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Mathieu Gardrat

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Urban growth and freight transport: from sprawl to distension

Mathieu Gardrat^a *

^aLAET, Lyon, France

Abstract

This paper aims at discussing the effects of the urban growth on freight mobility through the analysis of urban activities localisation. Thanks to the results of this work, we lay the basics of an original concept that synthetizes logistics sprawl and other localisation dynamics taking into principal consideration the mobility of freight in general: *the logistics distension*.

Through the spatial analysis of activities and population localisation between 1982 and 2012 in Lyon's urban area, we show the evolution of the socio-economic morphology and evolution of the freight landscape. Through freight movements modelling, we show the evolution of freight mobility in the conurbation of Lyon with regard to the modifications of the urban fabric.

Keywords: Urban freight transport, urban growth, location of activities, modelling

1. Introduction

The profound changes in the socio-economic structure of urban territories for the past decades have had a considerable effect on the mobility of goods. The diversity of temporalities and spatial dynamics makes it all the more difficult for planners to understand the territory and to implement solutions, as they have little knowledge of the mechanisms that build the system of freight mobility. In this context "logistics sprawl" is now widely considered as a major topic for urban freight transportation, reinforcing reflexions on public policies, regulations, land-use and urban freight terminals. Logistics sprawl is defined as 'the spatial de-concentration of logistics facilities and distribution centres in metropolitan areas' (Dablanc 2014). The scientific studies over the past decade have shed light on the phenomenon of logistics sprawl and its potential effects by analysing the localisation of freight terminals. However, since mobility is a systemic expression of the structure of a city, it seems difficult to disconnect the localisation of freight terminals from other activities.

We assume that logistics sprawl coupled with a densification of the central areas might have increased the dependence of centres. The concentration of logistics and industry in peripheral areas is indeed expected to result in more intense exchanges between the centre and the periphery of cities while impacting the intermediate spaces. As the movement of urban sprawl is not recent, it is likely that specific location trends (of retailers or residential areas for example) within the urban fabric can temper the effects of sprawl on urban freight mobility. We can therefore argue that logistics sprawl as a concept misses some of the complexities of urban growth and its effects on freight mobility.

These complex modifications of urban territory highlight the challenges that planners now face in rebalancing the layout of urban activities and limiting the harmful effects of the sprawl of freight terminals. We therefore suggest a novel concept based on and extending logistics sprawl, through a systemic approach to urban freight mobility. We assume that the impact of logistics sprawl is therefore better defined if it is put into perspective in relation to the activities that receive and emit freight, while reflecting the mobility of freight through the territorial balance of freight.

* Corresponding author. Tel.: +33 4 72 72 64 53
E-mail address: mathieu.gardrat@cirs.fr

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Abstract

This paper aims at discussing the effects of the urban growth on freight mobility through the analysis of urban activities localisation. Through the spatial analysis of activities and population localisation between 1982 and 2012 in Lyons' urban area, we show the evolution of socio-economic morphology and of the freight landscape. Through freight movement modelling, we show the evolution of freight mobility in the conurbation of Lyons with regard to the alterations of urban fabric.

Thanks to the results of this study, we lay the basics of an original concept that synthetises logistics sprawl and other localisation dynamics mainly taking into consideration freight mobility: *logistics distension*.

Keywords: Urban freight transport, urban growth, location of activities, transport modelling

1. Introduction

The profound changes in the socio-economic structure of urban territories for the past decades have had a considerable effect on the mobility of goods. The diversity of temporalities and spatial dynamics makes it all the more difficult for planners to understand the territory and to implement solutions, as they have little knowledge of the mechanisms that build the system of freight mobility. In this context "logistics sprawl" is now widely considered as a major topic for urban freight transportation, reinforcing reflexions on public policies, regulations, land-use and urban freight terminals. Logistics sprawl is defined as 'the spatial de-concentration of logistics facilities and distribution centres in metropolitan areas' (Dablanc 2014). The scientific studies over the past decade have shed light on the phenomenon of logistics sprawl and its potential effects by analysing the localisation of freight terminals. However, since mobility is a systemic expression of the structure of a city, it seems difficult to disconnect the localisation of freight terminals from other activities.

We assume that logistics sprawl coupled with a densification of the central areas might have increased the dependence of centres. The concentration of logistics and industry in peripheral areas is indeed expected to result in more intense exchanges between the centre and the periphery of cities while impacting the intermediate spaces. As the movement of urban sprawl is not recent, it is likely that specific location trends (of retailers or residential areas for example) within the urban fabric can temper the effects of sprawl on urban freight mobility. We can therefore argue that logistics sprawl as a concept misses some of the complexities of urban growth and its effects on freight mobility.

