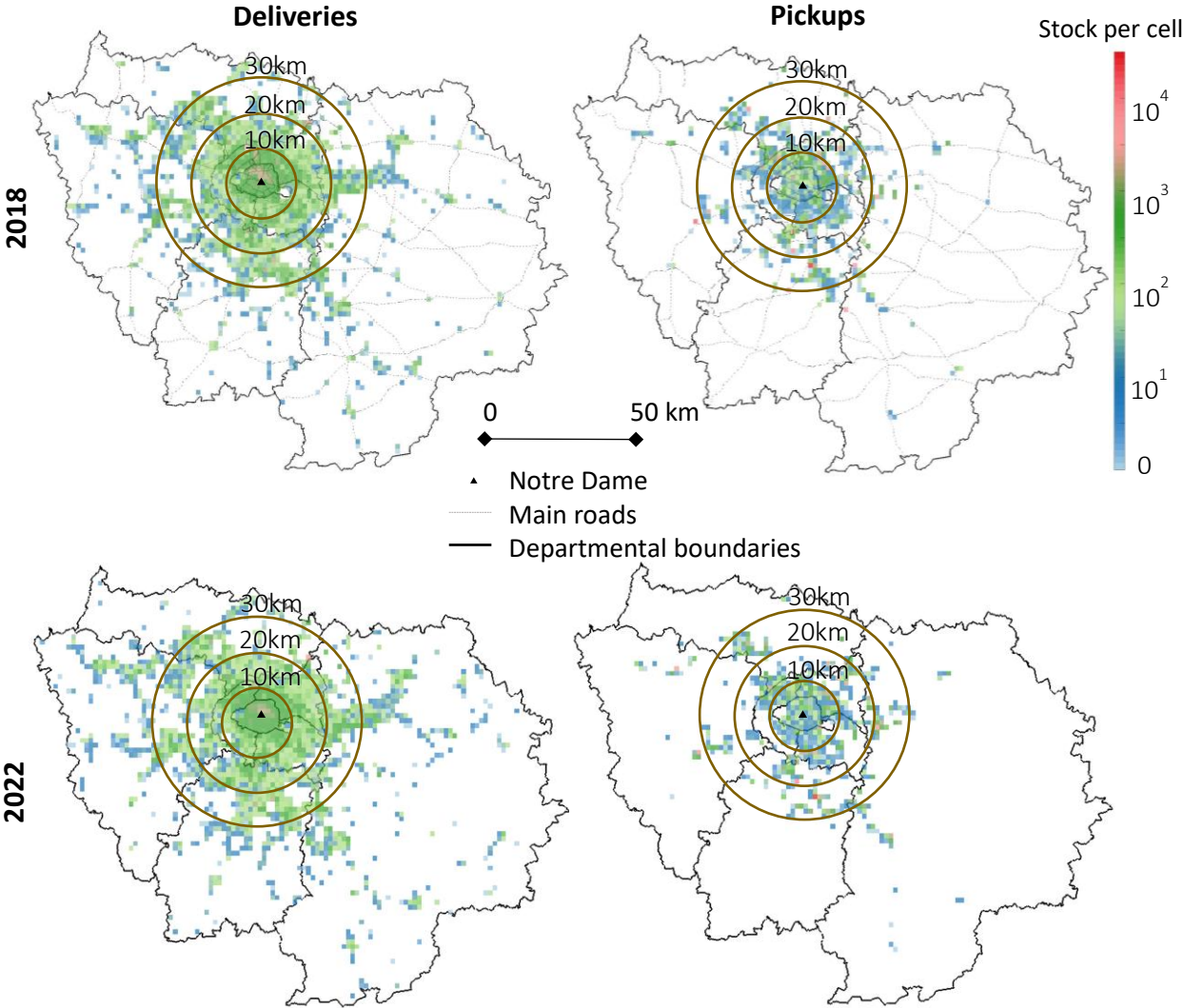


Figure 17 – Density of deliveries (left) and pick-ups (right) for two months, 2.5 km² grid, author’s realization

The first noteworthy observation is that pick-ups outnumber deliveries for this actor in Paris metropolitan area²³. 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). In 2018, 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 in 2018 and 322,148 in 2022. 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 in 2018 and 278,868 in 2022. Unlike pick-ups, the low density over a large part of the territory reveals a spatially dispersed demand. In 2018, 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. In 2022, deliveries in Paris represents only 10% of all deliveries.

Figure 18 gives the distribution of deliveries and pick-ups depending:

- (a) on the distance to the center of Paris (Notre-Dame) for 2018 compared to 2022 in total;
- (b) the distribution of deliveries and pickups for 2018;
- (c) the distribution of deliveries and pickups for 2022.

²³ 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.

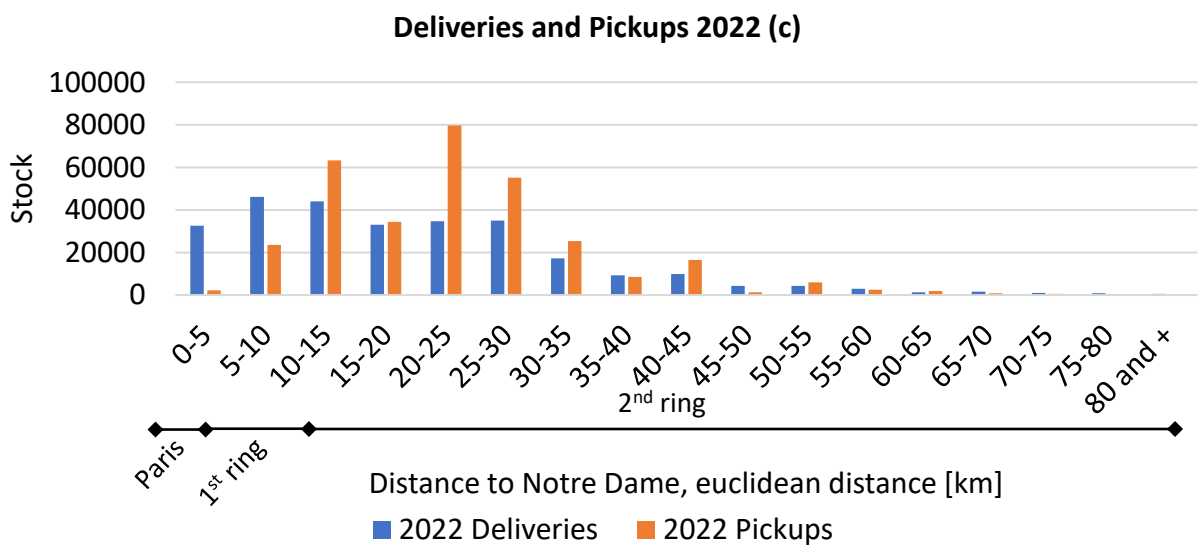
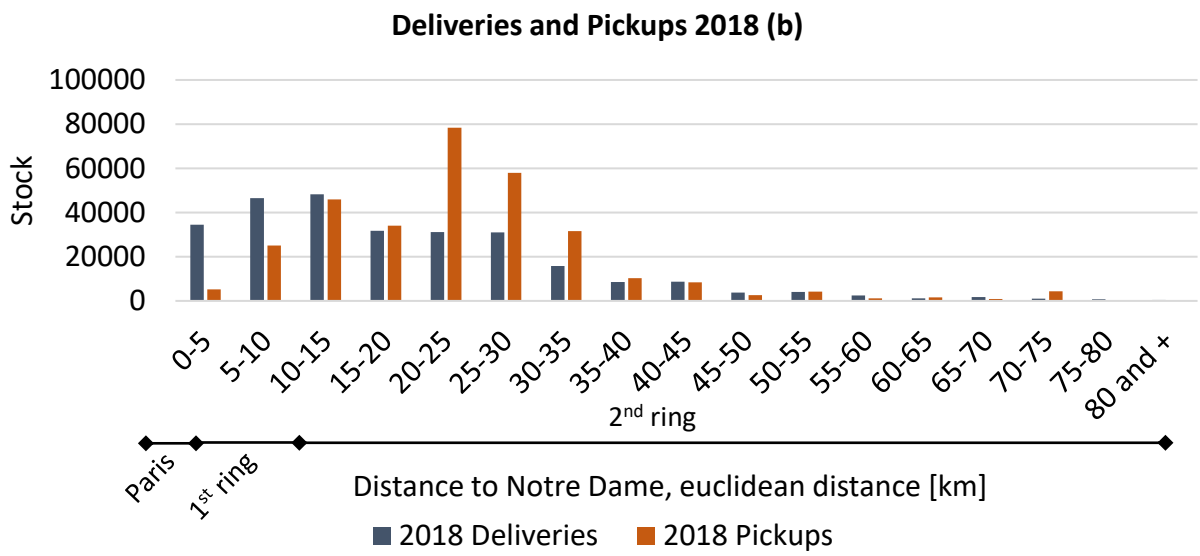
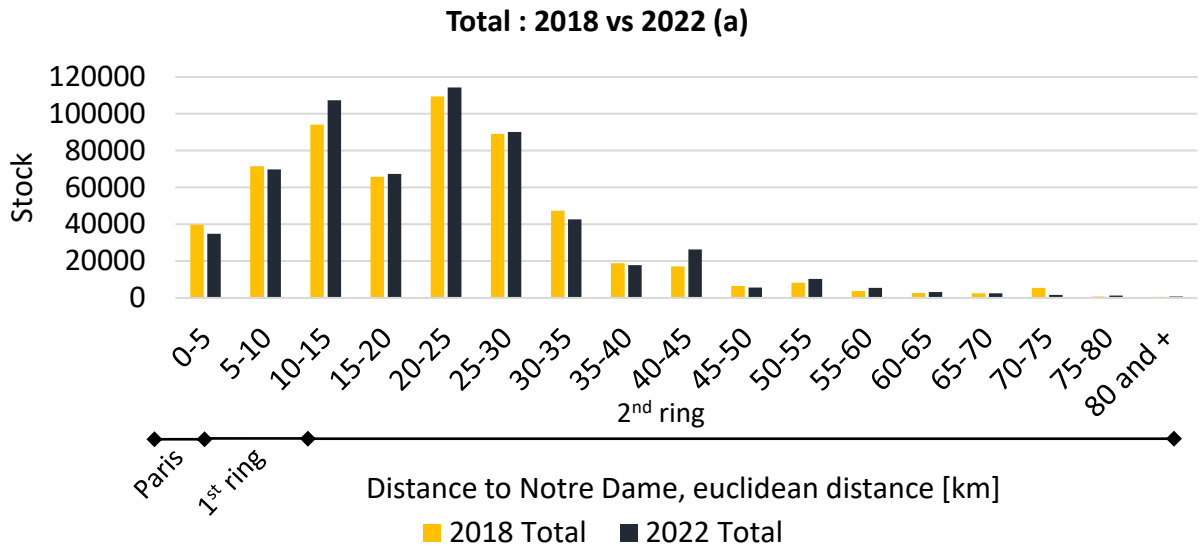


Figure 18 – Number of deliveries and pick-ups according to the distance to Notre Dame

Overall, besides the increase in stocks, the distribution has remained similar between 2018 and 2022. However, there has been a slight shift away from commodities, but it is complicated to know if this is a general trend over a small period of time even if COVID-19 happened during this time period (which changed the usual behaviors suddenly).

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. It is stable in 2018 and 2022.

2.1.6. Model used to calculate the optimal localization of platforms

Knowing the carrier's activity, the question is whether or not it would be possible to optimize the location of its platforms. The model used to find these locations was 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 platforms (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 considered;
- 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).

2.2. Results

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

2.2.1. Relevance between the number of platforms and the average distance

Figure 19 shows the results of the modelling (P-median algorithm). The situation of DB Schenker in 2018 for national traffic (4 platforms) is called S0. The optimized situation in 2018 (current platforms with points reallocation) is called S1. A change in the allocation of points to the platforms 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 platforms for 2018 data (orange).

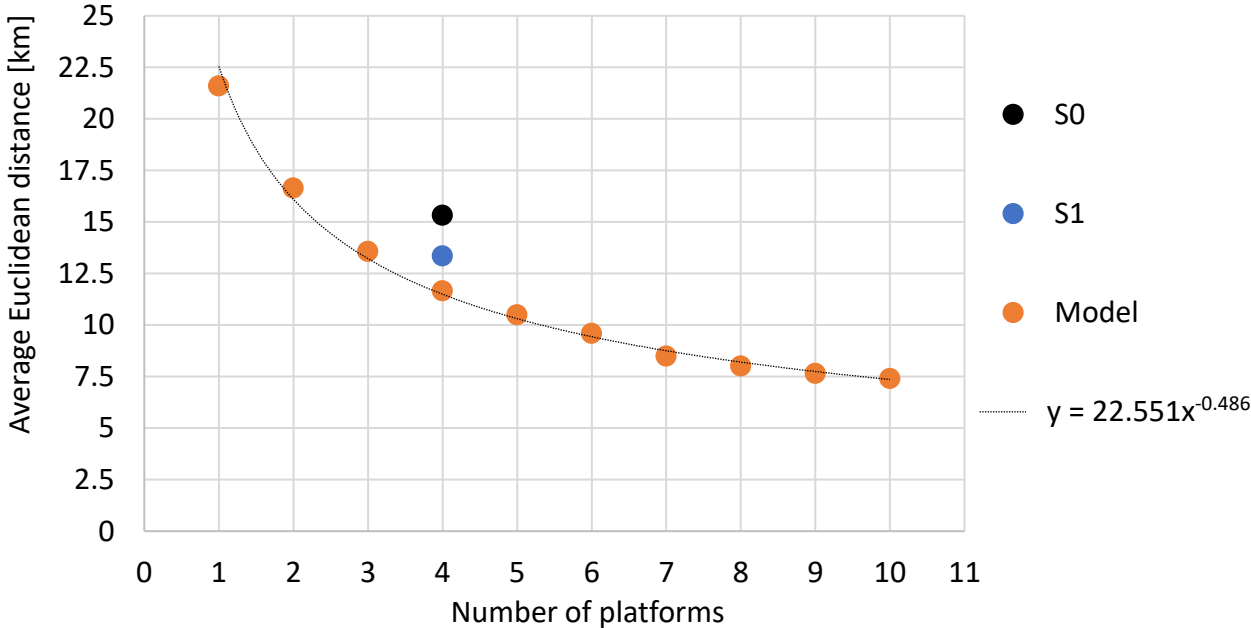


Figure 19 – Average distance (Euclidean distance) between the platforms and the delivery and pick-up points determined by the P-Median model using 2018 database

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

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

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 4 shows for 2018 database 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 platforms	4	5
Current situation (S0)	15.3	-
Reorganisation with same platforms (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 4 – Average distance [km] between platforms and delivery and pick-up points under different criteria for 2018

2.2.2. Location of platforms

The optimal location of the platforms is given in Figure 20. As the current organization includes 4 platforms (in 2018), the model has been used for 4 and 5 platforms for both 2018 (orange) and 2022 dataset (purple).

For 2018, with 4 platforms, the model does not provide a platform within Paris. The second ring hosts 3 platforms out of 4 in both cases. A strong similarity in results is present in the 2018 and 2022 dataset results with outputs very close to each other.

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

With 5 platforms, the outputs differ a little for both outputs. Patterns are found with areas in the southwest, south and northwest (near) Paris. However, for the last two platforms, it seems that a change in the geographic distribution took place in the north. In particular, the purple platform near Serris suggests that the opening of the platform has allowed a development of the activity in this area.

Moreover, with 5 platforms, the 2022 database gives outputs closer to the center of Paris than the 2018 database. This is in line with the results of Figure 18. More globally, the results from the 2022 data are extremely close to the situation of DB Schenker with 5 platforms. This confirms the carriers' choice to be close to its customers as well as to look for compatible customers (i.e. close to its platforms) with its organization.

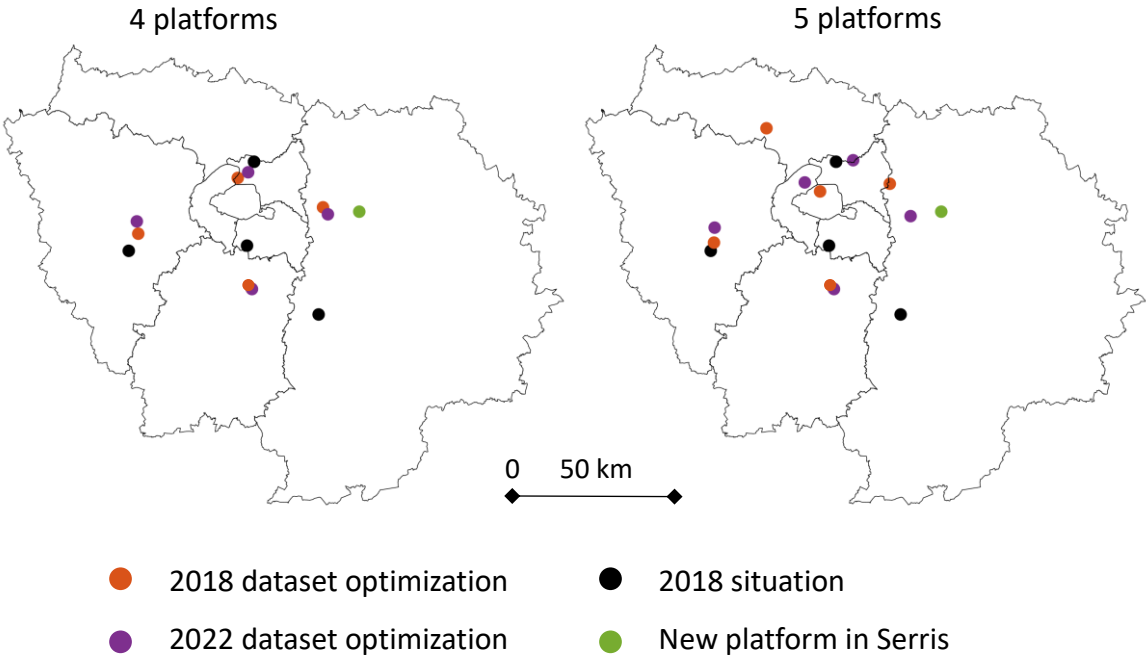


Figure 20 – Current location of platforms (black) and optimization results (orange) for 4 and 5 platforms, author's realization

An examination of the optimal locations for 2018 dataset, distinguishing between deliveries and pick-ups, shows a more contrasted situation (Figure 21). To the south and the east, the platforms 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 platforms 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 platforms is dependent on deliveries/pick-ups, but the carriers cannot have separate platforms for processing activities separately.

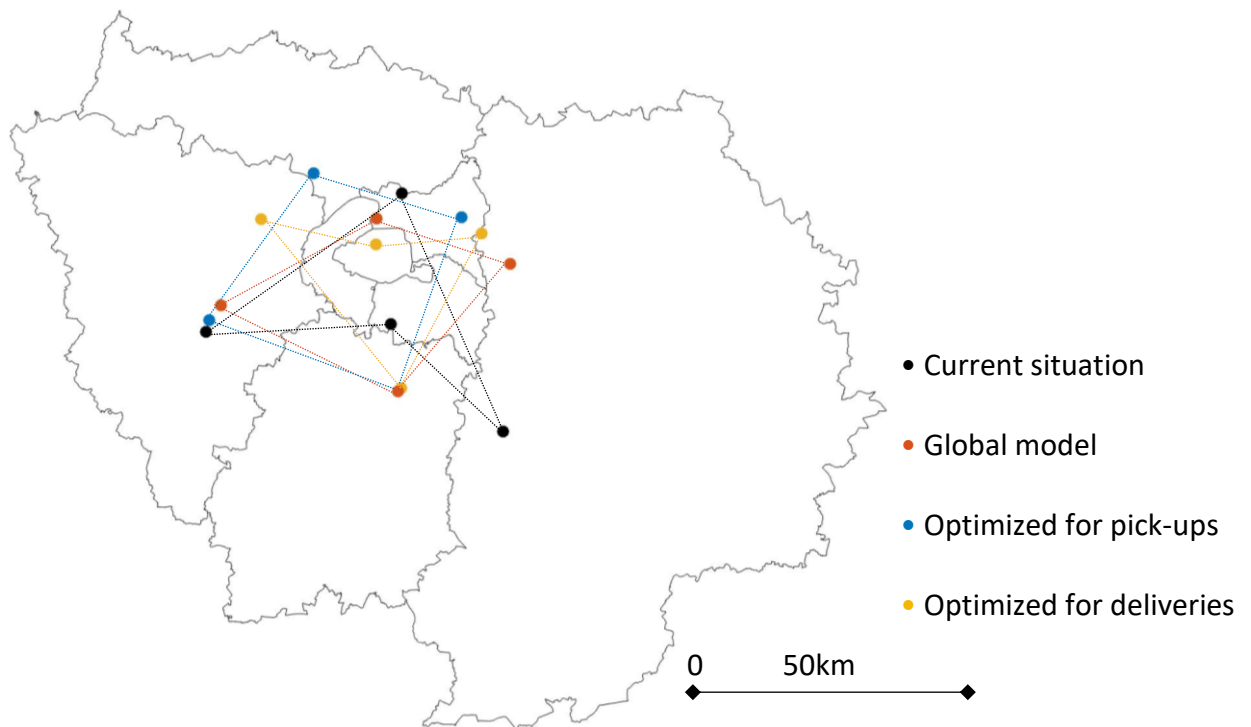


Figure 21 – Current location of platforms (black), global results (yellow), optimized for deliveries (orange) and optimized for pick-ups (blue) for 4 platforms according to the 2018 dataset, the lines are here to allow a better reading, author's realization

Thus, for DB Schenker, the location of the platforms corresponds to minimizing the total distance of local operations without considering the long-distance network. These results do not consider the land price for the platforms. To go further, we would have to compare the cost of the platforms to the savings achieved by being closer to customers. We would also have to consider the long-distance network. This last point also impacts the decision on the number of platforms in the Parisian area. Having a large number of platforms in the Paris metropolitan area would result in more tractions to connect them to the national network.