These complex modifications of urban territory highlight the challenges that planners now face in rebalancing the layout of urban activities and limiting the harmful effects of the sprawl of freight terminals. We therefore suggest a novel concept based on and extending logistics sprawl, through a systemic approach to urban freight mobility. We assume that the impact of logistics sprawl is therefore better defined if it is put into perspective in relation to the activities that receive and emit freight, while reflecting the mobility of freight through the territorial balance of freight. We therefore ask two main questions:

1. How can we measure the territorial balance/imbalance of freight in urban areas?
2. What are the impacts of this balance on freight mobility?

Answering these questions will lead us to formalise the concept of logistics distension. To present this work, a literature review is produced in section 2. Section 3 presents the methodology used to carry out our analysis of urban growth, which is described in section 4. Section 5 presents the effects of urban evolution on freight mobility and

introduces the concept of logistics distension. Section 6 concludes the paper with the limits and opportunities of this study.

2. Literature review

Extensive studies have been carried out for the past 15 years on the movements of freight terminals in urban areas and more particularly their increasing distance to city centres (Hesse 2004; Cidell 2010; Sakai, Kawamura, and Hyodo 2016; Heitz and Beziat 2016; Woudsma, Jakubicek, and Dablanc 2016). However, most of these researches elude the impact of logistics sprawl on freight mobility and more generally on environment, congestion or economics (Aljohani and Thompson 2016). The large majority of studies are focused on freight terminal localisation patterns in various regions of the world using centographic and barycentric methods. These studies focus on logistics facilities, showing higher growth of locations in suburban areas specifically in major metropolitan areas (Bowen 2008; Woudsma, Jakubicek, and Dablanc 2016; Sakai, Kawamura, and Hyodo 2015) with a few exceptions (Dablanc, Ogilvie, and Goodchild 2014). The impacts of this relocation on distances travelled is usually approached in these studies by the increased average distance from city centres with longer trips being a mechanical effect of the sprawl. One of the few works that tackled both the questions of distances travelled and evolution of freight terminals was carried out by Dablanc and Rakotonarivo (Dablanc and Rakotonarivo 2010), who assessed the impact of logistics sprawl in Paris between 1974 and 2008 in terms of distances travelled and environment and laid the basics of the concept. We also note that the objects studied can widely vary between researches, sometimes encompassing all types logistics facilities, and sometimes only specific types of warehouses, therefore approaching different forms of freight mobility and perimeters (Andreoli, Goodchild, and Vitasek 2010; Heitz and Dablanc 2015), which can lead to a lack of comparability.

However, analysing freight terminals, despite their significant role in urban freight mobility, is not enough to explain the generation and structure of freight flows. It has indeed been showed that at most, 50% of transport is performed by transport operators, the rest being made through own account transport (Ambrosini and Routhier 2004; Patier and Routhier 2009; Danielis, Rotaris, and Marcucci 2010). Incidentally, these freight flows do not necessarily transit through dedicated freight terminals. Therefore, in order to explain and assess the sprawl effects, all the types of activities and their link to urban freight terminals have to be taken into account. Therefore, freight transport can only be considered efficiently if all forms of economic activities are included into the analysis. It is also important to keep in mind that the definitions of urban freight transport used by the scientific community encompasses freight flows between economic activities, end-consumer shopping trips, e-commerce and urban management activities (public works, waste management) (Patier 2002; Segalou, Ambrosini, and Routhier 2004).

Other concepts related to urban freight transport underline the complexity of the subject, its vastness and needs for holistic approaches: "City logistics aims to globally optimise urban freight systems by considering the costs and benefits of schemes to the public as well as the private sector"(Taniguchi and Thompson 2002). In this definition, optimisation denotes a voluntary action, but more importantly the notion of system emerges and appears as a fundamental element for understanding urban freight transport and its effects (Taniguchi and Tamagawa 2005; Tamagawa, Taniguchi, and Yamada 2010).

In our research, a wider definition of urban freight mobility as a system is necessary to understand the motivations behind the construction of the concept of logistics distension. For this, we use the logistics sprawl as the basic concept and widen its scope. In our case, urban freight mobility encompasses the movements of goods due to economic activities, end-consumer shopping trips, e-commerce and urban management activities, but also includes long term movements of activities in the city which also explain the modifications of freight transport behaviours (Bonnafous et al. 2016; Gardrat 2017).