2.3. 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 four levels: the relevance of the model's results to the company's current location; the influence of DB Schenker's activity on the location of platforms, a new perspective on the consequences of logistics sprawl and the impact of COVID-19 crisis.

The first major result is the coherence between the company's organization and the model's outputs. The current locations of the platforms 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 platforms, each with its own territory. The greater the number of platforms, the closer the customers are. However, the number of platforms is limited by their cost. If there were only deliveries, the platforms would be closer to the center, but with the whole activity (pick-ups and deliveries), the platforms 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 platforms 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 platforms. Geographic proximity gives an advantage over competitors (e.g. a later pick-up time). In addition, the presence of a sales team in each platform emphasizes this process and highlights the strategy of local implementation. This explains why pick-up peaks are close to platforms. Deliveries do not lend themselves to the same control, which explains their dispersion.

Thirdly, for parcel service carriers, Dablanc and Rakotonarivo (2010) have shown that the platforms 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 calculations²⁴ only concern the servicing of the center of Paris, assuming that all the 90 platforms 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 platforms serve the center of Paris as illustrated in Figure 22. Then, considering 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 logistics sprawl worsens the situation. The temporal analysis over 4 years, although limited, shows that the operator's activity also tends to move away slightly over time. However, this study does not refute the previous studies but provides an alternate perspective.

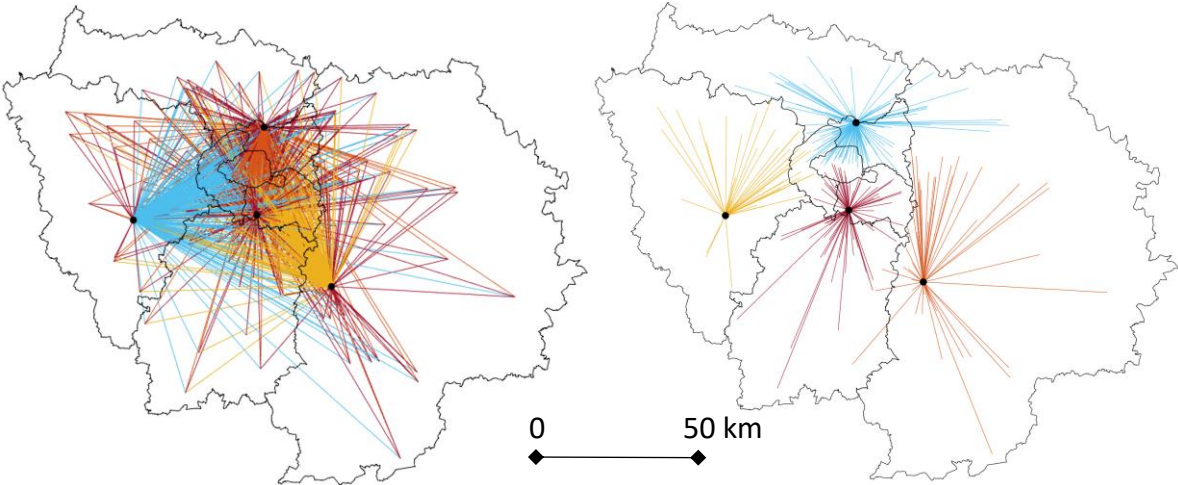


Figure 22 – Impact of a polycentric organization to operate a territory, left without polycentrism, right with polycentrism, author's realization

Finally, the effect of Covid seems at first sight to be limited, as volumes have remained similar before and after. However, just after the announcement of the French lockdown, DB Schenker's traffic was reduced by 60%, which required a change in activity²⁵. This explain

²⁴ The calculation considers 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.

²⁵ https://www.bfmtv.com/economie/db-schenker-le-secteur-transport-logistique-au-defi-du-covid-et-de-la-transition-ecologique_VN-202101130178.html

the significant change that can be observed in the flows with convergence of activity around the first ring next to platforms. Second, there has been an increase in the volume of intra-Paris metropolitan area flows (+12%) and more globally a modification of the flows in order to develop the activity around the platforms (including the new platform of Serris).

2.4. Conclusion

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 platforms. 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 platforms. 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 consider 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 platforms, none would optimally be located within Paris. There would be one if only deliveries were considered, but since there are deliveries and pick-ups, the optimal platforms 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 platform directly connected to all other national platforms. It could be a satellite platform connected only to some platforms around Paris which would then organize the last mile by cargo bike, solution that will be study the following chapter.

To complete this work and calculate the optimal number of platforms for the company, it would be necessary, on the one hand, to compare the cost of adding a platform 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 platforms.

This work is based on the situation of *DB Schenker*. The other carriers (*Géodis*, *Heppner*, *FedEx*, *DHL*, etc.) operating national traffic also have several platforms 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-ups on the platforms' 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.

2.5. Additional work on other carriers – extension to express carriers

2.5.1. General information

It was possible to apply the same methodology as above on the data of two majors express carriers also operating in Paris metropolitan area. We had access to the data of one week of operations in October 2019 (representing 1,120,126 shipments). The objective is to understand whether the previous conclusions apply as well for express carriers. Express carrier A is more present internationally. Express carrier B is more present on a national scale. This is reflected in the stocks presented in Table 5.

Flows Stocks	Carrier A		Carrier B	
	Domestic	International	Domestic	International
Stocks	219,108	57,750	826,691	16,577
Average weight [kg]	7.7	6.7	4.8	13.9
Median weight[kg]	3.2	1.4	2.5	3
# platforms	3	4	6	1
Size of all platforms [m ²]	12,412	15,498	70,473	5,614

Table 5 – Statistics on the two express carriers

Concerning the activity, both express carriers have a network of agencies to operate Paris metropolitan area, 7 platforms in both cases with a division for domestic and international operations²⁶ (in the same way as for DB Schenker previously). We notice a finer mesh in the case of carrier A with smaller platforms than for carrier B. Note that carrier A has a platform in the heart of Paris, which is rather unusual but should be seen more as a micro-hub than a platform (10 times smaller than the other hubs). Moreover, for the long-distance network, carrier A has a hub and spoke organization, while carrier B has a point to point organization on a national scale but hub and spoke on an international scale.

²⁶ In addition, as with DB Schenker, the two express carriers also use polycentrism with a dedicated sub-territory for each platform.

The organization of a typical day is similar to a parcel carrier’s, with deliveries and pick-ups taking place during the day between 7 am and 7 pm, Figure 23. Nighttime allows for long-distance routing. The databases give a little more information on the time of the "first and last miles" operations. The deliveries are mainly done before noon while the pickups are mainly done in the afternoon. This is due to the fact that no matter what time the shipment is picked up during the day, it will have to return to the platform to be sorted before being delivered to its destination. Since the vehicles only make one round per day, there is no difference on the final delivery if the package is picked up at 8 am or 6 pm. However, on the shipper's side, this leaves a full day that would not accelerate the delivery time. Also, it is more interesting to get deliveries out quickly during the day rather than at the end of the day.

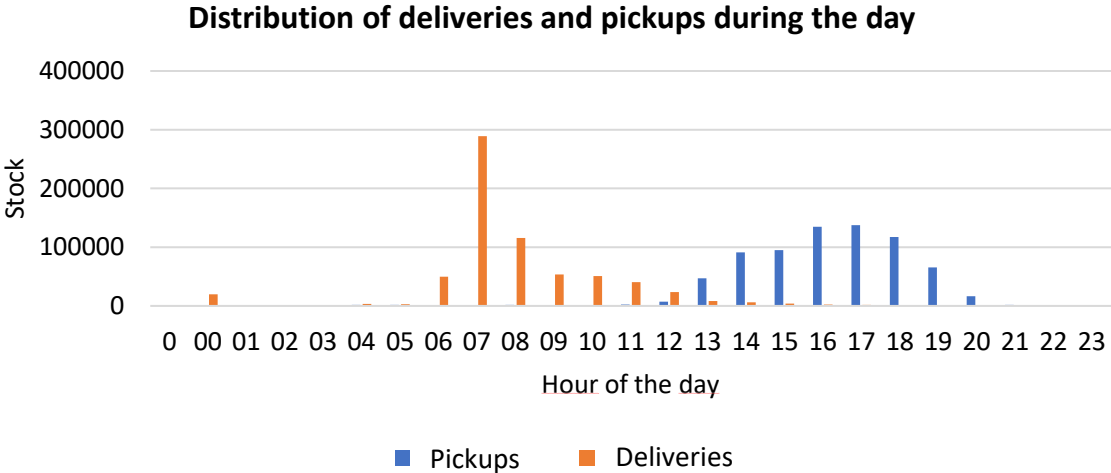


Figure 23 – Distribution of deliveries and pickups during the day for both carriers, author’s realization

Regarding shipment weight, both have a similar shipment topology. Carrier A has slightly heavier packages on average than Carrier B according to Table 5. This is confirmed by looking at the Figure 24. The main difference is a lower proportion of shipments under 3 kg and a higher proportion of shipments between 5 and 11 kg and over 30 kg for Carrier A than for Carrier B. Comparing with the Figure 15, the differences can be seen between the express and parcel service described in the Figure 4.

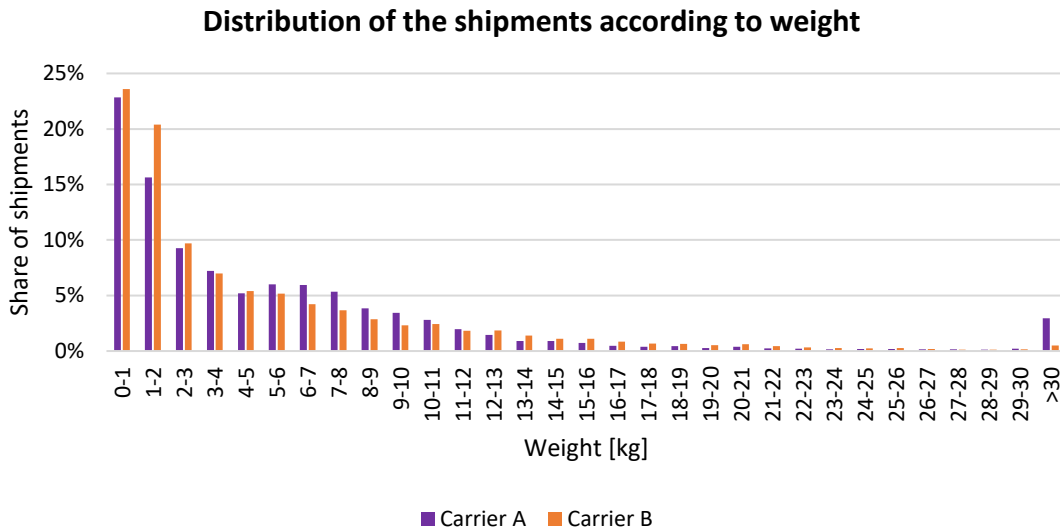


Figure 24 – Distribution of the shipments according to weight in pourcentage, author’s realization

2.5.2. Geographical analysis of the demand

As in Figure 18, it was possible to look at the distance of the shipments from Notre Dame (center of Paris). For this purpose, the international and domestic shipments have been separated in Figure 25. In addition, to improve the readability of the figure, the stocks are displayed as a percentage of the total carrier stock (carrier A and carrier B separately).

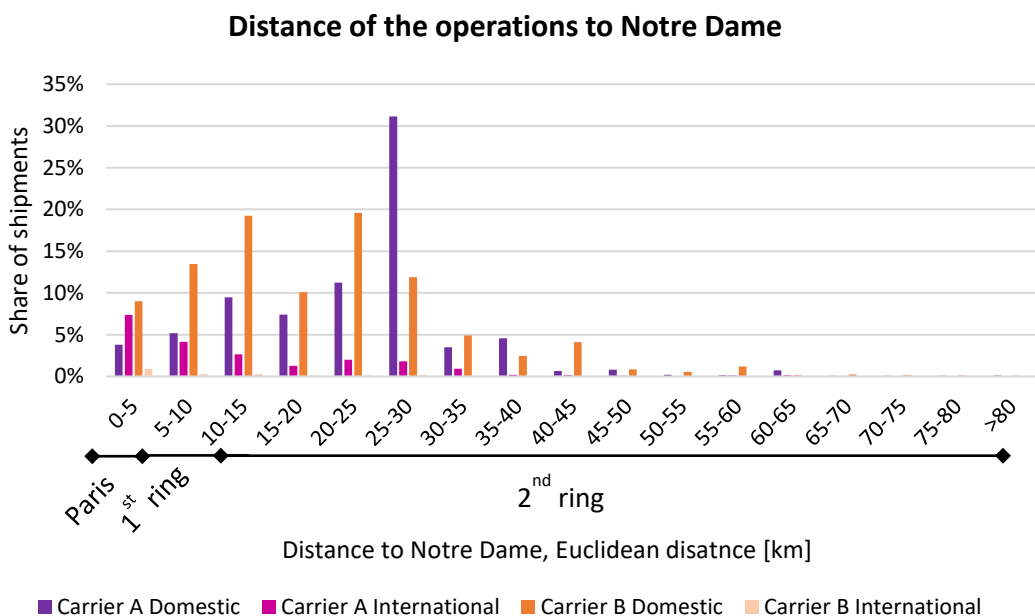


Figure 25 – Distance of the operations to Notre Dame, author’s realization

Figure 25 shows that international shipments tend to be in the center (Paris and 1st ring) while domestic shipments are located in the 2nd ring. Overall, the shipments are located in the periphery (2nd ring) of the region. This confirms what was shown earlier: while Paris has a high density, it represents only a small part of total shipments.

2.5.3. Outputs of the model

The same methodology as in section 0 has been applied in the case of the two express carriers. The international and domestic shipments have been separated to be as close as possible to reality (different circuits). In continuity, each situation is analyzed with the same number of platforms as in the real situation (Table 5). The 4 situations are represented in Figure 26.

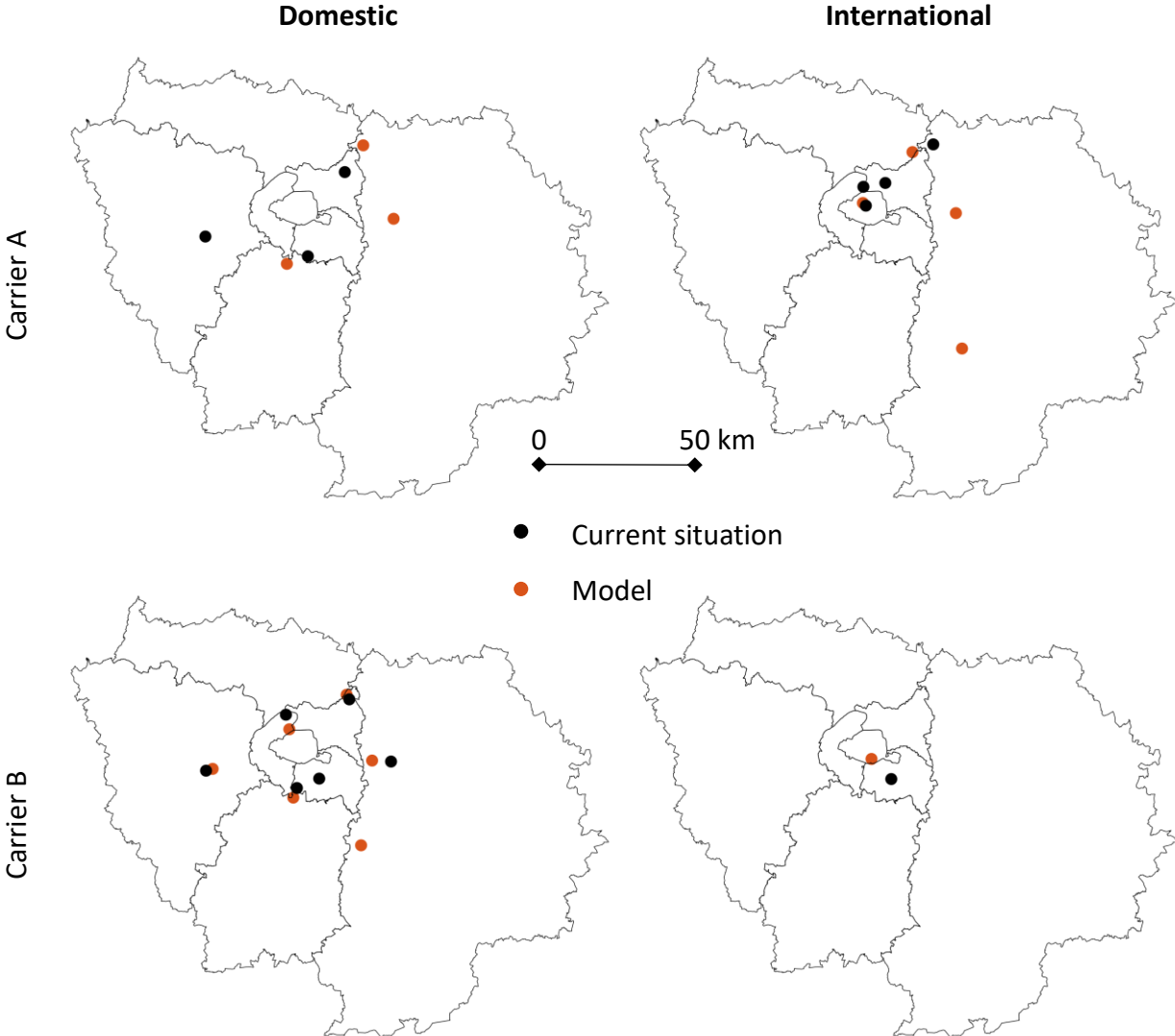


Figure 26 – Current location of platforms (black) and optimization results (orange) for the 4 situations, author's realization

In the two cases of domestic shipments (which represent 79% and 80% of flows respectively), the platforms are in the 1st and 2nd rings. This is in line with what was seen for DB Schenker.

As far as international shipments are concerned, each time a platform is present in the heart of the city. This is in line with Figure 25, which shows a stronger representation of international flows in the heart of the city, in contrast to domestic flows. However, as mentioned above, international shipments represent only a small part of the total flows.

Regarding the geographical implementation of the platforms, the results from the data of carrier B are rather consistent with the current implementation contrary to carrier A. When studying carrier A, the results suggest different implementations for both national and international operations. Moreover, there is a strong concentration of platforms for international transport in the northwest of Paris. These implementations can be explained by the choices made by carrier A, which has acquired several competitors (and thus integrated their platforms) in recent years (the last one dating from 2012). The carrier is still in a merger phase between the network. Another element that explains why international platforms are concentrated in the north is that the international hub is in the north of Paris. Having all international platforms in the north of Paris allows easy access to the hub. It is interesting to note that a similar strategy is not adopted for domestic traffic. Platforms are around Paris while the hub is in the south. However, 2 of the 3 hubs are in the south and one in the north. As far as carrier B is concerned, its development has been achieved without the acquisition of other carriers. The construction of the network of platforms was done over time and corresponds in this case (for 5 platforms out of 6 in the national case) to implementations close to the model outputs.