Given these elements, we perceive that solely analysing the localisation of freight terminals is not enough to understand the impacts of urban growth on freight mobility. All the forms of activities influence urban freight mobility and our hypothesis is that logistics sprawl is a bigger problem if freight terminals and the establishments they serve tend to go further away from each other. Indeed, if all activities undergo the same sprawl, we can object that the problem of logistics sprawl might not be as acute as hypothesised in most of the researches concerning

logistics sprawl. Moreover, other impacts of sprawl, such as global and local pollutants, are greatly influenced by other factors such as the types of vehicles and facilities (Sakai, Kawamura, and Hyodo 2015). In this paper we try to address the question of logistics sprawl through a systemic approach by studying urban growth and its impacts on the economic structure of a city and freight mobility in terms of distance travelled. This reflexion has to be supported by modelling as no dataset allows reliable comparisons between freight transport behaviours and the economic structures of cities (Allen, Browne, and Cherrett 2012).

For the past forty years, many researches have tackled freight transport modelling on a citywide scale at more or less disaggregated levels. Classically, trips are generated through geo-economic characteristics of the urban areas studied (generally employment and/or establishments). The majority of the models based on geo-economic data are usually derived from four-step models, originally based on passenger traffic. Most of these models are traffic-oriented and used for infrastructure planning, and take into account a large variety of freight dimensions such as waste management, construction and even service trips but have finally proved to be methodologically inadequate (Demetsky 1974; Watson 1975; Slavin 1976; Lim and Meyburg 1978; Maejima 1979; Ogden 1992).

Various approaches were therefore developed to include trip generation as a primary step to improve the estimation of vehicle flows (Iding, Meester, and Tavasszy 2002; Holguin-Veras et al. 2011). The nature of the calibration implies specific data collection to either measure the volume of vehicles going from an A zone to a B zone through traffic counts or trips generated from establishments. Most recent researches have in fact focused on these approaches since an increasing amount of data on trip generation has become available (Slavin 1998; Crocco et al. 2010; Gentile and Vigo 2013).

Lately, more aggregated approaches allowing simpler data processing in order to maintain high transferability and long term analysis have been developed under the concept of freight landscape (Rodrigue, Dablanc, and Giuliano 2017; Sakai et al. 2018). Most of these approaches allow measuring freight flows to some extent and the vehicle trips they generate. Although operating at an aggregated level, these methods rely on a strong link between freight flow generation and urban structures, and illustrate the potentials of land-use and transport interactions analyses.

Incidentally, if land-use and transport interactions related to passenger transport have been carried out for many years (Geurs and Van Wee 2004; Wegener 2004; Nicolas 2010; Van Wee 2015), none actually ever tried to simulate the impacts of urban growth on freight transport over a period spanning several decades. The main reason being that freight transport is usually considered more complex to describe than passengers' for several reasons that concern a large variety of (Ogden 1992):

- level of implications, perceptions and sometimes divergent needs of stakeholders regarding freight transport,
- transport operators' structures, sizes and fields of expertise,
- commodities and points to serve.

Nevertheless, most of the complexity of urban freight transport also lies in the distinction between commodities and vehicles flows. In urban environment, measuring a quantity of goods moved from one point to another is poorly relevant given the variability of shipments sizes, frequencies, modes of organisations (line haul vs round trips) and of course types of goods. In this context, representing freight transport and land use interactions is an arduous task. Our work is therefore an attempt at confronting urban growth, its impact on freight transport and presenting a concept to broaden the study of logistics sprawl.

3. Methodology

In order to efficiently measure the impact of urban growth, understanding freight transport structures is essential. We hypothesise that urban freight transport determinants can ultimately be reduced to three main elements explaining the formation of flows: the location of activities, the volume of freight operations they generate and finally their characteristics (Bonnafoous et al. 2016):

- The first element is the location and nature of activities that determine freight-trip generation volumes (emission and attraction) and their characteristics (Holguin-Veras et al. 2011; Toilier et al. 2018). As cities evolve, the

- places from which freight is emitted and attracted change over time.
- The second element relates to activity sectors explaining FTG volumes: freight vehicles serve each type of activity more or less frequently depending on their industrial sector. These differences depend on supply chain and inventory strategies and evolve gradually (Christopher and Towill 2000; Ballou 2007).
- Finally, the last element refers to transport and logistics organisations: mode of transport (types of vehicles), modes of organisation (line haul or round trips) and the modes of management involved (own account or third party) to carry out the transport. This element depends on supply chain strategies as well, but also environmental variables such as regulation or accessibility (Russo and Comi 2010). As for FTG rates, these elements also change over time.