2.5.4. Discussion and sub conclusion

The complementary study on the two express carriers confirms the results previously obtained concerning the optimization of a location of the platforms in the periphery. This completes the existing literature by highlighting the importance of the location of the activity of the carriers in their choice of location in addition to the issues of cost and availability of land, accessibility, etc.

In the case of carrier A, a difference can be observed between the model results and the geographical implementation. This can be explained by the history (heritage of platforms by the acquisition of other carriers) and the choices of the long distance (international hub north of Paris).

Concerning the distribution of activities, in all three cases we do not have a demand that decreases with distance from the center but rather an increase up to 25 - 30 km from the center before decreasing. This brings a look at the distribution of activity within a metropolitan area.

However, the international shipments raise questions as they do not respond to the same logic in both cases, it would be necessary to explore this area to understand the reasons for this difference with the domestic flows in both cases.

This complementary study also shows the organization of the rounds during the day with the deliveries then the pickups in a general optimization process. This phenomenon had also been observed during a field study at DB Schenker but it was not possible to validate this point from the database.

3. Chapter conclusion

More generally, this chapter provides an understanding of the organization of the transport chain on a national scale. This chapter shows that, although often studied separately, the long-distance and the first and last mile are intertwined with each other. In this scheme, the sorting platforms are the link between the two networks.

From an organizational point of view, this implies that it is not possible to modify one of the networks. From a temporal point of view, the different networks are aligned to allow d+1 delivery as shown in the Figure 27. This implies that increasing the range allocated to one would negatively impact the other network. Finally, an organization that may appear simple at first sight, turns out to be a stack of network layers with different scopes and both temporal and spatial.

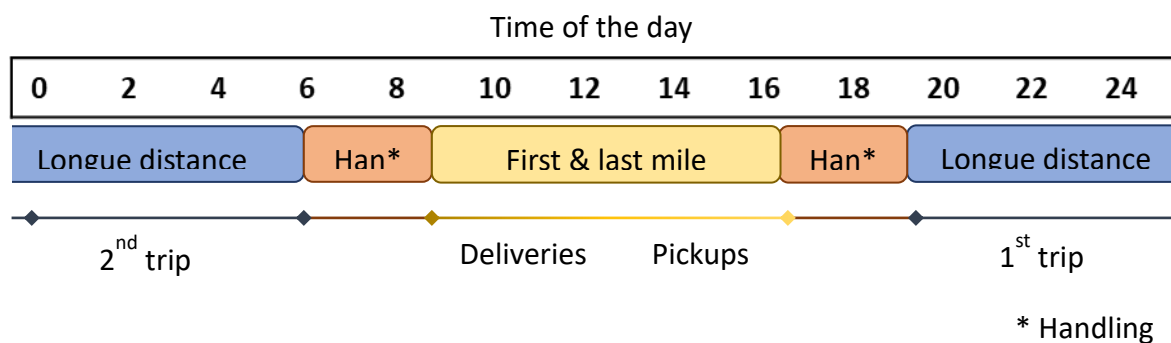


Figure 27 - Sequence of operations on a d+1 delivery, author's realization

On the question of localization, it has been shown that the choice of the implementation of the platforms responds to a minimization of the distance to its activity and that in most cases there is a real consistency between the outputs of the model and the current situation. In few cases, the implementation of a platform in the heart of the cities can be optimal under certain constraints. This highlights the importance of the localization of the carriers' activity in the choice of the geographical implementation of the platforms. In the same idea, this study provides elements on the distribution of demand for a carrier. This was possible thanks to the use of operational data made available by carriers, which allowed the problem to be studied in the opposite direction to what was mainly available in the literature. The data was used to find the optimal location for the number of platforms and then compare the results with the

current implementation rather than trying to understand the implementation strategies based on the current location of the platforms.

This chapter provides an understanding of the operational functioning of a carrier. It also allows to understand the constraints that result from it, that allows to study in the following the possibility for a carrier to transfer a part of its transport chain towards decarbonized modes (both for the long distance but also for the first and last miles).

MODAL SHIFT: FROM TRUCKS TO CARGO BIKES

Adaptation of the article published in:

Robichet, A., Nierat, P., Combes, F., 2022. First and Last Miles by Cargo Bikes: Ecological Commitment or Economically Feasible? The Case of a Parcel Service Company in Paris. *Transp. Res. Rec.* 2676, 269–278

The previous chapter has established the groundwork for the overall organization of a carrier, which is currently dominated by road-based transportation. However, in light of the goal of carbon neutrality and the questionable carbon footprint of electric vehicles based on life cycle analyses, it is crucial to explore modal shifts towards low or no carbon modes when feasible. Thus, this chapter addresses the feasibility of implementing cargo bikes for the first and last miles.

The aim of this chapter is to investigate the economic potential for carriers to adopt cargo bikes while considering their operational constraints. The study highlights the importance of logistics real estate in dense urban areas as a key factor for the success of using cargo bikes. Furthermore, this study utilizes data from a carrier to evaluate a developed economic model.

Overall, this chapter contributes to a better understanding of the potential for carriers to implement cargo bikes and the economic factors that must be considered in this process.

1. Introduction

As outlined in the previous chapter, locating carrier platforms in the suburbs is generally more advantageous than in urban centers. However, this configuration presents a challenge for cargo bike deliveries due to the significant distance involved to access the operation area, making cargo bikes less competitive compared to light commercial trucks (LCTs). Therefore, to facilitate cargo bike operations, a load break point called a micro-hub is essential in dense city centers. These micro-hubs allow for more efficient and effective cargo bike deliveries in these areas. Trucks are used to travel between the platforms and the micro-hubs, which serve as a departure point for the cargo bikes. This approach maximizes the advantages of each mode, enabling the carrier to consolidate shipments to the nearest micro-hub and then achieve precise dissemination with cargo bikes, which are better suited for navigating dense urban areas

To summarize, in this study, we address the economic possibility to deliver by cargo bikes shipments compared to trucks (electric or diesel). The case study is based on data from DB Schenker in Paris.

This chapter is organized as follow: Model presentation includes a brief presentation of the case study (territory and data) and the model used. Then, the results include the economic results without and with the externalities. Finally, the results are discussed before the conclusion.

2. Model presentation

2.1. Territory studied

Paris has a population of 2,175,601 inhabitants for an area of 105.4 km², which corresponds to a density of 21,000 inhabitants/km² (Insee, 2019). 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 French Gross Domestic Product.

From a geographical point of view, as shown in Figure 28, 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 include two large parks, the Bois de Vincennes and Bois de Boulogne.

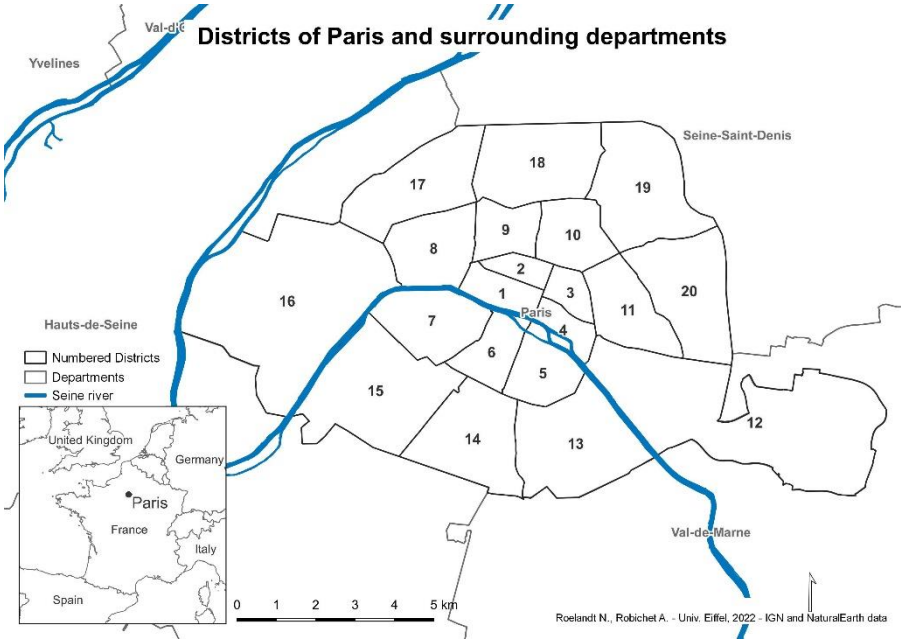


Figure 28 – Map of Paris with districts, Roelandt N.

2.2. Running of parcel service carrier

Running of a parcel service carrier is already explained in Figure 3.

In this study, we aim at comparing two scenarios with low greenhouse gas (GHG) emissions for the last mile. The basic scenario is the use of diesel trucks (S0). The first case consists in keeping the traditional organization and substituting the diesel LCT by electric LCT. 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 LCT. This is scenario S1. The second one is based on the use of cargo bikes. As the operating area of a cargo bike is smaller than that of a LCT, supplementary hubs, called micro-hubs, are set up in dense areas. Micro-hubs support the national platforms at the local level (they are not directly connected to the national network). Cargo bikes operate in a radial pattern around micro-hub. The number of operations per round is limited by their payload (200 kg). In addition to cargo bikes, electric LCT provide, firstly, the connection between platforms 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 S2. Those operations are summarized in Figure 29.

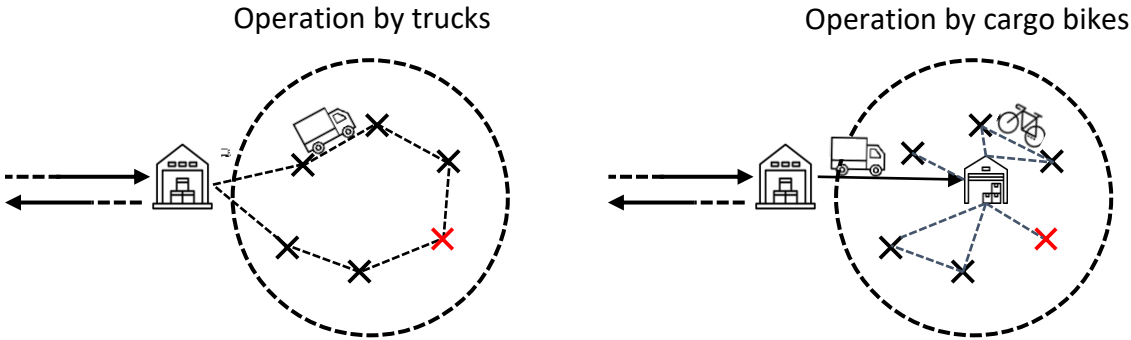


Figure 29 – Organization to operate one point (red) with the current situation with diesel or electric LCT (S0 and S1) and the scenario studied with the use of cargo bikes (S2), author’s realization

2.3. Data

For this study, only the database of 2018 with the data of Paris has been used. The database has been described in Section 2.1.3. Data (page 63).

The average weight of parcels (deliveries and pick-ups) in the Paris area is 88 kg (Table 6), 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) however the weight limit in Llorca *et al.* (2021) is 10 kg compared to the 200 kg limit in this study (Llorca and Moeckel, 2021) (some cargo bike trailers can also move – as a cart of dolly – packages weighing more than 50 kg).

Table 6 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.

	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	-	-

Table 6 - General information of DB Schenker's activity in Paris metropolitan area in 2018 (two months operation)

2.4. Geographical distribution

First, when studying the proportion of deliveries (31,536) vs. pick-ups (5,098) (Table 6), it is clear that Paris receives many more shipments than it sends. This is due to the limited number of production sites inside Paris.

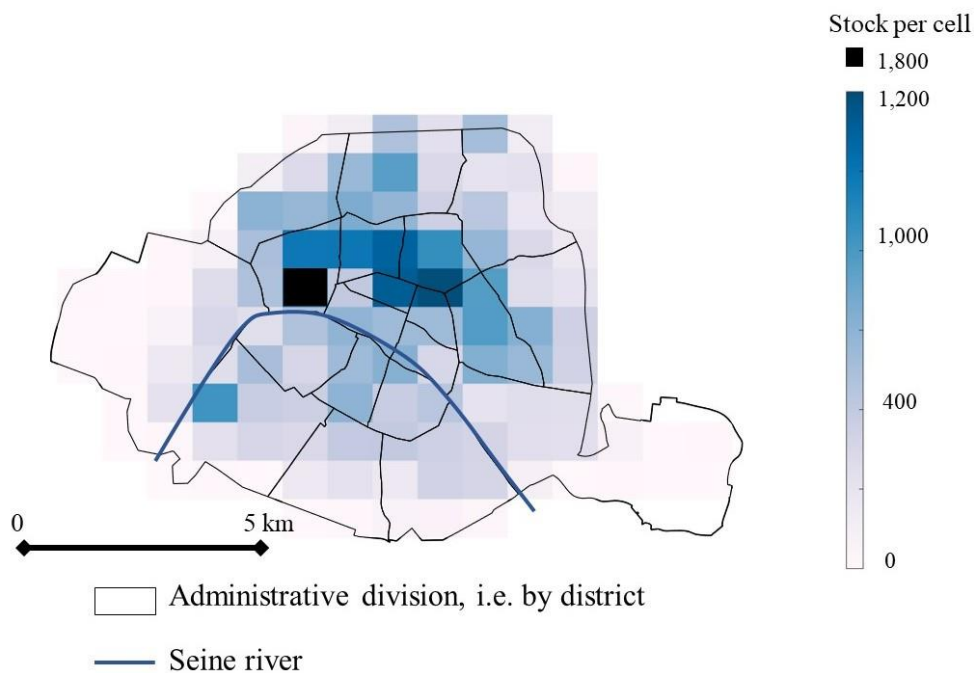


Figure 30 – Density of deliveries and pick-ups in Paris city for two months, 1.5 km² grid, author's realization

Figure 30 shows the density of DB Schenker's operations (deliveries and pick-ups) within Paris for the two months. The stocks scale is linear from 0 to 800 operation per km², excepted one cell with a much higher density (1,216 operations/km²), colored black.

The concentration of operations is high (in 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 inside administrative districts: it is relevant noting that this administrative partition is not necessarily the most relevant one to design a delivery operation process (section Model).

2.5. Model

In this section, the models of the different scenarios are described, and so are the two algorithms (facility location and vehicle routing problem) used for this study. The P-median model is used to solve the facility location problem and for the spatial partitioning of Paris (the P-median model is also the one used above in the Section First and last miles in urban area). 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's (Kay, 2016). Those models were chosen over other more complex models as all necessary information needed to implement them are not available (among the missing information, the delivery and pick-up time slots) (Caggiani *et al.*, 2021) .

2.5.1. Cost models and assumptions

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

- A diesel and electric LCT with a payload of 1,420 kg (Renault Master): it was chosen because it is the electric vehicle with the highest payload without need for a heavy vehicle license;
- A diesel and electric LCT with a payload of 4,500 kg (Fuso eCanter): it was chosen because it is an electric vehicle that is already part of DB Schenker's fleet;
- An electric cargo bike with a payload of 200 kg.

The daily costs or total cost of ownership down to one day of operation (total cost of vehicles, energy, maintenance, driver) are available in Table 7 assuming vehicles are used 7 h/day. It is assumed that a driver needing a heavy goods vehicle license (total weight over 3.5t) is paid on the basis of a heavy goods vehicle driver, while the others are paid the minimum wage. Structural costs are ignored since they are identical in all cases.

Vehicle	Cost per day [€]	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

Table 7 – Characteristics per vehicle

Under scenario S0 and S1, the fleet is calculated as the minimization of the total cost of ownership (TCO) relative to one day. The fleet mixes small LCTs and large LCTs (see below Vehicle Routing Problem (VRP)).

Under scenario S2, additional costs come from the micro-hubs, and the vehicles to supply those from the peripheral platforms. Each micro-hub has a fixed rental cost (C_{MH}), calculated from the average commercial actual estate prices for a 150 m² space (around 310 €/day). Therefore, the total retail cost is proportional to the number of micro-hubs.

To supply one micro-hub, we assume that LCTs ($N_{LCVsupply,i}$) are required for 2 hours per day (the LCT 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 $i \in \{1, \dots, n\}$, the cargo bikes can operate p parcels 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 (Sheth *et al.*, 2019)). Therefore, the total cost of ownership per day ($TCO_{CB,i}$) to deliver p parcels from the micro-hub i with $N_{CB,i}$ cargo bikes ($N_{CB,i}$) is:

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

C_{CB} and C_{LCV} denote, respectively, the daily cost of a cargo bike and a LCT (values in Table 7). For the cost of the LCT, it depends on the actual type of vehicle required to supply the micro-hub (either a Renault Master or a Fuso eCanter).

$TCO_{FleetLCV,n}$ is the per day cost of the fleet of LCTs needed to operate parcels that cannot be operated by cargo bike, i.e. all the parcels that either weigh more than 200 kg and/or that are to be delivered within 2 km from each of the micro-hubs. Hence, $TCO_{FleetLCV,n}$ depends on the number of micro-hubs.

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

$$TCO_{S2,n} = \sum_{i=1}^n TCO_{CB,i} + TCO_{FleetLCV,n}$$

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 has impacted the activity (decrease of activity) and the following days (increase in activity to balance).

2.5.2. 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 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 (same than previously):

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

In order to respect DB Schenker's current organization (i.e. operations at the 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 LCT can hardly go from one of these areas of 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 1 to 20 were tested.

The locations of the micro-hubs were calculated considering all delivery and pickup 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.

2.5.3. Vehicle Routing Problem (VRP)

The VRP problem is solved with the Matlog package (Kay, 2016). The objective is not to study 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 7). It appears from interviews and field visits that there are few parcels with time constraint for this operator, therefore, it is not considered.

The fleet optimization is performed separately for cargo bikes and electric 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.

2.5.4. Externalities

Externalities have been estimated using the recently updated French Handbook on the external costs of transport (CGDD, 2020) and are resumed in the Figure 31. 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. 53 gCO_{2, eq}/kWh (RTE, 2022).

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 31 highlights the important share of CO₂ and local pollutants in the social cost of a vehicle. Tax revenue correspond to the tax on fuel (i.e. TICPE in France) that applies to diesel 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.

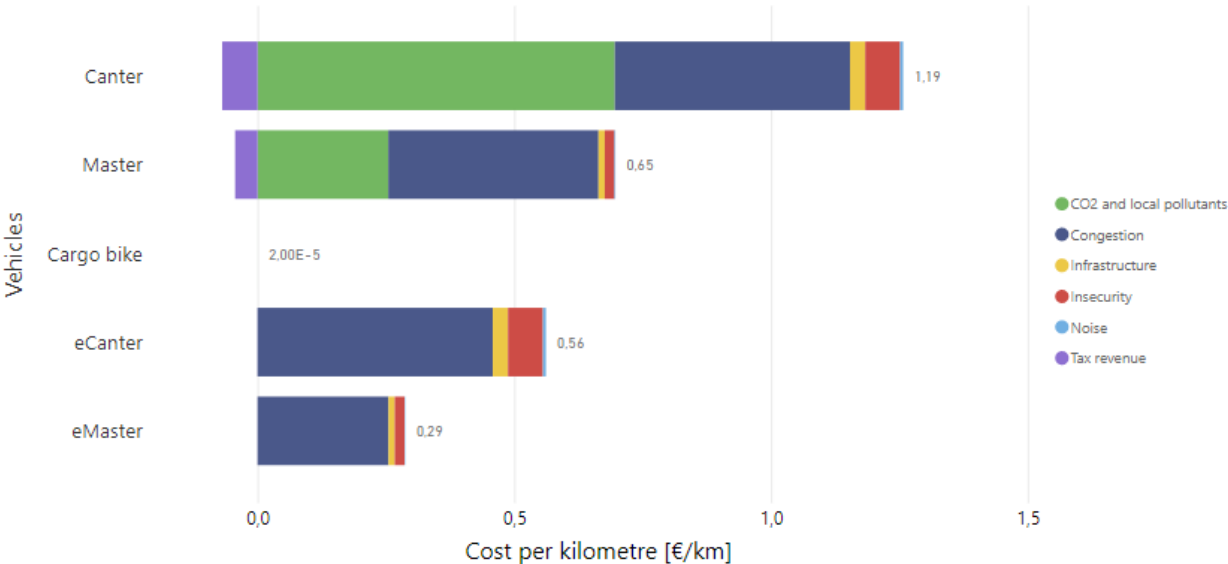


Figure 31 – Social cost per kilometer according to the type of vehicle, (CGDD, 2020)

Finally, from the TCO defined above, the total social cost (TSC) can be calculated as the sum of the TCO plus the externalities.

3. 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 renting price of the micro-hubs is the most limiting element for the implementation of a delivery by cargo bikes.

3.1. Relevance area of cargo bikes

There is a practical importance for a parcel operator to organize his operations with respect to existing administrative partitions, as it leverages easily available information, 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 number and location 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, for each iteration (i.e. number of micro-hubs, ranging from 0 to 20), we start from a blank slate. For each iteration, the share of parcels operated by cargo bikes, the total cost (cargo bikes, micro-hubs rent, needed LCTs) are calculated.

Figure 32 shows the evolution of the daily cost of operation and of the share of parcels operated by cargo bikes of both scenarios, as functions of the number of micro-hubs. For scenario S2, two solutions are represented: the one with unconstrained optimization of the localization of micro-hubs – the bright pink curve – and the one where the locations of micro-hubs are constrained to the district centroids – the purple curve. Scenarios S0 and S1 are also presented (respectively green and blue line). In this two-last case, no parcel is operated by cargo bike.

First of all, for this particular stakeholder, the diesel LCTs are the most economical whatever the scenario considered. When we look at the decarbonized scenarios (S1 and S2) it is not profitable to deliver the entire Paris area by cargo bikes. The cost would be much greater than that of using a 100% electric fleet.

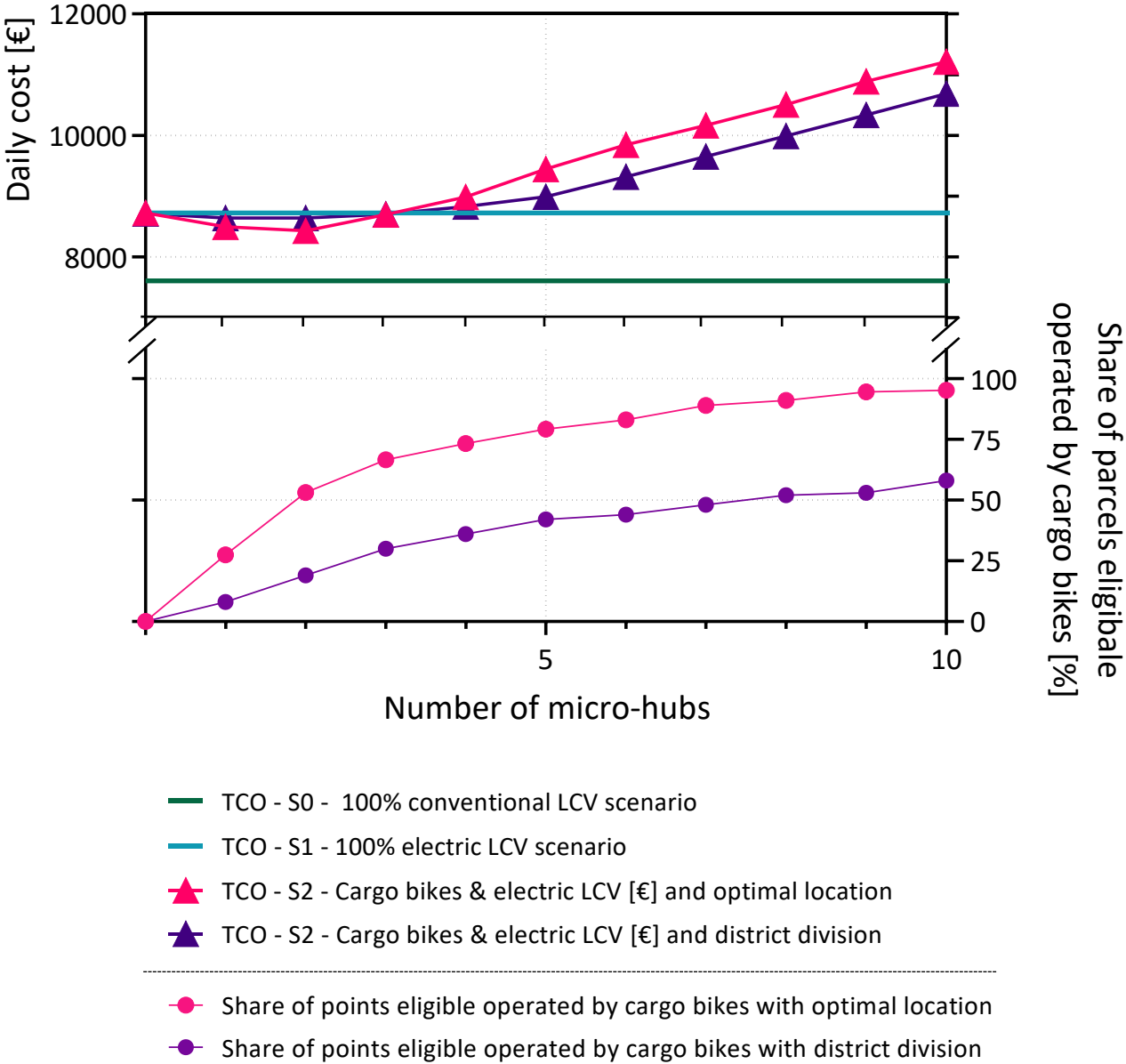


Figure 32 – Comparison of the daily cost of operating a solution with and without cargo bikes (above) and share of eligible point to cargo bikes (below) according to the number of micro-hubs, author’s realization

The second result is that it is possible to set up a network of 3 micro-hubs (optimal location) performing 67% of the daily operations for a similar – even slightly lower – cost than the one with a 100% electric LCTs fleet. However, with more than 3 micro-hubs, the network of micro-

hubs and cargo bikes quickly gets more expensive than a traditional organization with a fleet of electric LCTs.

Assume that the objective is to maximize the share of operations done by cargo bikes (with optimal micro-hub location), it is possible to do by increasing the number of micro-hubs. However, there are decreasing returns: beyond 10 micro-hubs, the share of parcels operated 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 LCTs.

Coming back to the question of the administrative division: it appears, expectedly, that respecting the administrative division is costly. More precisely, the lowest cost is obtained with two micro-hubs, and only 53% of shipments are operated 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. Considering this last result, only the scenario without considering the administrative divisions is retained for the following.

3.2. Impact of the micro-hubs rent price

The rent of the micro-hubs is a critical limitation to the implementation of cargo bikes. In order to further investigate the sensitivity of cargo-bike financial profitability to real estate prices, the following was done. Consider the scenario with electric LCTs as a base case: for each share between 0 and 100%, it is possible to determine the maximum micro-hub renting cost per m² 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 LCT. Figure 33 is built with the following input parameters from the data:

- S_{MH} : Surface of the micro-hub: 150 m²;
- N_{CB} : Number of operations per day per cargo bike (value: 17);
- N_{LCV} : Number of operations per day per electric LCT (value: 22).

Thus, it is possible to define the equivalent electric LCTs fleet needed to operate p parcels ($TCO_{LCVeqCB}$). From Equation (1), by equalizing the costs of the two formulas (i.e. $TCO_{LCVeqCB} = TCO_{CB}$), we deduce the maximum rent per m² as:

$$Max_rent_per_m^2(p) = \frac{[TCO_{LCVeqCB}(p) - (C_{CB} * N_{CB}(p) + \frac{2}{7} * C_{LCV} * N_{LCVsupply}(p))]}{S_{MH}} \quad (3)$$

Function $Max_rent_per_m^2$ is represented on Figure 33. Due of 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 LCT for supply or three electric LCTs (similar cost) are needed to perform 41 to 52 operations per day. However, four cargo bikes and one electric LCT for supply or only three electric LCTs are required to perform 52 to 60 operations.

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

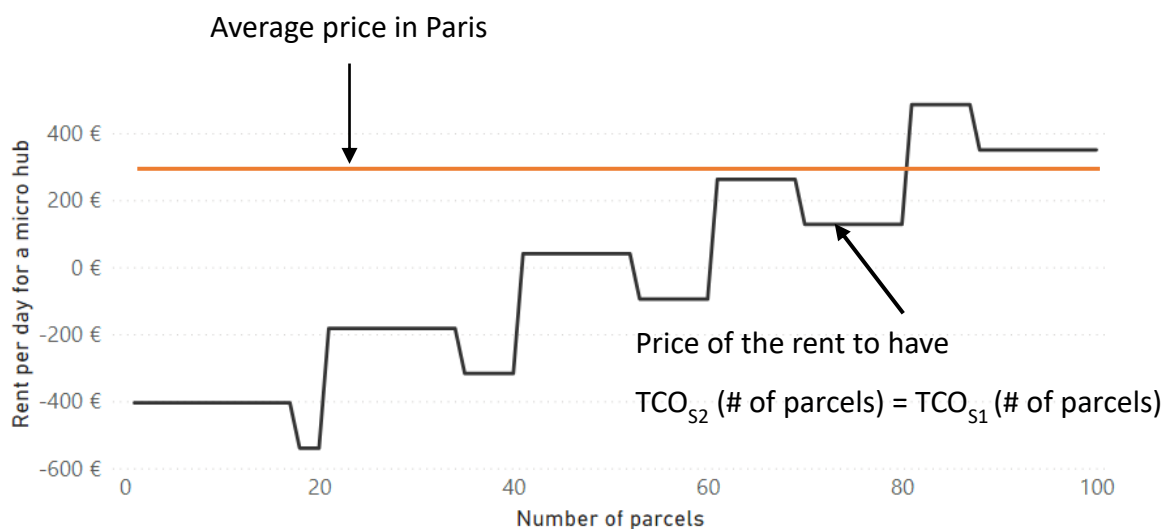


Figure 33 – Maximum price per m2 of a micro-hub rent according to the number of parcels per day, author's realization

In addition, it is found that while high density is necessary to implement cargo bikes, due to 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.

3.3. Impact of the externalities

This section explores the impact of the consideration of externalities.

3.3.1. Relevance area of cargo bikes with externalities

Figure 34 shows the evolution of the social cost and the share of parcels operated by cargo bikes of all scenarios as a function of the number of micro-hubs and the social cost of operating with a fleet of conventional or electric LCTs.

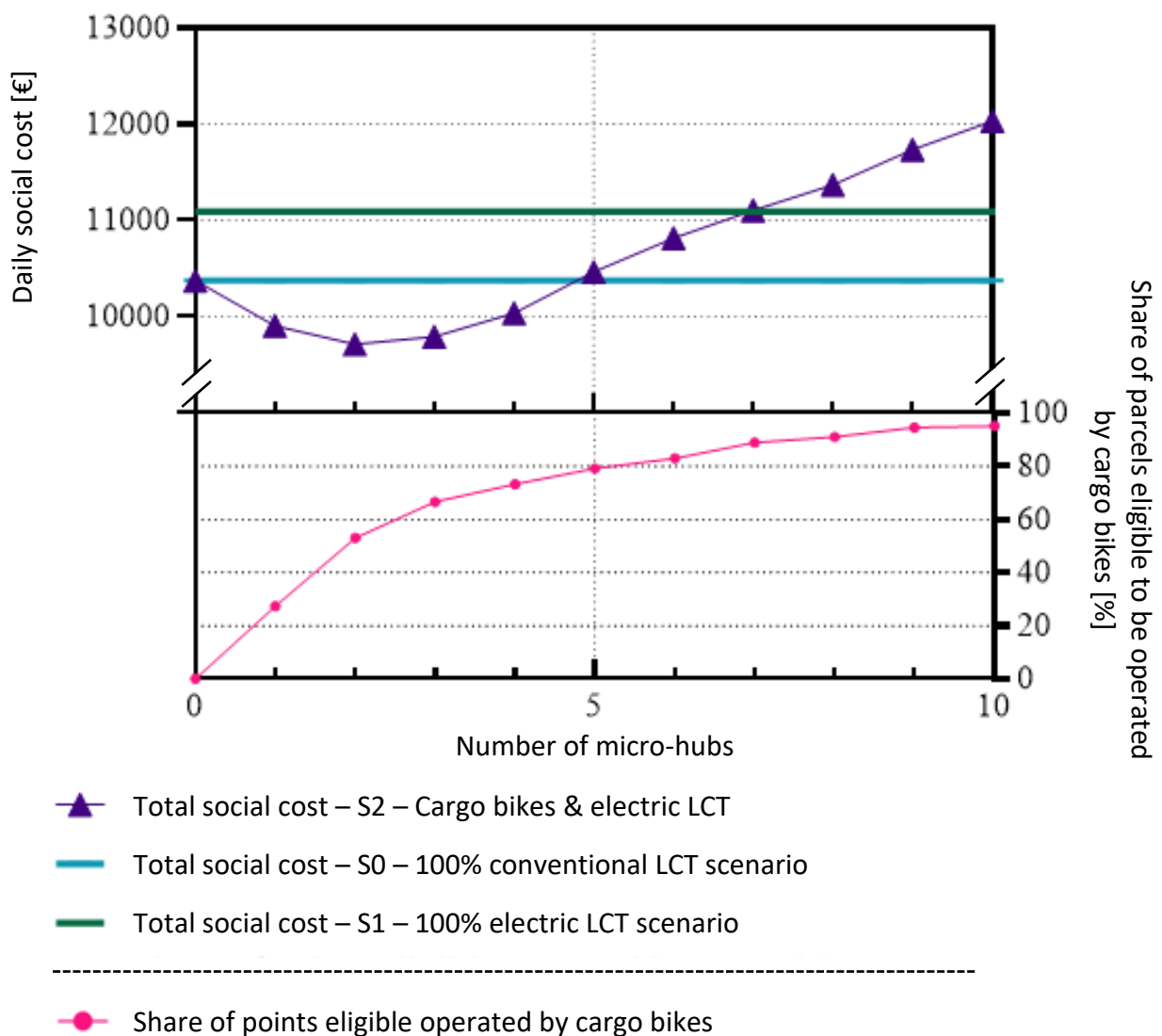


Figure 34 – Comparison of the daily social cost of operating a solution with and without cargo bikes (above) and share of eligible point to cargo bikes (below) according to the number of micro-hubs, author's realization

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 diesel 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 with two micro-hubs that allow to operate 53% of the points by cargo bikes.

3.3.2. Impact of the micro-hubs rent price with externalities

Regarding the impact on the cost of land, considering the externalities has a large impact on the cost of S1. The S2 solution is also impacted but less due to the cost of LCTs to supply the micro-hub. The maximum land price curves with and without externalities are shown on Figure 35.

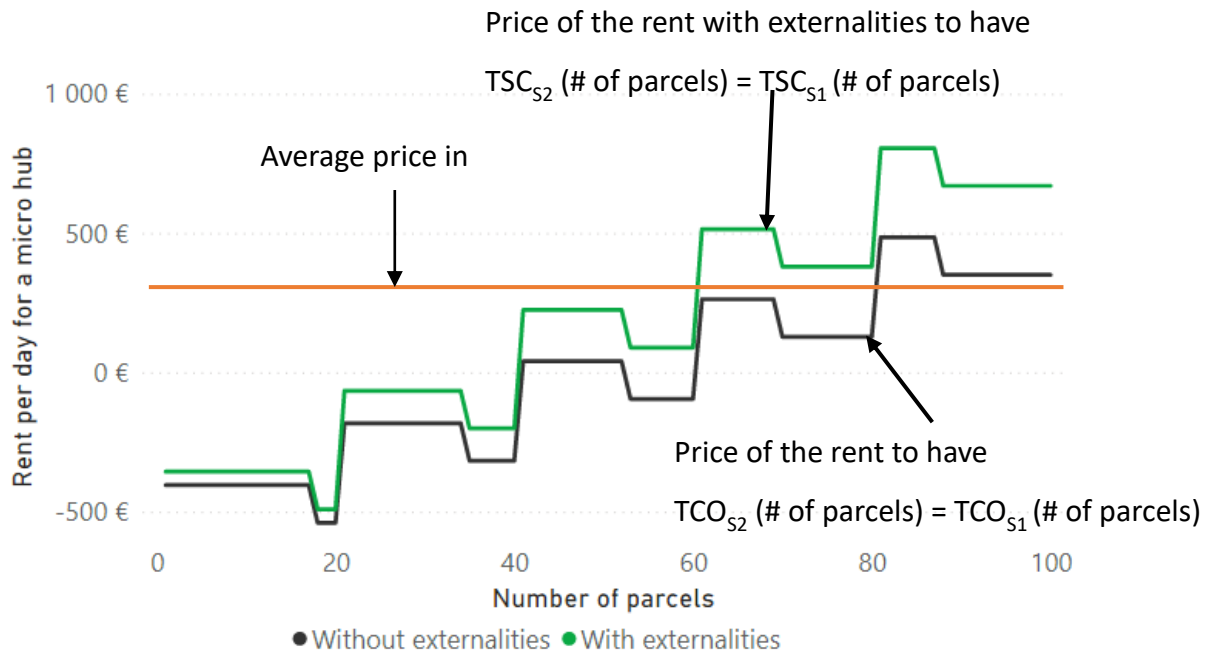


Figure 35 – Maximum price per m² of a micro-hub rent according to the number of parcels per day with externalities, author's realization

Considering the externalities, the equilibrium point between the two solutions decreases from 81 to 61 parcels per day for our case study. We can also see that the impact of externalities grows with the number of deliveries. In fact, despite the increase in the number of parcels, only one truck is needed to supply the micro-hubs, whereas in S2 the number of LCTs is increased to make the operations.

4. Discussion

Results show that it is technically possible to pick up or deliver a large majority of the parcels by cargo bikes (91%). However, it is not economically interesting to operate all parcels by cargo bikes. This confirms the hypothesis made by Conway *et al.* (2012) about the economic feasibility of delivering Paris by cargo bikes without subsidy (Conway *et al.*, 2012). The present 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 bikes operations, given the fact 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 (Elbert and Friedrich, 2020) 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 bikes deliveries can represent an opportunity to pool flows.

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).

In addition, this study emphasizes, once again, the importance of considering externalities, which considerably modify the total social cost of each scenarios. An important result is that, when comparing total 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.

On another hand, in our case study, when it comes to TCO, diesel LCTs are always more interesting than the other solutions. When externalities are considered, diesel LCTs are no longer relevant and cargo bikes have a of relevance area compared to LCTs. Beyond taking externalities into consideration, it seems more relevant to compare comparable scenarios,

here the cargo bikes (S2) can be compared with a fleet of electric LCTs (low carbon vehicle when used) and not a fleet of diesel LCTs.

Finally, it seems interesting to raise the question of the rent 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 beyond 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 LCT by discussing the relationship between one limiting parameter of the cargo bike solution and a LCT 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.

5. Conclusion

The objective of this study is to compare two sustainable scenarios for the last mile via cargo bikes and/or electric LCTs fleet and diesel LCTs fleet within Paris based on DB Schenker's operating data. The first important result is that it is economically feasible to operate a part of the parcels via cargo bikes but not all of them when considering only low carbon or decarbonized mode.

Secondly, the renting of micro-hubs is a major cost barrier. As the average price of a commercial space in Paris is high, this 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 is necessary to have a minimum density to compensate for the cost of transporting the parcels between the micro-hubs and the cross-docking platform by vehicle.

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

The social cost of electric LCTs is cheaper than diesel 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, the availability of space for micro-hubs is low, which limits their development.

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.

6. Additional work on the impact of action radius and weight limit

In a perspective of development of the capacities of cargo bikes, it was tested the impact of an evolution of the technologies of cargo bikes by increasing the range of action from 2 km to 3 km and the weight that can be loaded from 200 kg to 350 kg.

Figure 36 reproduces what has been presented previously but with variation of the radius of action (horizontal) and the weight limit of loading (vertical) and thus represents 4 configurations. The situation on the top left is the reference case (the one studied previously). As previously discussed, the cargo bike solution is only compared to a fleet of electric LCTs.

Overall, both parameters increase the economic relevance of the cargo bike, but not in the same way. The increase in weight improves the cost of the cargo bike, while the evolution of the radius of action allows to influence the share of parcels that can be operated by cargo bike.

As far as the range of action is concerned, compared to the size of Paris (85 km² without the woods), with 3 km that makes an activity area of 28 km², it becomes possible to operate Paris with 3 micro-hubs. However, with an average heavy shipment (88 kg), the cost of the round trip for the 3 km shipment, the cargo bike is not as attractive anymore. However, a higher number of shipments (due to a larger catchment area) makes the solution more viable.