These three elements are intertwined and should not be considered separately in order to describe freight transport structure efficiently. To illustrate this relation, we simplified this system into an equation of matrices.

$$\mathbf{T} = \mathbf{E.M.L} \quad (1)$$

T is the structure of freight transport, which can be described in FTG volume, types of vehicles, organisation modes, management modes, vehicle-kilometers, parking duration, etc. E is the location and nature of activities, M the FTG rates for each type of activity and L the logistics characteristics of freight trips. In this paper, we will mainly monitor the evolution of the E term of this equation and keep M and L unchanged as no study exists for monitoring urban freight transport behaviours over a period long enough to measure and explain the evolution of freight practices for all sectors on a specific territory. By maintaining M and L unchanged, our approach will allow us to explore the impact of the location of E activities on the structure of freight transport. To carry out this work, our method will be articulated in two steps that will allow us to discuss the relationships between the conformation of territories and freight mobility.

The first phase will be to account for the evolution of territories with a freight transport reading, aggregating and comparing the locations of activity sectors that play a structuring role in urban freight transport. This analysis will provide several “images” of an urban territory at set intervals during a period of several decades. Through radio centric approaches and maps, a reading of these “images” will lay the basic elements for discussing land-use and freight transport interactions. In our perspective, this work will provide us the E term in our equation.

Secondly, a modelling sequence will be applied to the different dates provided in order to render goods mobility structures. This modelling framework will provide the M and L elements of our equation (1) and bring elements to discuss the effects of urban growth on freight transport:

- A “freight transport balance” used to explore the territorial inequities related to urban goods movements.
- An estimation of the distances travelled by freight vehicles illustrating the impact of goods transport in terms of congestion and environmental footprint.

The elements produced in the modelling sequence will allow us to assess the impact of urban growth on freight transport and eventually nourish the concept of logistics distension. The two phases of our method are exposed in detail in the next sub-sections.

3.1. Measuring the geo economic evolution of an urban territory related to freight transport

Our analysis of urban territories and their socio-economic structure is based on data related to the localisation of activities and employment. Furthermore, comprehensive data have to be processed over a long enough period. In order to perform this analysis, we chose to divide these socio-economic data into five aggregated categories of activities that summarise the main functions and logistics behaviours of an agglomeration (Bonnafous et al. 2016; Toilier et al. 2016; Holguín-Veras, Sánchez-Díaz, and Browne 2016):

- B2B trade and transport activities. These activities are characterised by their role as commercial and logistics intermediary for the vast majority of the activities of a territory. The wholesale trade warehouses, the couriers

and express transport facilities will fall into this category, and may serve all the activities described below. Put together these activities represent 20% of urban freight operations*.

- B2C retail activities. This category is responsible for the majority of household purchases. Large retailers and businesses have a strong functional link with households, but also with B2B trade and transport activities, acting as intermediaries between these two. They are responsible for 25% of all freight operations in cities.
- Crafts and material services to people and companies have a strong functional link either with other companies or with the populations. These establishments are for example plumbers, locksmiths, shoemakers, mechanics... Their location is characterised by a proximity of populations and jobs within the same urban area. These activities account for 20% of operations.
- The tertiary offices induce lower FTG compared to other activities. However, the volume of jobs they represent, their density and location in the already constrained urban centres makes it a strong generator of freight trips in the city. These activities account for 20% of operations.
- The activities related to the production and transformation of goods (industry, agriculture). These activities produce flows in large quantities and use high-capacity vehicles (articulated trucks, rail or waterways services). This is probably the category which is most remotely linked with dense urban environment in terms of logistics, with a strong link with other regions. Production and transformation are responsible for 15% of all freight operations in cities.

Studying the evolution of these five types of activities needs to be done over several decades to monitor the changes in urban structure. An analysis inspired by radio-centric methods, originally introduced by Clark and later Bussière (Clark 1951; Bussière 1972; Tabourin, Andan, and Routhier 1995; Bonnel, Bouzouina, and Monchambert 2013), will provide a simple but efficient display of urban growth.

The urban growth profiles that we present here (Figure 1) summarise the dynamics that will be met in our study. It should be noted that these forms can be combined: for example, sprawl and densification characterise the metropolisation process. The researches involving these radio-centric models aim at modelling urban growth but in this paper we will mainly focus on the description of the evolution of urban morphology. Modelling will be used otherwise to quantify the effects of urban growth on freight mobility.