Increasing the weight limit does not significantly increase the share of shipments operated by cargo bikes, but it does take advantage of the high density in Paris. The increase allows to capture the vast majority of the shipments in the catchment area, which allows to strongly absorb the cost of the micro-hubs.

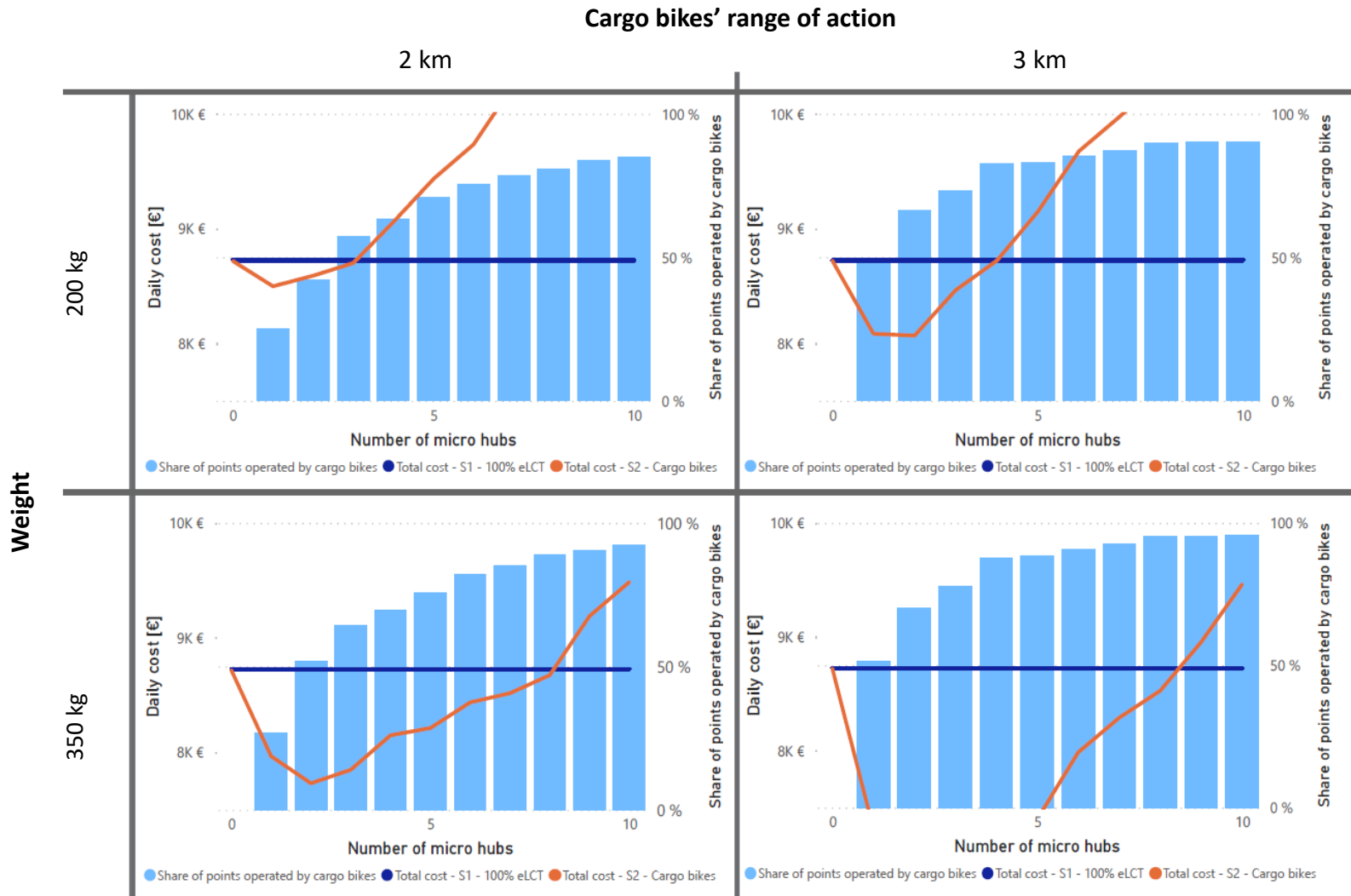


Figure 36 – Impact of the evolution of cargo bikes' range of action and maximum weight, author's realization

MODAL SHIFT: FROM TRUCKS TO COMBINED TRANSPORT

After considering the possibilities of modal shift for the first and last miles, this chapter considers the feasibility for a actor to transfer from a road network to a combined transport network (rail-road) for long distance.

Unlike the previous chapter, this section is based on a mode that has existed for many years. The question in this chapter is therefore how to reintegrate rail into the transport chain, rather than how to integrate it. As a reminder, in France, rail represented up to 78% of t.km in the period 1921-1924 before declining to 11% of t.km in 2021. In 2021, combined transport represents 39% of rail t.km in France, i.e. 4% of t.km for all modes (SDES, 2022).

This chapter is divided into two parts: the first part focuses on the national network of a courier (DB Schenker), the second part focuses on the flows of a consortium of companies at European (8 major French shippers and one parcel service carrier). A mapping of the combined transport services has also been carried out. All data are presented in more detail below.

From a methodological point of view, the first part is mainly based on the existing combined transport services. The second part is a more theoretical approach that seeks to study the impact of pooling for combined transport. The two parts are independents.

From a semantic point of view, the use of the word trucks in this section refers to semi-trailers.

1. National network – DB Schenker

1.1. Introduction

This section is divided into four parts, first a brief presentation of the studied territory, second the current operation of a parcel carrier and then the operation with potential modal shift is detailed. In the third part, the data used will be explained as well as the tool developed (fourth part) to carry out the comparative study of the transportation plans of the two modes.

1.1.1. Territory studied

The French territory has an important railway network with more than 28,000 km of railroads (SNCF, 2022). The four major actors in combined transport (Naviland Cargo, Novatrans, T3M ad VIIA) in France have their own specific characteristics. A particularity of the French rail service is the existence of 6 "rail highways" for the transport of goods operated in the form of transport by rail of classic road semi-trailers by the company VIIA. This is the transport of a standard road semi-trailer, not equipped for intermodal transport. The semi-trailer is loaded onto the box car by rolling it (horizontal loading). In contrast, semi-trailers suitable for conventional combined transport have reinforced sidewalls with gripping areas for horizontal loading. The objective of these highways is to compete directly with road transport, particularly on routes crossing France.

Naviland Cargo has developed its strategy for maritime containers as an extension of maritime transport. Its service aims to provide connections to and from seaports. As for Novatrans and T3M, they have developed around a road activity. These differences between the actors result in the existence of a diverse services with actors each proposing a specific service.

As far as the electrification of the tracks is concerned, the main paths are electrified, but a significant part of the secondary network requires the use of diesel locomotives. On the network scale, 59% of the tracks are electrified (Ministère de la Transition Ecologique, 2021). From the point of view of intermodal terminals, there are 67 intermodal terminals with rail services, but there is no combined transport offer between all these terminals (only from 33

of them)²⁷. Therefore, for many road connections, there is no rail service to shift them from road to intermodal.

1.1.2. Traditional parcel service and combined transport's operations

Parcel service carriers' operation are described in section 1.1 (page 8) and constrains are outlined in section 3 (page 86).

Combined transport's operations are described in section 1.4.3 (page 20).

In summary, in order to meet the operational requirements of DB Schenker and of combined transport, the chain must correspond to the Figure 37.

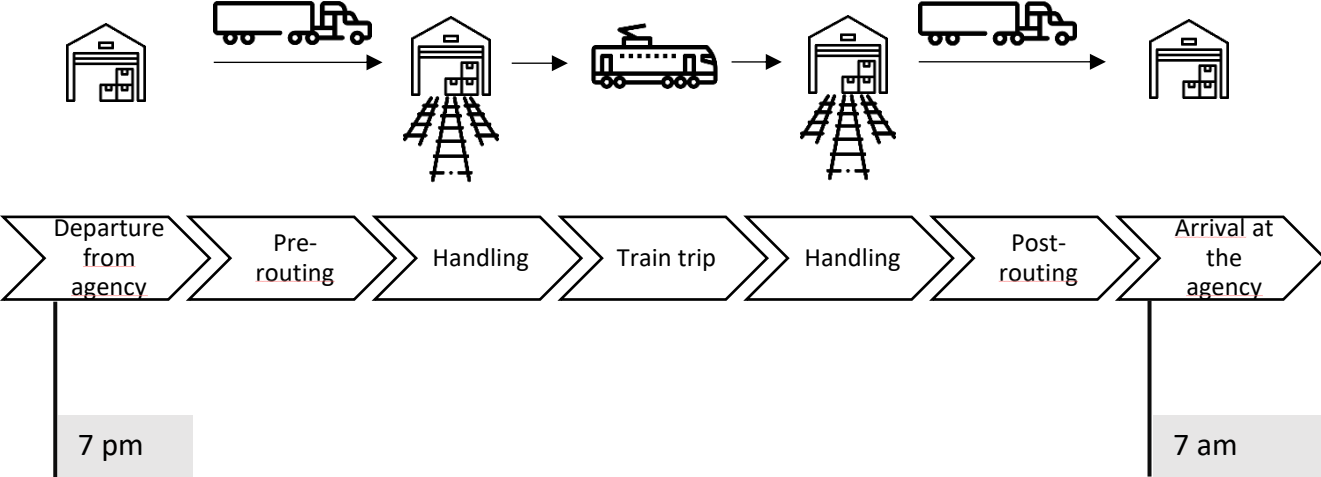


Figure 37 – Transport chain with combined transport in the case of a parcel service carrier, author's realization

²⁷ This does not mean that there is no activity in 34 of them but it does mean that there is no public offer from 34 combined transport terminals

1.1.3. Data

This study is based on two databases:

- The national transport plan of a freight carrier: *DB Schenker*;
- The inventory of the combined transport available in France.

DB Schenker's national transport plan

DB Schenker's national transport plan has been described in section 1.1 (page 56). In summary, there is 1,437 connections between 80 platforms for resulting in 2,097 daily trips (1 connection can have multiple daily trips).

For the following part of the study, in order to satisfy the different trips in the chain, the goods cannot leave the departure platform for the long distance before 7 pm and must arrive at the arrival platform before 7 am.

Combined transport service

The database for combined transport has been realized by a manual collection of the services available on the internet for 2022. It has been chosen to focus on the 4 major actors in French combined transport: Naviland Cargo, Novatrans, T3M and VIIA. The results show 128 connections for 669 weekly trips (Table 8). In the case of the railways, we speak of a number of weekly connections because, from an operational point of view, not all connections are made every day, unlike the road transport plan of the company studied.

From a geographical point of view, 19 sorting platforms of DB Schenker are located in the same urban area one of the 33 intermodal terminals considered. None of the DB Schenker platforms is directly connected to the rail network. This result shows a similar trend to Germany, where on a national scale very few sorting platforms (6.4%) from all companies are directly connected to the rail network (Rolko and Friedrich, 2017).

From an operational point of view, we have considered the closing time and the release time of intermodal trains for the customers. Those times do not correspond to the departure and arrival times of the trains but to the last time at which the swap body must arrived at the departure terminal and the time at which it is made available at the arrival terminal. Indeed,

there are many steps between the time when the swap body arrives at the terminal and the time the train starts (Ballis and Golias, 2004).

Operator	Number of connections	Number of weekly trips
Novatrans	56	266
Naviland Cargo	48	252
T3M	18	85
VIIA	6	66

Table 8 – Number of connections and weekly number of trips depending of the operator in France for 2022, collected by the author

1.2. Model

1.2.1. Transportation plan comparison tool

To compare road and rail transport plans, all trips were integrated into one dataset. To be able to compare the two modes, another dataset was created that included the time between the carrier’s platforms and the intermodal terminals. Thus, with the two datasets, it was possible to compare a 100% road service and a road-rail-road service (combined transport) by integrating the pre- and post-haulage times. In order to identify the routes on which it is possible to use rail transport, we have carried out SQL queries from the database previously created (the SQL queries have been automated to simplify the comparison on all the routes). Thus, it is possible to make queries considering the following criteria:

- Place and time of departure;
- Place and time of arrival;
- Day of departure;
- Day of arrival;
- At the departure or arrival of an intermodal terminal or at the departure or arrival of a road carrier’s platform;

The results display the details of the trip according to the criteria chosen previously. That is to say the complete path, for example, for a search at the departure and arrival of a platform:

- Pre-haulage with maximum departure time and duration of it;

- The train service concerned with the cut-off times;
- Post-carriage with maximum departure time and duration of it.

Once the connections on which it is possible to imagine a modal shift have been identified, a more detailed analysis is performed. This consists of identifying, according to the cut-off times (arrival and availability times) of combined transport, the area accessible by truck based on parcel constraints (7pm - 7am). This makes it possible to identify if other platforms further away can be concerned by this connection of combined transport. This operation is performed under Qgis using the TravelTime extension.

1.2.2. Methodology for the calculation of the economic cost

This section is divided into two parts: road and rail costs. Structural costs of the parcel service carrier (cost of the head office, structure costs, etc.) are not considered because they are identical in both cases. Indeed, in this study we are only focused in the transport between the platforms, what happens before or after remains unchanged. The structural costs of the railway company are considered here as it operates as a subcontractor.

For the cost of road transport, we have relied on data from the "CNR - Comité National Routier" which offers data on the costs of different vehicles. For our study, a daily cost of 584€ for a 40t long haul truck is considered.

For the cost of the railway, we relied on the different data available online, in particular on the tariffs of different rail freight operators in France (DB Cargo AG, 2018; Fret SNCF, 2022). By rebuilding the studied connections and with the hypothesis of 10t of goods per swap body a train costs approximately 22.5€/km. Regarding the pre and post haulage, in the best-case scenario, the truck can be use only $\frac{1}{4}$ of the daily time for the pre or post-haulage, meaning that the trucks can operate other flows for $\frac{3}{4}$ of the day. This is scenario S1 with a cost for pre or post haulage of 141€. Scenario S2 is the worst-case scenario in which no mutualization with other flows is possible, in this case the cost is 584€ for each part (pre and post haulage).

It is a choice not to apply a kilometric cost for the pre and post haulage. Indeed, the pre and post haulage in this case of study are carried out almost exclusively in urban environment, the distances covered are short. The time of use of the truck (driving in dense environment,

waiting at the intermodal terminal) is the main cost. The use of a kilometric cost would risk underestimating the cost of this item.

1.2.3. Methodology for the calculation of the environmental impact

To calculate the environmental impact, we used the calculator developed by EcoTransitWorld. It calculates emissions along the entire trip, considering the exact path of the goods from the point of departure to the point of arrival. The different parameters take into account, among other things (Anthes, Schmidt and Schmidt, 2020):

- Vehicle type;
- Load factors;
- Network specific attributes (electrification of rail, type of road).

This calculator has been chosen because it has been proven one of the most efficient (Heinold, 2020), it enables the recognized calculation of emissions and the one used by professional (Cichosz *et al.*, 2018).

The same three scenarios explained for economic cost are used for the environmental impact. As a result, S1 and S2 have the same environmental cost (the only change being the mutualization or not of the truck but not the kilometers covered for the combined transport).

In any case, to give an order of scale at a European scale, an average train emits 24 g.CO₂e/t.km and a long distance truck emits 105 g.CO₂e/t.km (Eurostat, 2018).

1.3. Result

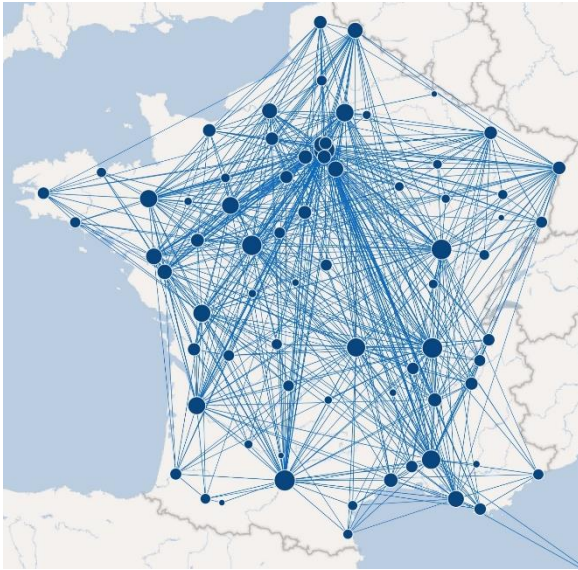
The results are divided into two main parts. First, we estimated the share of DB Schenker trips that could be operated by combined transport based on current supply. In this part, we have integrated the results of a more theoretical work that estimates the number of trips that could theoretically correspond to the expectations of the parcel service sector. In the second part, a more global evaluation (integration of the environmental impact) is presented on a route where modal shift is already possible today.

1.3.1. General results

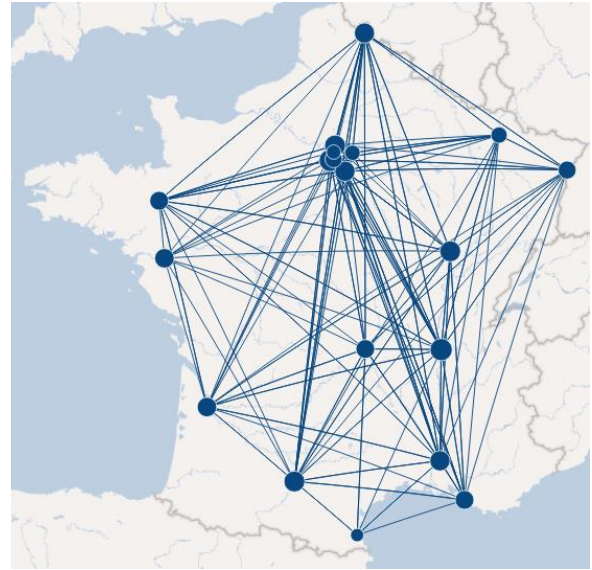
Initially, there were 2,061 trips for 1,437 connections. After removing the platforms that are not in the same urban area as an intermodal terminal, only 229 connections, with 249 daily trips, were concerned for DB Schenker.

Operational constraints were then applied, i.e. a closing time after 7pm and release time before 7 am (these conditions have been defined because of the constraints of parcels carrier explained earlier). From the database, we found that 7% of the combined transport connections has a closing time after 7pm and 41% of the connections has a release time before 7am. By merging the two constraints and adding that the trip must take less than 1 day (to limit to the trains making the trip during the night), we are left with only 3 remaining connections on 2 axes (Paris - Bordeaux round trip and Paris to Toulouse) corresponding to 0.2% of daily trips. If we keep the same time constraints but with a 48-hour journey, only 15 connections are possible, i.e. 1% of all DB Schenker connections.

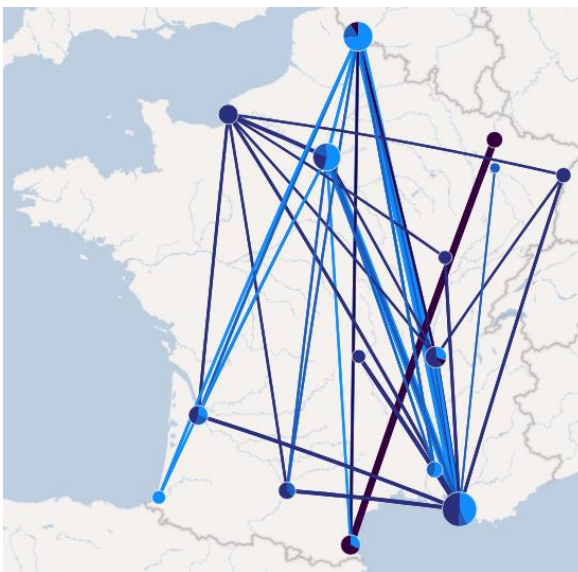
All DB Schenker connections (1,437)



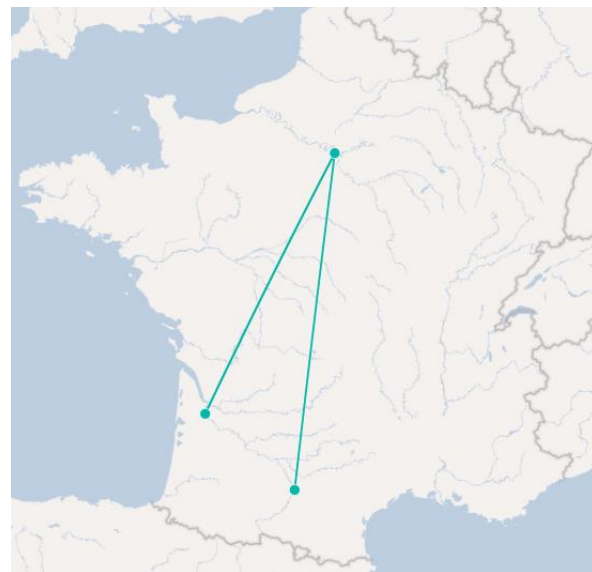
DB Schenker connections' next to an intermodal platform (229)



Combined transport service (128)



Compatible combined transport for DB Schenker (3)



0 200 km
◆————◆

Figure 38 – Graphical representation (a) of all DB Schenker connections, (b) connections from a platform near an intermodal terminal (in the same urban area), (c) all referenced combined transport services in France, (d) combined transport service in adequacy with the constraints for one day, author's realization

In addition to the results obtained previously, we wondered if the problem was the time between closing time and release time. For this purpose, we have carried out a theoretical work where we have determined the number of connections where, with different schedules,

it would be possible to realize a combined transport within the operational constraints of the parcel service. By different schedules we mean that the durations between closing time and release time are kept but the closing time is modified to match the time constraints (the release time is calculated accordingly based on the duration). Considering all these assumptions and conditions, it would be possible to carry out rail transport on 13 axes, i.e. 26 connections corresponding to 1.8% of all DB Schenker connections.

The Figure 38 illustrates, first, the gap between the total number of daily truck connections made by DB Schenker and the current combined transport services. When constraints are added the proportion of compatible services is close to none.

1.3.2. Study of the Paris - Bordeaux axis

The Paris-Bordeaux axis has the advantage of having a compatible service in both directions, which is why we study this axis in greater depth. We propose to detail the method for the direction Paris to Bordeaux. In this case, the closing time is at 7:50 pm in Paris and the availability is at 5:30 am in Bordeaux. First of all, we have identified all the sorting platforms of DB Schenker that may be located outside the urban area of the intermodal terminal but that may reach the terminal in the allotted time considering the congestion (important in our case for the departure).

In addition, to identify the impact of greater flexibility on the carriers' side, two different pairs of time constraints for the departure and arrival time at the platforms are studied:

- a time slot from 7 pm to 7 am;
- a time slot from 6:30 pm to 7:30 am.

Figure 39 highlights the importance of the time of day in relation to the size of the accessibility area due to traffic. It is indeed possible to reach terminals outside the urban areas, especially around Bordeaux when time constraints are less tight for the carrier with later departing and earlier arriving trains. In this situation on the axis studied, it is possible to

consider the modal shift of 20 trips compared with 3 in the more temporally tight situation.²⁸
 All the results with economic and environmental cost are shown in the Table 9.

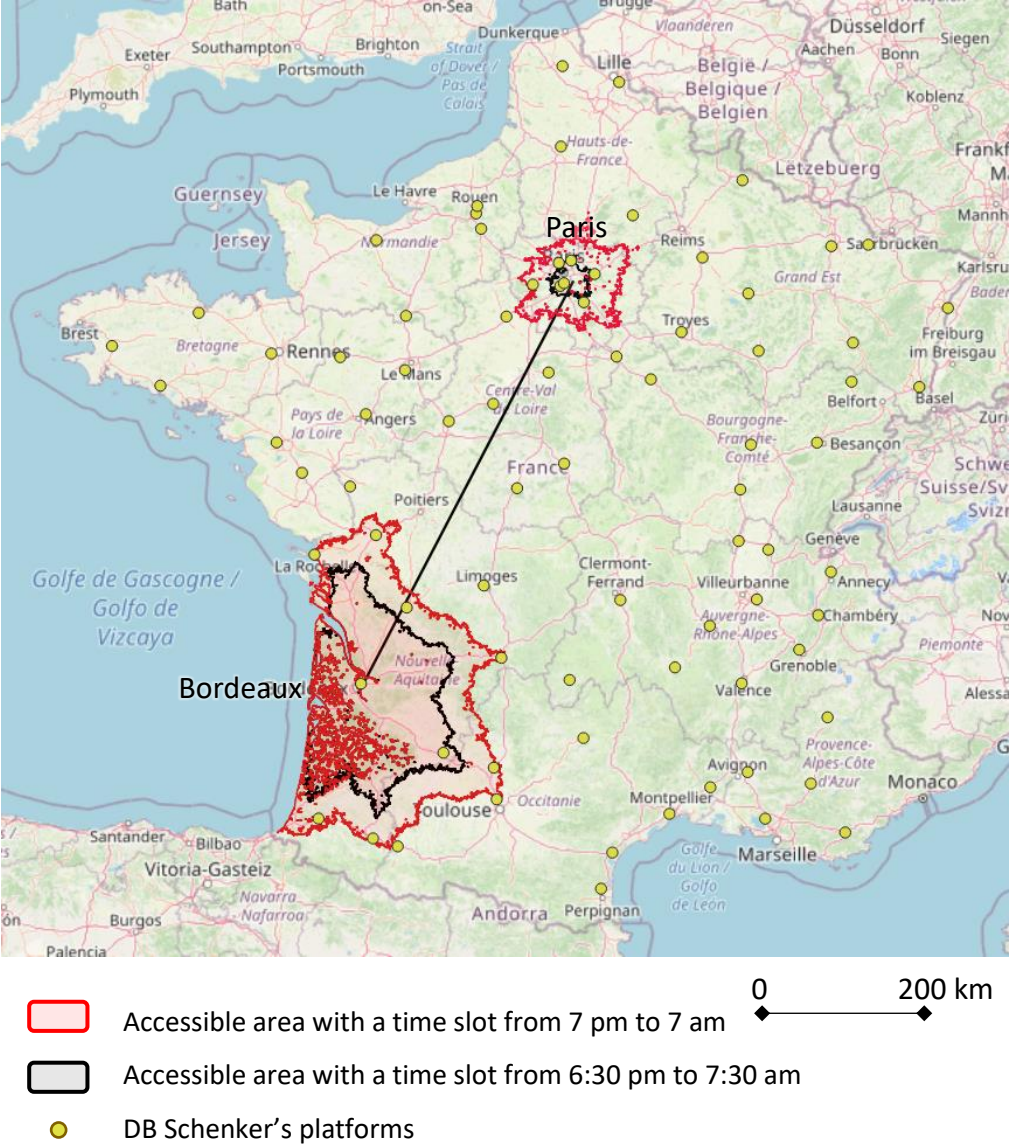


Figure 39 – Accessible areas according to the different time slot, author's realization

The main result is that the ecological gains are maximum when the platforms are close to the intermodal terminals (i.e. reduced time slot). In the case of a larger time slot, it is possible

²⁸ There is not necessarily a direct connection and by extension one or multiple trips between each platform

to integrate more distant platforms and the ecological gain is less important because of long pre or post haulage distance.

On the economic side, combined transport is never profitable. Even in the case of mutualization, the cost of pre and post haulage is too high (~50% of the total cost). The distance traveled by rail is not important enough to compensate this extra cost. In the case of a non-mutualization, the cost is too high. In this case, the cost of pre and post haulage is more important of the cost of 100% road transport.

Axes	Time slot	Number of platforms			Emissions saved	Cost	
		Departure	Arrival	# of trips	S1 & S2 /S0	S1/S0	S2/S0
Paris -> Bordeaux	19h - 7h	4	2	3	93%	+ 0.3%	+ 150%
	19h30 - 7h30	7	10	20	68%	+ 0.3%	+ 150%
Bordeaux -> Paris	19h - 7h	1	6	3	95%	+ 0.3%	+ 150%
	19h30 - 7h30	1	8	3	93%	+ 0.3%	+ 150%

Table 9 – Results of the in-depth study on the Paris - Bordeaux axis

1.4. Discussion and conclusion

This study questions the possibility and the relevance of transferring some parcel trips to rail. In our case, two major difficulties appear and limit the use of rail. It also raises broader questions about strategies for decarbonizing long-haul freight.

First of all, the company studied has a national coverage, the services of combined transport in France today do not allow this coverage. Moreover, it is concentrated between the major urban areas in France, Paris, and does not cover complete zones such as the northwest of the country (where there is an intermodal platform but no service). However, the actor studied does not justify the implementation of a train to this region because its trips are not significant enough. This is consistent with other studies arguing that the infrastructure is necessary but not sufficient for the modal shift to take place (it is necessary to have supply and demand) (Nierat and Combes, 2020).

The second major difficulty is the incompatibility between the constraints of parcel carrier and combined transport. The current service does not allow for a major shift from road to rail for DB Schenker. However, in some cases (0.2% of daily trips) it is possible to shift to rail, and these with significant environmental gains. This incompatibility is also reflected in the theoretical study that was conducted. In a theoretical framework and without considering

economic constraints, it would be possible to transfer a maximum of 1.8% of DB Schenker connections.

However, when the economic cost is considered, moving from road to rail (when possible) will lead to an increase of the transport cost. In the context of time and economic constraints, one point to be developed is pre- and post-haulage. It seems that this is the key element for the success or not of combined transport. For example, the ability to use a truck to do pre- or post-haulage and other operations in a day can make the combined transport economically competitive, in the event that it cannot, the costs become prohibitive.

This raises the question, in the case of a clear willingness from government to develop rail, should the railways adapt to the courier service or should the parcel service adapt to the railways? More globally, should the parcel service shift to rail at all? The consequences are not the same. If the parcel service has to adapt without modifying the current organization, then it will have to migrate to deliveries in 48 hours or probably more (48 hours service only reaches 1% of the routes), or adapt to the train and therefore deliver later and collect the parcels earlier from the customers. In addition, Chapter Spatial organization (page 55) has shown that the implementation of platforms in the Paris metropolitan area is organized for the first and last mile. In the case of the use of combined transport, the implementation of intermodal terminals should be considered in the location of the platforms.

On the other hand, if combined transport was to be adapted to parcel services, schedules would have to be modified to match the constraints with faster trains. However, parcel services represent only a part of freight transport. This share does not have the necessary volumes to fill trains even on certain routes. Therefore, it may not be useful to adapt a sector (combined transport) to a branch of freight transport.

On an economic side, studies show that it is essential to have a lower (and not equivalent) price for the rail solution to have a modal shift (Nierat, 1997; Frémont and Franc, 2010; Mostert, Caris and Limbourg, 2017). We also have to consider that an actor has an inertia to change and that for an equivalent situation he will remain the same. A strong incentive is needed to make the change (in this financial case). In addition, it must be considered that for a actor such as DB Schenker, integrating a share of combined transport means switching from a unimodal system (100% road) to a bi-modal system (road and rail), which makes the system

more complex. In this context, the market areas seem to make sense to define the areas of relevance for combined transport (Nierat, 1997).

It should be noted that today in France, the fees for the circulation of a train is function of the weight. This choice is a strong advantage for the courier service which has an average load per container of around 10 t. To give an idea of the prices according to the weight of the swap bodies, Nierat (2019) specifies that, on the Paris-Avignon link, the price varies between 1 (reference when the gross weight is less than 10.5 t) and 1.38 when this weight is greater than 25.5 t. It is even 0.67 when the ITU is empty. It is even 0.67 when the ITU is empty (Nierat, 2019).

From a more global point of view, this puts into perspective Europe's willingness to increase the share of rail freight. The parcel courier service represents only a part of the transport of goods, and today it unmatches with combined services in France. There is therefore a question (a strategic choice) of whether it is possible to set up a service for all transports or a service adapted to certain market segments. Using the train systematically to decarbonize seems unsuitable for certain market segments, which would see their service deeply deteriorate, as in the case of the parcel service, or would face price increases in other configurations when the volume of traffic is not sufficient to have economical and efficient trains. The study focuses only on the parcel service and the share of rail freight is certainly low in France (11%) but corresponds to another demand (i.e. heavy industry, continuity with maritime traffic). Even if this represents only a few connections, the authors hopes is to see this study as a possible starting point towards a more sustainable transport.

2. European scale – consortium of companies

This part looks at the impact of pooling on the feasibility of combined transport. This study is the result of a working group initiated by shippers who are not able (or not sufficiently able) to carry out rail transport economically on their own, hence the choice to group together to massify flows.

This part is completely independent of the part above.

As mentioned earlier, on an axis, there can be several connections from one or more actors. On each connection, there are one or more trips.

2.1. Model presentation

This section is divided into four parts, first a presentation of the operation with modal shift is detailed. In the second part, the data used are described as well as the methodology developed (third part) in order to evaluate the possibility to use combined transport instead of trucks.

2.1.1. Combined transport

Traditionally in industry, goods are transported directly between factories by heavy goods vehicles making long-distance connections (tractions). The connections are generally important with multiple trips and the companies operate their flows via FTL (Full truck load). The use of the road mode allows for operational flexibility (flexible departure times compared to the train). It also has the advantage of a high level of service. In case of problems, it is easily possible to use another solution. Moreover, for a large industrial company, it is very likely that the flows between two factories are far greater than 1 or more trucks per week (given the small volume required to fill a truck compared to a train). It is thus possible to make several trips per week and thus not to increase the storage in the factories by providing the same frequencies as the trucks.

When industrials use combined transport, instead of direct road transport to the final destination, goods are usually loaded in a swap body²⁹ that is routed to an intermodal terminal (pre-haulage). There, the swap body is transferred to a train that will transport the swap body (pooled with other actors' flows) to its intermodal destination terminal. Once there, the swap body will be transported by truck to its destination (post-haulage). Those operations are summarized in Figure 40.

For the following, it is assumed that a semi-trailer as well as the swap body (one ITU) are 2 TEUs long and that a combined transport train contains a maximum of 40 ITUs³⁰. The specific cases of the Iberian Peninsula (Spain and Portugal) will be treated separately due to its technical specificities.

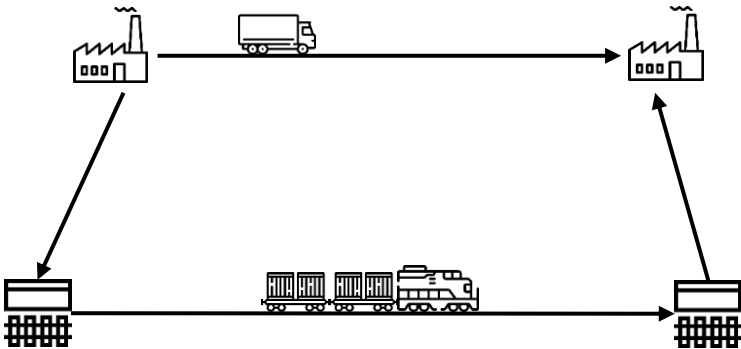


Figure 40 - Scheme of the traditional operations of industrials and operations with modal shift, author's realization

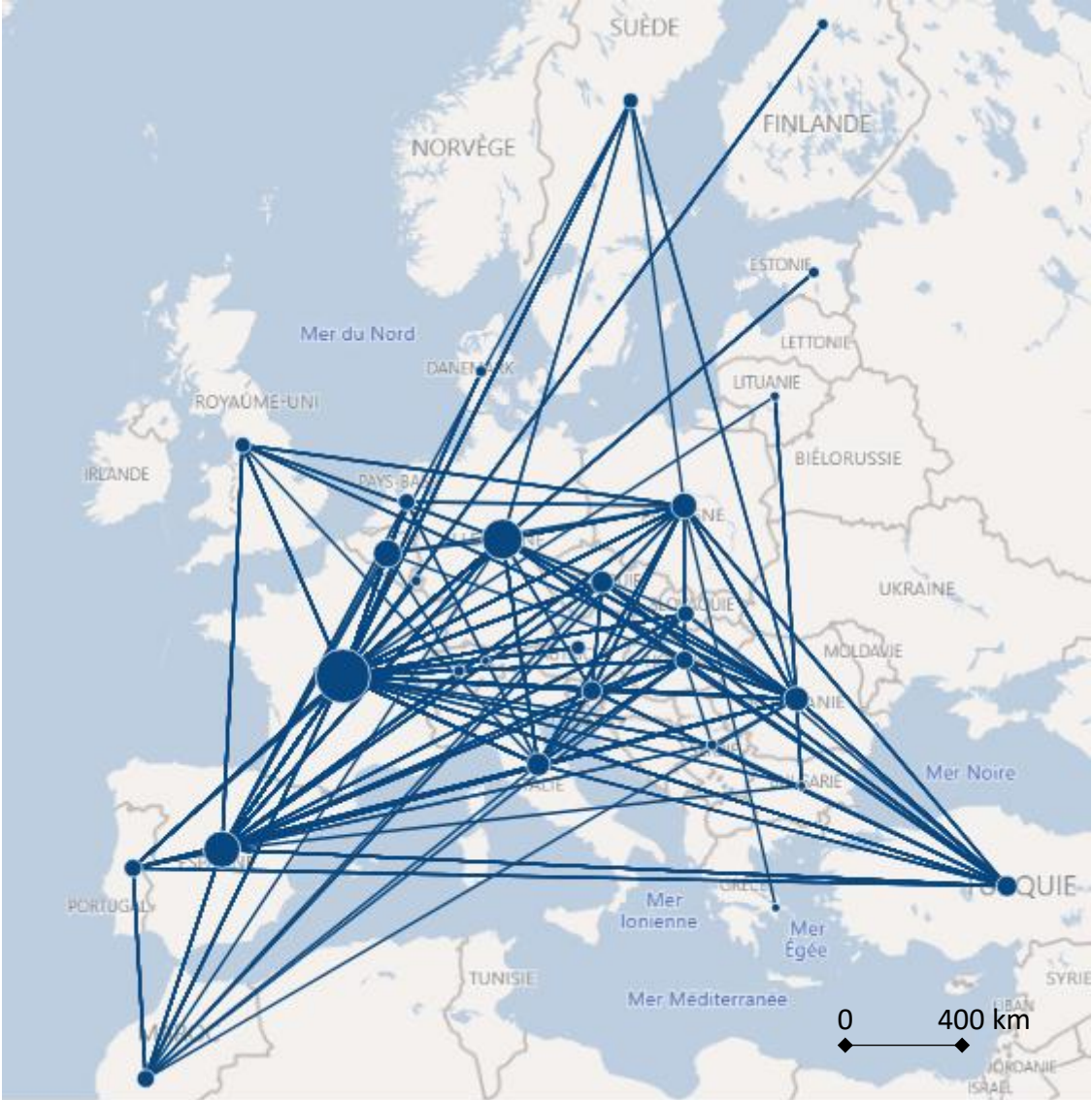
2.1.2. Database

The database was created from the inbound and outbound connections of 9 companies in different fields of activity: transport, automobile, chemicals, metal industry, food and cosmetics. The study is focused on the European (and bordering) scale. As the study is conducted under the initiative of the France Supply Chain association, most of the connections

²⁹ Rolling stock management is not studied here

³⁰ Even if false, the maximum length of the trains is different according to the countries, this hypothesis is made in a first step. The case of Spain is treated separately in the following.

are from or to France. For confidentiality reasons, the connections will always be aggregated between the actors in the rest of the article.



Number of ITUs received per week

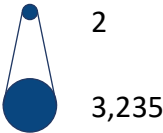


Figure 41 - Visual representation of the axis of the database, circles proportional to the number of ITU received by countries, national traffics are not considered here, author's realization

As the project focuses on the modal shift towards combined transport, the database mainly includes road connections. Some actors gave all their connections, other only select few of them. In total, it consists of 6,164 origins and destinations (connections) between 29 countries

(in addition to EU: Morocco, Great Britain, Switzerland and Turkey) over one year. On average, a trip is 544 km long and the average load is 15.7 t.kg per ITU. The average number of weekly trips per connection is 2.8. In the end, the database represents 8.9 G t.km (as an indicator, all the goods carried in France represent 334.5 G t.km in 2021, (SDES, 2021)). Figure 41 is the visual representation of the connections in the database aggregated at the country level.

More precisely, the database gives: the point of departure, the point of arrival, the average, maximum and minimum number of trips per week, the volume per trip (in ITU), the average tonnage per trip, the current transit time and the authorized transit time. The day of the trip is not indicated.