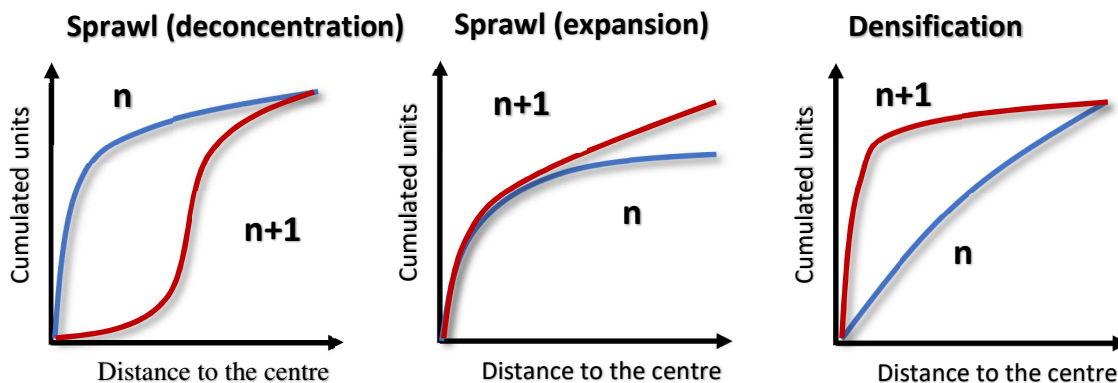


Figure 1: Three main urban growth profiles in a radio-centric representation (n being a time reference)

By mixing this radio-centric approach with cartographic displays, we will refine our reading of the location dynamics in Lyons' urban area. Choropleth maps combined with centographic statistics will complete activity distribution analysis on the territory by providing three-dimensional representations. Displays of standard

* The freight operations numbers are extracted from the French urban freight surveys

deviational ellipses and barycentre (Gong 2002) will therefore illustrate the modifications of the geographical conformation of urban activities.

3.2 Modelling freight transport

In order to measure freight mobility, we will use approaches derived from freight trip generation models (Holguin-Veras et al. 2011; Comi, Donnelly, and Russo 2014) and more particularly the Freturb model. The method we expose here uses parts from the Freturb model and parts specifically added for this study.

Freturb is a multipurpose model designed for urban freight analysis (Toilier et al. 2018). This model is able to quantify “operations” defined as follows: *the event corresponding to a goods delivery or pick-up (or both at the same time) operated by vehicle for a given establishment* (Bonnafeous 2001; Patier and Routhier 2009). In Freturb, the number of weekly operations (n_e) generated by an economic establishment[†] (e) is explained by its industry sector (a), its number of employees (o), and the nature of its premises (p)[‡]. Accordingly, the total number of movements M_z in the zone z is:

$$M_z = \sum_{e \in z} n_e(a, p, o) \quad (2)$$

The combination of these variables produces a typology of establishments, comprising 116 different classes noted ε , each representing a unique triplet (a, p, o) . Each $n_e(a, p, o)$ is characterised by emission and attraction ratios allowing to eventually determine the number of operations received or emitted. These emissions and receptions will be calculated to illustrate the logistics specialisation (ratio between emissions and receptions) These elements correspond to the M term in our equation (1). Freight trip attraction (FTA) and emission (FTE) are provided in Table 1 for the 5 aggregated categories presented in section 3.1.

In order to explore this phenomenon, we drew from approaches relating to the mobility of people (Tabourin, Andan, and Routhier 1995; Aguilera-Belanger et al. 1999) to explain how territorial imbalances structure mobility. In these works, the location of jobs is confronted to the residential location of active people. The relation between these two elements makes it possible to highlight the specialisation rates of the territories and the mobility they generate: an i zone containing a surplus of jobs compared to the number of active residents in the same zone necessarily implies a mobility of people from other areas to fill the jobs in that i area. Measuring the potential of peoples’ mobility in a territory can easily be done by comparing active residents and employment localisation. This measure of territorial inequities, illustrating the functional specialisation of urban sub-spaces, is a first approach of mobility demand and we try here to replicate this approach for freight transport.

However, it is difficult in a freight approach to establish a correspondence between jobs and flow-generating or flow-receiving activities without modelling it: an establishment receives and emits goods or freight trips in various proportions. In addition, according to the logistic profiles of activities, a job does not generate the same quantity of goods movements. The unit to be used to measure territorial imbalances is therefore not employment but operations, which are either receptions or emissions.