The following assumes that actors can adjust rotation days, but the number of trips per week remains unchanged. This means that for a connection with two weekly trips of one ITU, the assumption is made that actors can schedule goods to leave on different days, such as Monday and Wednesday for example. However, the number of weekly trips is still respected, meaning that it is not assumed, for example, that the two ITUs can both leave on Monday.

Before applying the methodology explained in the following, a treatment was carried out on the database, geocoding of the points of departure and arrival, calculation of the Euclidean distances in direct route in road mode, harmonization of the notations and suppression of the flows out of the perimeter of the study.

2.1.3. Origin-destination matrix between countries

The origin-destination matrix (OD matrix) between countries is presented Table 10. From it, it is possible to identify the axes from which it is possible to work.

As expressed earlier, the nature of the group (under the leadership of a French association) marks the connections that are strongly from or to France. In green are represented the

studied axis, with more than 80 ITUs per week³¹ (if an axis has more than 80 ITUs per week in a way, the full axis is studied). This limit has been chosen after empirical tests, with the number of trips per connection game, under 80 ITUs per week, it is not possible to group the trips to have 40 ITUs and to respect the number of weekly trips.

The study excludes axes where only one actor operates, even if the axis exceeds 80 ITUs. In such cases, we assume that the actor, if possible, would already have chosen to use combined transport. In other words, mutualization brings nothing and serves no purpose in this case.

The OD matrix shows a similarity with the global trade of France with important representation of Germany then Spain, Belgium and Italia, which confirms that even if we study a reduced consortium of companies, the number of trips respect the global trends (Insee, 2020). Nevertheless, Romania is over-represented. Contrary, Switzerland and Great Britain are under-represented in the database used.

³¹ The case of intra-national connections is not explained in this study as they have been studied and the results indicates that it is not possible to use to combined transport. The main issue is that the connections are geographically diffuse preventing mutualization.

from \ to	Austria	Belgium	Bulgaria	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Italy	Liechtenstein	Lithuania	Luxembourg	Morocco	Netherlands	Poland	Portugal	Romania	Serbia	Slovakia	Slovenia	Spain	Sweden	Switzerland	Turkey	United
Austria								10																				
Belgium								64	3																			
Bulgaria								7												16				3				
Croatia								4																				
Czech Republic								84								2				41			13	24			17	
France	22	470		118	23	16	6	7495	833		25	297	1	1	32	48	70	163	44	136	17	61	53	648	21	8	95	27
Germany				5				230	119		15	8				1		32	4	35		6	3	83	5		6	20
Hungary								56	9			15				3				47	4		8	20			3	
Italy								167	25		17	242				4	6	28		15		6	5	55			9	8
Lithuania																				6								
Morocco								39								448			8	1				27				
Netherlands								12				5						5						4				
Poland		4						144	26	4	23	20				3	5	8		100			15	40	7		23	26
Portugal								45								14			8	17				90			15	
Romania		1	1	5				85	21		2	10		1				48	8	293	4	1	23	67	1		72	1
Serbia								27																6			3	
Slovakia								28												18			10	16			6	
Slovenia				9				43			9	1						7		12		5	6	9			3	
Spain		16		16				527	70		21	42				112		8	53	62		7	11	1296	5		75	20
Sweden									1																			
Switzerland		5																						2				
Turkey				7				77	1		5	4							1	3	72			36	23		545	
United Kingdom								20																14				

Table 10 – Weekly trips in ITUs between countries

2.1.4. Methodology

The objective is to identify axes on which it is possible to make a modal shift. For the sake of simplicity, the connections have been studied at the country level. A specific methodology (due to technological constraint) is applied on the axis: France - Iberian Peninsula.

General case

The methodology adopted is firstly, based on an Origin-Destination (OD) matrix between countries, to identify the axis on which the number of ITUs is equal or greater than 80. On these routes, more detailed work is carried out. As explained before, the choice of 80 ITUs is empirical. The choice of 80 ITUs allows us to avoid studying axes that are too weak while studying axes where it would be possible to reach the 40 ITUs required under certain conditions.

The number of rail trips on the axis is calculated as follows: the number of trips per connections per actor is respected and are not aggregated. Let's take the example of three theoretical connections with 90 weekly ITUs. In the first case, the 90 ITUs are divided into 90 different connections (one trip per connection), in this case, it is possible to imagine two trains (with 40 ITUs each time). A second case possible case is 18 connections with 5 weekly trips each. In this case, it is not possible to reach the 40 ITUs needed to launch the train without aggregating the trips of an actor (aggregating the trips would mean not respecting the number of weekly trips). A third and intermediate case would be 45 connections with 2 weekly trips. In this case, it is possible to imagine two trains. In the last case, the number of weekly trips is respected.

Once the axes have been identified, the train route is determined, defining one departure intermodal terminal and one arrival intermodal terminal. For this purpose, the centroid of the departures (and arrivals) is calculated, and then the nearest intermodal terminal is identified using the database produced by the intermodal transport association - GVK (SGKV, 2022). The Figure 42 summarizes the previous paragraph.

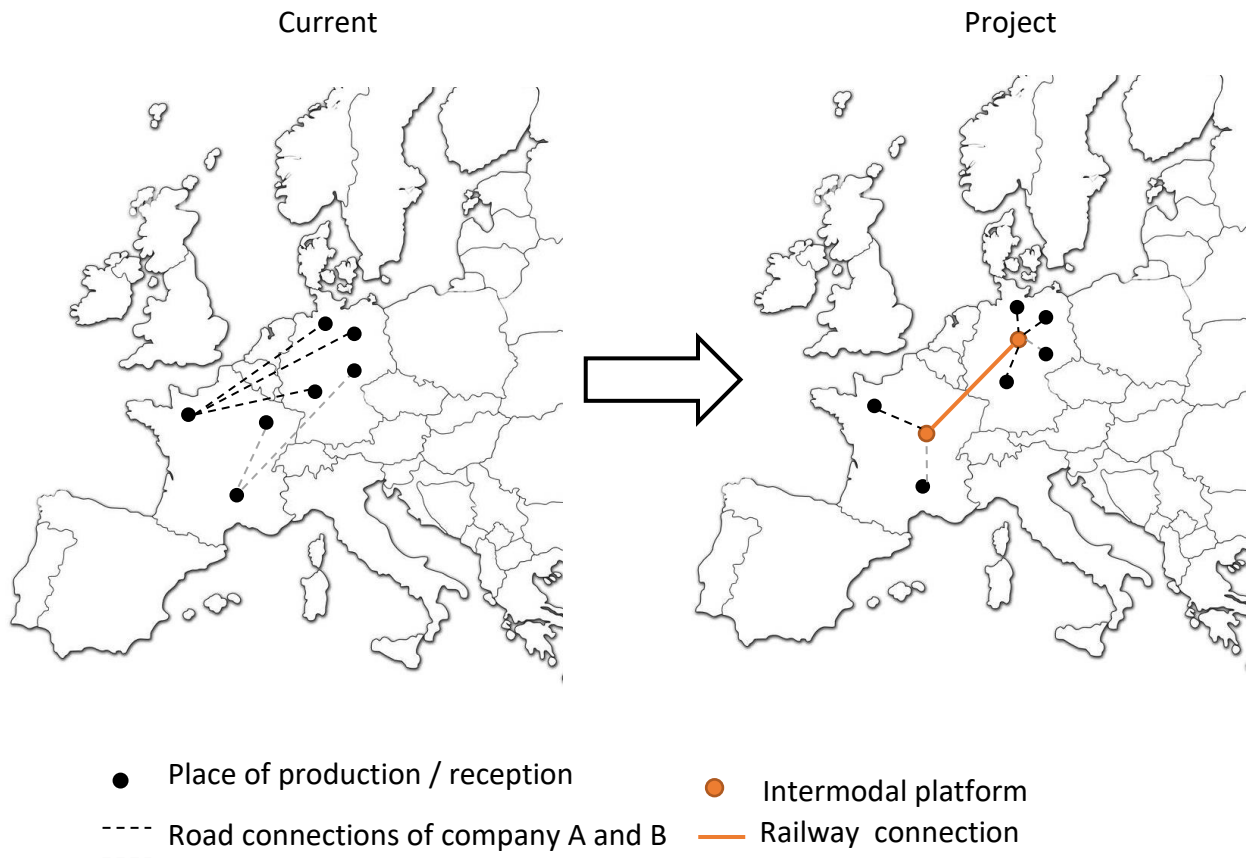


Figure 42 - Diagram of the identification of the rail route for a theoretical case between two actors on the France - Germany axis, author's realization

For each connection, the direct route (by truck) is calculated. It allows to have a reference scenario. Then, once the intermodal train is identified, the distance of the pre and post haulage is calculated as well as the rail distance. This allows to calculate the road kilometers saved as:

$$\text{Kilometers saved} = \text{Distance in direct route (road)} - \text{pre and post haulage}$$

Similarly, the t.km are calculated as:

$$t.km = \text{distance travelled [km]} * \text{tonnage of goods [t.kg]}$$

In the case of combined transport, the t.km corresponds to the sum of t.km in pre- and post-haulage and in the rail trip.

For the calculation of CO₂ emission gains, the European average emissions per mode have been used (Eurostat, 2018) :

- On average, a train emits 24 g.CO₂e/t.km;
- On average, a train truck emits 105 g.CO₂e/t.km.

France – Iberian Peninsula axes

The case of the Iberian Peninsula (Spain and Portugal) is special because in both cases, the maximum size of trains allowed is smaller than in the rest of Europe (450 m long except in the case of the railways to Barcelona) (FIS and Kersten, 2020). Furthermore, the track gauge is not the same as in France (1,435 mm for France compared to 1,668 mm for Iberian Peninsula). This implies the need to transship swap bodies at the border, in addition, due to the train limit, the Iberian train capacity is 27 ITUs compared to 40 ITUs in France. There are two possibilities³² for a actor who wants to operate combined transport on this axis:

- To operate a journey Iberian Peninsula - border with 27 ITUs on the train and to convey in parallel 13 trucks until the border to reach the 40 ITUs on the railroad way in France;
- To transport the 40 ITU by truck to the border and to use rail only in France.

In the rest of the paper and after exchange with the different members of the project, the second solution has been retained, i.e. road route on the Spanish part. Moreover, in the rest of the paper, due to the geographical specificities (peninsulas), it makes sense to aggregate the connections from Portugal and Spain and to study them together.

³² A solution not mentioned but possible would be to make 3 trains in Spain (27, 27 and 26 ITUs) to make 2 trains of 40 ITUs in France.

2.1.5. Economic model

Once the axes have been identified, an economic model can be applied to estimate the cost of modal shift for both total cost of ownership and total social cost (total social cost and externalities). For this purpose, the cost model applied by Nierat is used (Nierat, 2022). The total social cost is defined as the total cost of ownership plus the external costs.

Items	Truck	Train	Unit
Speed	65	55	km/h
Distance travelled	0.6	6	€/km
Time	43	1000	€/h
Fixed term	0	1000	€
Waiting time (load, unload)	1.5	1	h
Handling		50	€/ITU
External costs	0.6171	2.731	€/v.km

Table 11 – Rail and road transport cost model, (Nierat, 2022)

2.2. Results

The section is divided into two parts: economic and operational analysis of the studied axis and a focus on the France – Czech Republic axis.

2.2.1. Possible axis

From the OD matrix (Table 10), the axes with 80 ITUs or more per week could be identified. From there, the 26 eligible axes have been studied. Only the axis where trains could be launched have been kept in the following (the number of trips per connection has sometimes made it impossible to reach 40 ITUs per train). Finally, 12 routes were identified compatible with combined transport.

Table 12 can be read as follows:

- Axis: axis considered in the given direction (from ... to ...);
- # actors: number of firms operating on the axis;
- Potential trips: total number of weekly ITUs on the axis;

- Realized trips: total number of weekly ITUs that can be switched to combined transport within the limit of the number of trips per connections and number of ITUs per train;
- # train: maximum number of trains that can be potentially launched thanks to the mutualization;
- Km saved: number of road kilometers avoided due to the use of combined transport;
- CO₂ emission: share of emissions avoided due to combined transport;
- TCO: total cost of ownership for both solutions;
- TSC: total social cost for both solutions;
- t.km evolution: evolution of t.km between a 100% road solution and combined transport.

The axes have been classified into 3 categories:

- in red: axes with the necessary volume to have at maximum one train per week (40 ITUs) in only one direction;
- in green: the axes having the necessary volume to launch at least one train in both directions (not necessarily the same number of trains in both);
- without color: the axes on which it is possible to launch trains but where combined transport is not economically interesting.

The results show two strong axes: France - Spain and France - Germany. There is also a certain imbalance depending on the direction, except for the France - Spain axis. Looking at the evolution of the potential trips to realized trips, it can be observed that the higher the number of potential trips, the more trains can be launched, which allows to respect a higher number of weekly trips by train per week, thus increasing the number of realized trips, etc. In other words, mutualization allows more weekly trips per train per axis, which makes it possible to imagine a combined transport offer that can substitute part of the current truck organization.

Axe	# firms	Potential	Realized	# train	Truck km avoided %	Evolution of total t.km	TCO			TSC		
		trips (ITU)	trips (ITU)				100% truck	CT*	%	100% truck	CT*	%
FR - PL	5	136	80	2	-34%	34%	231 366 €	210 856 €	-10%	334 530 €	239 209 €	-40%
PL - FR	4	143	40	1	-30%	35%	243 659 €	231 074 €	-5%	352 321 €	244 165 €	-44%
FR - RO	2	139	40	1	-35%	31%	297 738 €	291 308 €	-2%	433 148 €	319 021 €	-36%
RO - FR	2	85	39	<1	-36%	33%	197 763 €	185 866 €	-6%	288 243 €	205 667 €	-40%
FR - CZR	3	118	80	2	-34%	35%	141 023 €	134 097 €	-5%	203 801 €	157 223 €	-30%
CZR - FR	1	84	40	1	-33%	37%	96 187 €	93 334 €	-3%	138 821 €	104 144 €	-33%
FR - IT	4	52	24	<1	-48%	50%	53 905 €	63 975 €	+16%	77 540 €	71 681 €	-8%
IT - FR	2	114	40	1	-46%	44%	122 953 €	123 821 €	+1%	177 103 €	134 672 €	-32%
FR - DE	5	414	400	10	-61%	45%	322 400 €	376 180 €	+14%	467 045 €	479 550 €	+3%
DE - FR	3	230	120	3	-56%	40%	176 897 €	188 615 €	+6%	229 977 €	227 151 €	-1%
FR - SP	5	493	480	12	-51%	22%	661 937 €	614 873 €	-8%	959 808 €	792 890 €	-21%
SP - FR	3	488	480	12	-49%	19%	657 469 €	593 062 €	-11%	953 418 €	759 452 €	-26%

Table 12 – Possibilities of combined transport based on the methodology applied to the identified axis, *Combined transport

As expected, the use of combined transport saves a significant proportion of road kilometers. However, it can be observed that there are large differences in the number of kilometers saved depending on the axis studied. The same applies to CO₂ emissions. In any case, the use of combined transport is always positive from the point of view of carbon emissions.

In general, the use of combined transport increases the t.km significantly. This is due to the fact that pre- and post-haulage often involves moving goods not necessarily in the direction of the final destination (see Figure 42).

From an economic point of view and assuming that the train is full, the greater the distance, the more interesting is combined transport. This is due to the fact that the kilometers traveled by train are cheaper than the kilometers traveled by truck. Another parameter that impacts the cost of transport is the pre and post haulage and more specifically the bad kilometers that allow to reach the intermodal platform but do not go in the direction of the destination. These kilometers are paid twice; once by truck and once by train. In Table 12, these kilometers can be seen in the evolution of total t.km. In our case, it can be assumed that S0 is in direct trace and that the tonnage is constant. The evolution of t.km corresponds to the additional bad kilometers. The economic impact of these bad kilometers is direct, although the number of ITUs is important on the France-Germany axis, the combined transport solution is suffering from the explosion of the t.km (at least +40%). The opposite case is the France - Spain route. The combined transport solution is profitable despite the small distance thanks to the low evolution of the t.km. This is due to the methodology with demassification at the border inducing a limited number of bad kilometers on the Spanish part.

As far as the TSC is concerned, combined transport benefits greatly from the difference in the cost of externalities between rail and truck (~1 to 10 ratio). Except for the case France - Germany which has a strong increase of t.km, all axes have a much lower TSC for combined transport.

The overall study has provided empirical evidence on the impact of rail distance or the impact of pre and post haulage. However, as the study is aggregated among actors, it seems relevant to look at the actor level and see if the general results apply to each of them.

2.2.2. Focus on France → Czech Republic

A particular focus is made on the France -> Czech Republic axis. Overall, from Table 12, it can be seen that combined transport is 5% cheaper than 100% road transport in terms of TCO and 30% cheaper in terms of CST. However, when looking at the economic point of view of each actor the result is not the same. Looking at the direction France -> Czech Republic, 3 actors are concerned. Globally there is potentially 118 weekly ITUs. When considering the number of trips per connections, this figure goes from 118 to 86 ITUs compatible with two rotations per week (Figure 43).

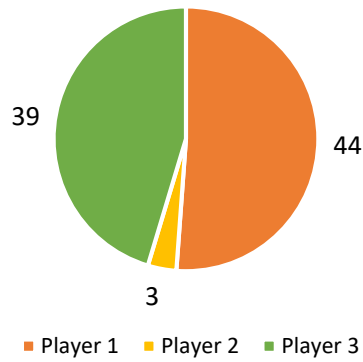


Figure 43 – Number of weekly ITUs per actors compatible with 2 rotations per week

Table 13 indicates the TCO and TSC for each actor using the combined transport solution compared to the truck under the assumptions that 100% of their trips goes through the combined transport and that the train is full. It can be observed that if globally it is interesting to do combined transport, for the actor 2 it is not interesting because its TCO for combined transport is higher. This can be explained by the fact that the t.km increases more this actor, this can be translated by the fact that many bad kilometers are realized (i.e. kilometers by truck to go to the intermodal platform which are not in the direction of the destination).

	TCO	TSC	t.km
Actor 1	-8%	-24%	33%
Actor 2	2%	-3%	48%
Actor 3	-5%	-15%	31%

Table 13 – Cost of combined transport compared to 100% road solution

2.3. Discussion

Overall, this study illustrates that mutualization is one of the possibilities to help the development of combined transport but raises several issues, but the three main ones that will be discussed are the evolution of t.km when shifting from 100% road to combined transport and the increase of costs that this induces, the cost of pre and post haulage and the fact that on an axis there can be winners and losers.

The shift from road to combined transport always leads to an increase in t.km. In our case, the weight of the goods is constant, which means that the increase only comes from a longer distance travelled. This is significant. Figure 44 (a) is often used to represent the evolution of the costs of combined transport according to distance travelled by each mode (Hanssen, Mathisen and Jørgensen, 2012). For this, the implicit hypothesis is that the chain is aligned and that there are no extra kilometers. In our case study, the evolution of distances is at least +30% (excluding France - Spain). This shows that the case (a) is theoretical, reality is more likely to something like the case (b) in Figure 44. The implications of this are that the additional cost to be absorbed by the lower cost of rail includes not only the cost of handling at the intermodal terminal but also the cost of the additional km for pre and post haulage. Finally, it introduces a notion of good and bad kilometers in the pre or post-haulage for intermodal solution; bad kilometers being the kilometers that do not go in the direction of the destinations and that are just an additional cost. These kilometers are paid twice; once by truck and once by train. The pre and post haulage have an important impact on the economic feasibility of combined transport.

However, the idea that it would be sufficient to move production locations closer to intermodal terminals is interesting on paper. This follows from the assumption in cost models that road costs are mainly per kilometer. This is case (c) in the Figure, which is based on the work of Nierat (1997). In this case only the slope of the costs for pre- and post-haulage changes (increase). This is due to different organization and performance between short and long haul. For a short distance by truck, the speed will be lower, the empty run rate higher etc. than for a long-distance haul. This justifies that the cost per kilometer is higher for a short distance than for a long distance. This also raises broader issues of urban planning and facilities for production sites in relation to transport facilities (Nierat and Combes, 2020).

Moreover, an imbalance of number of ITUs depending on the direction can be observed. This is mainly due to the case study (only French companies), however, if this imbalance is real, it is to the advantage of rail. Indeed, in all cases, it is necessary to bring back the empty containers (swap bodies, containers, etc.) and that is much less expensive via rail (Nierat, 1997).

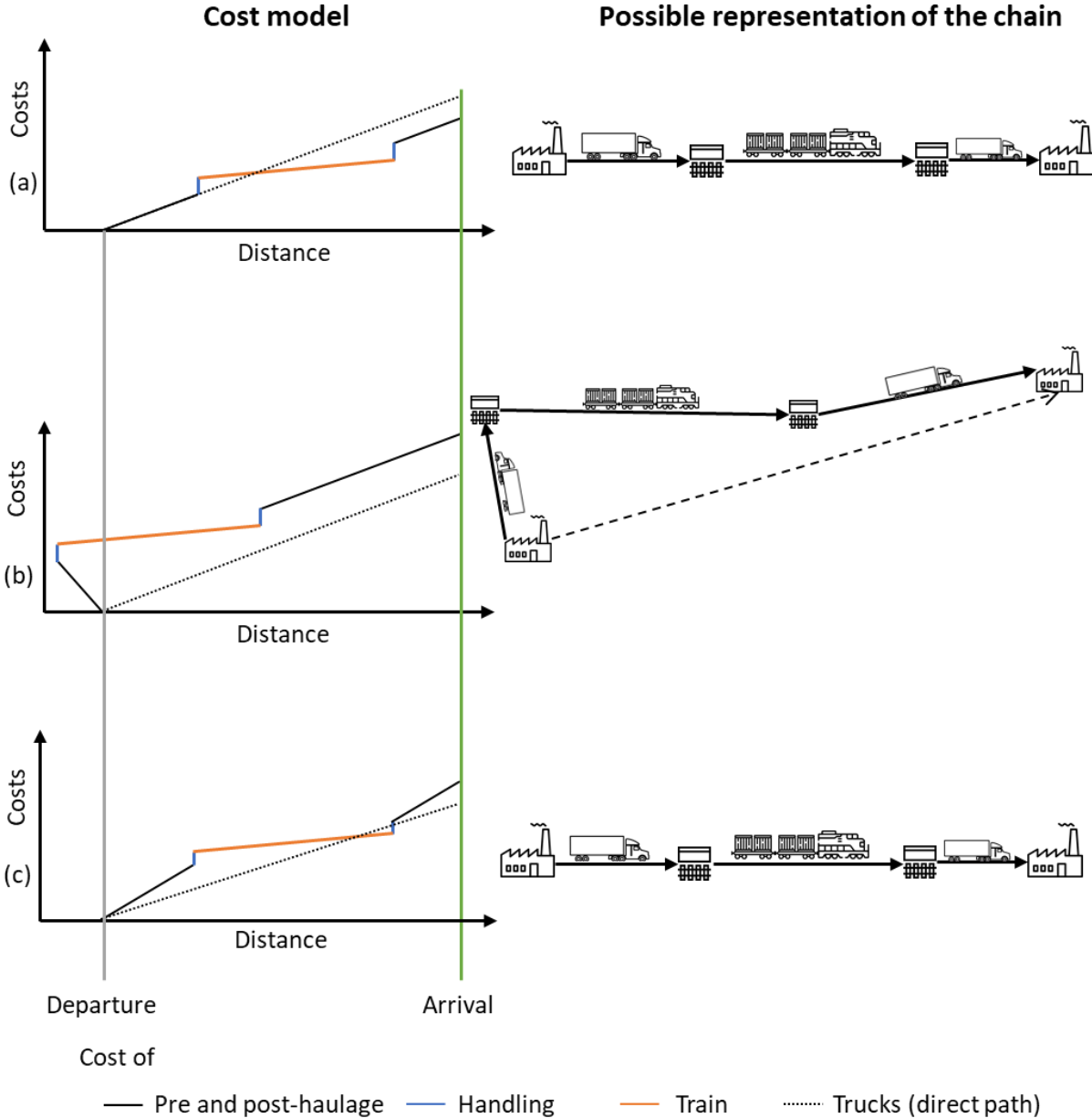


Figure 44 – Representation of three possible case of combined transport, author’s realization inspired by Hanssen *et al.* (2011) and Nierat (1997)

This study had the advantage of being based on a subdivision by actor, so the flows could be aggregated to carry out the study and then disaggregated to the actor level. The example

of the France -> Czech Republic axes is very interesting because it shows that, for an axes that is economically interesting overall, this is no longer the case when we go back to the level of the actor. There are winners and losers. However, it is necessary for everyone to commit to the axis to ensure viability; winners need losers. Indeed, rail transport has the defect of high fixed costs that can be absorbed when the train is full. It is therefore preferable to have several actors to ensure that the train is full, otherwise financial viability is threatened. In our case, if it is not possible to distribute the gains between the actors, the viability is threatened even if it is a small actor that chooses not to use combined transport. This poses more globally one question to enable mutualization: given that each actor is different, it will never happen that two actors are in the same configuration and therefore the mutualization must integrate a lever of redistribution for equity between actors at the risk of seeing an actor withdraw from the project and therefore that the overall project stops.

The case of the France-Spain axis shows an interesting configuration as most of the connections are from a region in France and the same for the Spanish side. In addition, due to the constraints on the Spanish side (train length limited to 450m against 750m in France) the solution chosen is to transport the goods to the border by train and then make the journey on the Spanish side by truck. Finally, through this arrangement, it is possible to reduce the additional km, there is notably no kilometer backwards (in the case where the place of production is before the intermodal terminal and it is thus necessary to go backwards) which are very expensive. This results in the lowest increase in t.km compare to other solutions.

2.4. Conclusion

The objective of this study was to investigate the impact of mutualization on the feasibility of combined transport. The results demonstrate that mutualization enables reaching the minimum threshold of 40 ITUs on a significant number of axis (but none all of them), thus enabling train operations. It is worth noting that none of the actors were able to operate trains on the studied axis without mutualization, but thanks to mutualization, it would be possible to operate 45 combined transport trains per week across Europe. This would result in an average reduction of 36% in CO₂ emissions compared to 100% road transportation. However, the results also highlight several points that require further examination.

Firstly, the study's results demonstrate that there is no correlation between the percentage of km saved and the percentage of CO₂ saved. This is due to the fact that it is necessary to consider the percentage of emissions and the evolution of t.km. The highest gains in CO₂ reduction are observed when the increase in t.km is minimal. It is rare for combined transport to occur where the distance travelled by both combined and road transportation is identical. This would require perfect alignment between the origins, the destinations and the intermodal terminals.

The last point of discussion pertains to the concept of good and bad kilometers. Referring to Figure 44, when goods have to be transported back and forth for pre- and post-haulage, there can be an accumulation of bad kilometers. To make the use of a train profitable, it is necessary to maximize its capacity. As the break-even point for the train occurs at 80% of its capacity, loading one more ITU leads to a better use of the train (for example from 39 to 40 ITUs) that enable the maximization of financial gains. On the other hand, the more bad kilometers accumulated during pre- and post-haulage, the more the financial balance will be against combined transport, which is consistent with market trends. (Nierat, 1997). This can create a winner-loser situation. If a actor's connection on a particular axis consists of only ITU with a negative balance, then this actor will lose by using combined transport. However, this extra ITU can make the use of combined transport viable for 38 other ITUs. Therefore, it is necessary to redistribute the gains to the losing actor so that the train can operate. It is important to note that if the train is not operated, the community as a whole will lose out with increased CO₂ emissions.

In addition, the study of the France-Spain axis shows that, thanks to the high number of connections, it would theoretically be possible to launch a large number of trains. This also means that it is possible to launch one less train, but to be sure of filling them all even in the event of unforeseen circumstances. The study presented only includes 9 shippers; in the context of a larger consortium, the proportion of trips that can be switched to combined transport would be greater.

It is important to note that the financial cost and actor willingness to switch from road to combined transport is a crucial factor that needs to be considered. Previous studies have shown that operators agree to pay more to avoid switching modes (Maier, Bergman and Lehner, 2002; Nierat and Combes, 2020). Therefore, it is necessary for combined transport to be more competitive than road transport to be an attractive option for operators. This is especially important in the context of a project that involves mutualization between actors, as the solution may be more complex.

More globally, it has been assumed that the rail network has the possibility to receive more flows. It is not forgotten that some axis of the combined transport chain is currently saturated: intermodal platforms, border crossings, etc. These issues should be the subject for future research.

Overall, this study highlights the potential for freight transport to shift to less polluting modes in response to the current climate crisis. It demonstrates that pooling can play a central role in decarbonization and is a promising avenue for reducing CO₂ emissions. As a complement to this work, it would be interesting to conduct an economic study to explore the win-lose concept further. Finally, the ongoing continuation of the study to the launch of the train will identify any operational, capacity or coordination obstacles.

3. Chapter conclusion

This chapter has explored the question of combined transport as a solution for decarbonizing long-distance freight. Several conclusions can be drawn from this work.

First of all, the first part highlights the important question of who combined transport is intended for. The DB Schenker study shows that the current offer does not correspond to the expectations, either economically, nor in terms of spatial coverage nor in terms of time constraints of the parcel service. In the consortium study (mainly industrials), the goods concerned are more in adequacy with the advantages of the rail (important volumes). However, on the European axes concerning France, the offer of combined transport is almost non-existent, hence the need for a theoretical approach.

Moreover, the study on the scale of a consortium shows that a game of winners and losers can be set up on certain axis, with combined transport being interesting overall, but not for each actor. This raises the question of the total viability of the project and the means to ensure the success of a pooling project.

Finally, the question of pre and post haulage is central in both studies. In the first section of this Chapter, the choice was made to have a higher cost per kilometer, which leads to a combined transport solution that is never profitable because of the pre- and post-haulage even they are short. However, this shows that the potential for the development of combined transport on a national scale for parcel services under the current conditions is mainly non-existent. In the second study, the choice was made to rely on some of the existing literature for the cost of pre- and post-haulage (mainly cost per km), which results in an underestimation of the latter. When looking at the total costs, they are not largely in favors of combined transport, if the pre- and post-haulage costs have been largely underestimated, this could lead to a change in the results and make combined transport unattractive.

CONCLUSION

This work is purported to provide a vision on the whole transport chain from the standpoint of its actors, with the objective to improve the understanding of the potential of modal shift from road freight transport towards low or no carbon modes. For this purpose, a monograph of a carrier - DB Schenker - was carried out; together with a set of additional case studies aimed at verifying the validity of the results or to provide an even more complete vision on a theme. Overall, this work allowed to emphasize the complexity of the organizations set up to transport goods from a point A to a point B, an apparently simple action. The objective of those organizations is to optimize the use of resources (trucks, platforms, etc.) under multiple constraints (delivery times, transport conditions, etc.) The identification of these constraints enables to explore two concrete paths to decarbonize part of road freight transport: cargo bikes and rail-road combined transport. By relying on the study of shippers and carriers, it was possible to explore a point of view that is not well develop in the literature.

This conclusion is divided into two parts. First, the main research results are summarized. Second, a more general conclusion on the contribution of the approach is drawn.

Main results

The thesis' first objective is to contribute to the understanding of freight transportation, through the perspective of the firms which produce it. The first question examined in this research serves directly that objective: the spatial organization of a prominent road freight parcel carrier was studied, both for the long distance and for the first and last mile operations, on the basis of an extensive dataset describing the carrier's operations. For the first and last mile combinations, conclusions drawn from the examination of the carrier's datasets could be tested for robustness with datasets provided by two other important express carriers. It was shown that the sequence of operations that forms the basis of the production process of a carrier, although often assumed to be simple and linear, is in fact a complex object, in which each stage of the sequence is intertwined. In particular, the examination of DB Schenker's long-distance network demonstrated that even within the long-distance network long-

distance routing is programmed such as the parcel can go through several connections in one night. Besides, for the first and last mile operations, we have shown that carriers implement a polycentric strategy to operate Paris metropolitan area, allowing to divide this large area into a multitude of smaller areas, each served by one of the platforms located in the periphery. This approach is specific to large metropolitan area, for this parcel service carrier in France, it is the only territory with a polycentric approach. The research also shows that organization at the metropolitan scale corresponds to the outputs of a model of optimization of the location of platforms in relation to its first and last mile activity: in other words, it is not possible to identify a substantial difference between the actual choices of the carrier and what would be preconized by a cost minimization algorithm.

The thesis also examines the possibility to improve the environmental impact of urban freight transport by introducing cargo-bikes into the first and last mile operations in order to, as much as possible, substitute them to conventional light commercial trucks (LCTs). This analysis is also based on a case study in Paris, an area which is particular for its very high inhabitant density, its intense economic activity, and its very dense urban freight transport activity. The analysis is also focused on parcel transport. With platforms located at the periphery, the use of cargo bikes, therefore, requires the implementation of micro-hubs. The advantages of cargo bikes over light commercial trucks (LCTs) is their higher travel speed in urban areas (an advantage that is lost in the urban periphery), and their lower cost. However, cargo bikes have a reduced payload; where one LCT can deliver and pickup many parcels in one round, a cargo bike requires several rounds in order to transport the same number of parcels, returning each time to micro-hubs. Those micro-hubs are costly; for the possibility that this whole organization is competitive compared to the conventional organization, this cost needs to be compensated by a high density of operations. However, this density of operations tends to be very strongly correlated to the density of inhabitants, which is often, in general, also correlated to a high real estate cost, which in turn requires more operations to compensate, etc., making the whole issue of the relevance of cargo bikes less trivial than it may seem at first glance. To conclude, this work has shown that it is possible to replace (or at least strongly complement) LCTs with cargo bikes in a cost-efficient way under certain conditions regarding the density of operations. This does not mean the end of trucks in the city! In fact, they will always be necessary, if only to supply the micro-hubs, but also to operate

all the parcels that cannot be carried by a cargo bike (too heavy, too bulky, etc.). This work also makes it possible to link studies on vehicle characteristics with those on logistics real estate by placing the micro-hub at the heart of the feasibility of a cargo bike solution.

In the last part, the question of the use of combined transport has been analyzed as a solution for the decarbonization of long distance. The study, in two steps, shows first of all a mismatch between the supply of combined transport services in France and the expectations of a parcel carrier which would like to shift some its long-distance transport operations from road to rail-road combined transport, both from an organizational point of view and in terms of spatial coverage. Leaving aside the economic constraint, the research shows that, under current conditions, it is only possible to shift 0.2% of the carrier's daily trips to combined transport. Although the use of combined transport is not possible under the present conditions, the question is to determine whether combined transport should be aligned with the constraints of parcel delivery. Combined transport currently addresses different needs (e.g. continuity with maritime transport); and modifying combined transport services to fulfill the requirements of a parcel carrier could lead to a misalignment with those of its current customers. As a matter of fact, the development of new markets for combined transport needs not specifically address parcel carriers. The final part of this research examines a different segment, whereof a consortium of 9 companies (shippers and carriers) consider pooling their needs in terms of transport to justify the implementation of a combined transport service adapted to their own requirements. The latter makes it possible to increase the volumes on the axes and thus to fill the trains but also to increase the number of rotations. This made it possible to imagine a combined railroad transport proposal that is compatible with the needs of the actors, without the constraint that they should modify the organization of their supply chain. However, this research also showed that mutualization is not an automatic condition of success, even when global cost-effectiveness is achieved. Indeed, it can give rise to a win/lose situation when looking at it from the standpoints of each firm, making the whole consortium vulnerable if no compensation scheme, or other kind of action with the same outcome, does not mitigate that risk. This last point raises important research perspectives as well as practical ones, in a time where the objectives in terms of rail mode share for freight transportation are high.

Given the urgency of the climate change situation, and with the objective of a more sustainable world, it is essential to drastically reduce CO₂ emissions. For freight transport, this should, in theory, be largely achieved through the use of modal shift to low or no carbon modes. In this context, cargo bikes and combined transport are two possibilities to achieve this transition, among many others. However, to enable the development of these two modes, it is first necessary to understand how typical actors of the freight transport system (carriers and shippers) work. From there, it is possible to assess realistically the potential of a modification of the current operation by examining how these new modes can be integrated into their current organizations. By conducting a comprehensive monograph of a actor (here DB Schenker) using operational data, it was possible to perform this exercise

The use of operational data complements the three other possibilities of acquiring data/information on transport, which are: standard surveys (national surveys, statistically representative surveys and stated preferences surveys), modeling and qualitative approaches. The research developed in this thesis combines some of the advantages of qualitative work (in-depth understanding) with some of the advantages of national surveys (long period of time and large samples). However, it is not a substitute for either.

This research has highlighted several scenarios in which actor analysis provides insight, where global analysis can lead to questionable extrapolations:

- The literature on parcel service platforms in several metropolises has identified a logistics sprawl and concluded that it leads to an increase in distance travelled. The study of three carriers in this manuscript has shown that this logistics sprawl does not mechanically entail, in all cases, the fact that distances covered would be much higher than if, for example, rents were uniform in the examined urban areas. On the contrary, in the cases examined in this thesis, the location of the platforms does seem to minimize transport costs. In addition, the global study of all the platforms, irrespective of which company operates which platform, does not allow to identify and understand the organization in place. Indeed, the three actors studied rely on a network of platforms (implementation of polycentrism) to operate in the Paris metropolitan area, not all platforms but only some of them operate in Paris.

- Similarly, for combined transport, it is customary to assess the potential for modal shift (or other questions such as how many combined transport terminals should be implemented and where) on the basis of national origin-destination datasets. However, if stopped at that level, studies may erroneously conclude that, on a fairly large number of connections, it is interesting for companies to shift from road to combined transport. In this case too, by looking at the level of the individual firm, one can see that the conclusions are not so clear-cut and highlight a major obstacle to the development of combined transport: on a connection that seems economically relevant at first glance, the gains will differ between two potential users. This is particularly relevant when examining whether mutualization can make combined transport competitive: it is true that it is necessary to find several customers to make it a possibility that combined transport can be cost competitive compared to road transport. But even when several shippers and carriers are ready to pool their flows for this condition to hold, some may lose out of participating in the initiative, putting its whole economic balance at risk. Going back to the perspective of the actor changes, in this case, the conclusions significantly.

In addition to these two examples, the quality of the data should also be mentioned. The use of operational datasets allows, first of all, a degree of precision in the information that is unfortunately completely outside the scope of what is usually available via global statistics (aggregated data). The geographic precision was essential to carry out all the studies in the three chapters, especially the spatial distribution of demand. Second, compared to fieldwork, operational data allows access to large sets that cannot be collected by hand. To the author's knowledge, no other study has had access to such a large amount of information (millions of shipments studied) on flows at the address level (i.e., no aggregation at the municipal or regional level) and with the same diversity (different companies).

Finally, the diversity of the information and the accuracy of the data also made it possible to work on the relationship between short and long distance. Although this work can be deepened, it does contribute to a growing field of research that was before little studied, even if it has received special attention in recent years (Guerrero, Niérat and Thill, 2023). It is the opinion of the author that the use of a complete monograph could bring significant elements to this field.

An obvious criticism of the work lies in the representativeness of the study. Admittedly, this work focuses on a limited number of actors (12 in the whole manuscript), however, these 12 actors constitute a rather diverse subset of road freight transport stakeholders with two express operators, one parcel service carrier and 9 industrials. Moreover, all of these 12 actors are major actors in their respective fields. Finally, this work focuses particularly on DB Schenker, an essential contribution is the study of the whole transport chain and not only on one link. To the author's knowledge, this type of global study is rare. More generally, the study shows that while the various road transport market segments have significant differences (size and weight of shipments), there also share similarities, such as the use of polycentricity for express and parcel carrier services.

In addition, it should be noted that this study is deliberately based on relatively simple, and easily reproducible methods. This has allowed us to apply them on datasets from different companies but also over different time frames, allowing a comparison between actors, but also in time. This will also allow us to repeat this methodology to study longer term trends or other actors, should the opportunity arise.

As a final note, this type of approach can be qualified as complementary and does superior to approaches based on standard public statistics. Those provide an overall, statistically representative view of freight transport, whereas the study by actor provides a precise view of certain issues. Where approaches based on classic datasets are better in terms of representative, it is the opinion of the author that this research provide more reliable conclusions on some specific behavioral questions regarding freight transportation as for example the potential to implement decarbonized solutions into its operations.

This work has provided elements of understanding of freight transport based on the point of view of a firm (carrier or shipper) through the use of operational data originating from these firms. Several questions were raised, which still need to be pursued. Some of them were already mentioned in the conclusions of each chapter and are not repeated here. A more general is stated here: how can studies at the level of firms support public policies at the national level? In other words, how can the results obtained by studying one actor be generalized to support public policies, knowing that if it is possible to study a limited number of actors, it is not possible to study them all?

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