In our analysis, we will summarise the impact of economic structure on the mobility of goods via a ‘balance of operations’ reflecting the ability of cities to supply themselves. By ‘balance’, we mean the difference between the quantity of operations emitted and received by an agglomeration. Ideally, this scale should be expressed in tons of goods. However, for reasons of statistical uncertainties and methodological difficulties related to the processing of freight surveys in cities, we will limit ourselves to the emissive or receptive nature of the movements of vehicles.

By building specific emission and reception functions from the French urban freight surveys, it is possible to accurately approach the emissions and receptions of an urban territory. To assess this balance, we will use the qualification of the operations into receptions and expeditions generated by economic establishments. This

[†]Note that while the scope of our research includes establishments engaged in an activity, including public administrations, small and large businesses, and so on, it does not include private households. B2C e-commerce flows, therefore, are not studied in our analysis.

[‡] This was validated using freight surveys collected in France during the 1990s (Patier and Routhier, 2009).

calculation, however, poses a major difficulty. The transport of freight in the city is represented by two main forms of organisation: line haul trips and delivery rounds. For the first ones an expedition implies a reception and the calculation of the freight trips balance is simple. For round-trips, however, an expedition is translated into several receptions. To account for the actual "supply" of transport, it is therefore necessary to balance the emissions of round-trips with the number of receptions they generate.

Approaching logistics specialisation is therefore done by calculating a balance of freight operation such as:

$$B = \sum_{\varepsilon,r} E_{\varepsilon,r} \cdot P_{\varepsilon,r} - \sum_{\varepsilon,r} R_{\varepsilon,r} \quad (3)$$

With B the balance of movements, $R_{\varepsilon,r}$ the number of receptions and $E_{\varepsilon,r}$ the number of emissions of an establishment class ε and organisation mode r (line haul or round-trips) and $P_{\varepsilon,r}$ the weighting factor of the number of receptions induced by shipments of an establishment class ε in the organisation mode r [§]. For line haul trips, the weighting factor equals to one, since an emission generates only one reception. For round-trips, P depends on the type of activity (Table 1) and corresponds to the number of receptions generated by one expedition for each type of activity. It is determined by the average number of operations in a round trip emitted by each type of activity observed in urban freight surveys performed in France (Patier and Routhier 2009; Gardrat 2017).

Table 1: Types of activities considered in this paper and their FTG profiles

Activities	FTG	Attraction/emission	FTE/establishment/week (E)	FTA/establishment/week (R)	Weighting factor P
B2C activities	High	Attraction	1.36	6.63	2.22
Crafts and material services	Medium	Attraction	1.06	3.14	2.47
Offices-tertiary	Low	Attraction	0.43	1.04	2.67
Transformation and agricultural industries	High	Emission/attraction	5.64	7.37	1.81
B2B trade transport	High	Emission	26.99	14.7	5.30

By defining a coverage rate between operations emitted and received, we explore the conditions under which the conurbation is supplied and the imbalances of its logistics structure.

Freight operations give a primary assessment of territorial structure in perspective of goods but in order to further discuss the effect of urban growth on freight mobility, other indicators have to be produced to consolidate our analysis. In our case, distances travelled by vehicles (vehicle-kilometers) appear to be the most relevant and comparable indicator to measure the evolutions of freight mobility. In order to build this distance indicator, operations have to be broken down according to their transport characteristics:

- the vehicle class (LGVs, rigid or articulated HGVs),
- the management mode (third party logistics, own account transport shipper or consignee),
- and the route type (direct or round trips).

This combination of factors gives 12 categories of logistics operations. These categories will also be identified by the index l . This gives:

$$M_z = \sum_{\varepsilon,l} M_{\varepsilon,z} \times f_l(\varepsilon) \quad (4)$$

where $f_{k,m,r}(\varepsilon)$ denotes the frequency of characteristics (k, m, r) among establishments of class ε and $M_{\varepsilon,z}$ the

§ P therefore takes the value 1 for line-haul and >1 for round trips.

number of movements generated by establishments of class ε in zone z .

In order to calculate the distance of a trip induced by an operation generated in zone z involving logistics l , we used methods suggested by Routhier and Toilier (Routhier and Toilier 2007), summarised as follows:

$$\partial_{z,l} = \frac{1}{n_l + 1} (2\partial_{z,l}^* + (n_l - 1)\partial_{z,l}^{**}) \quad (5)$$

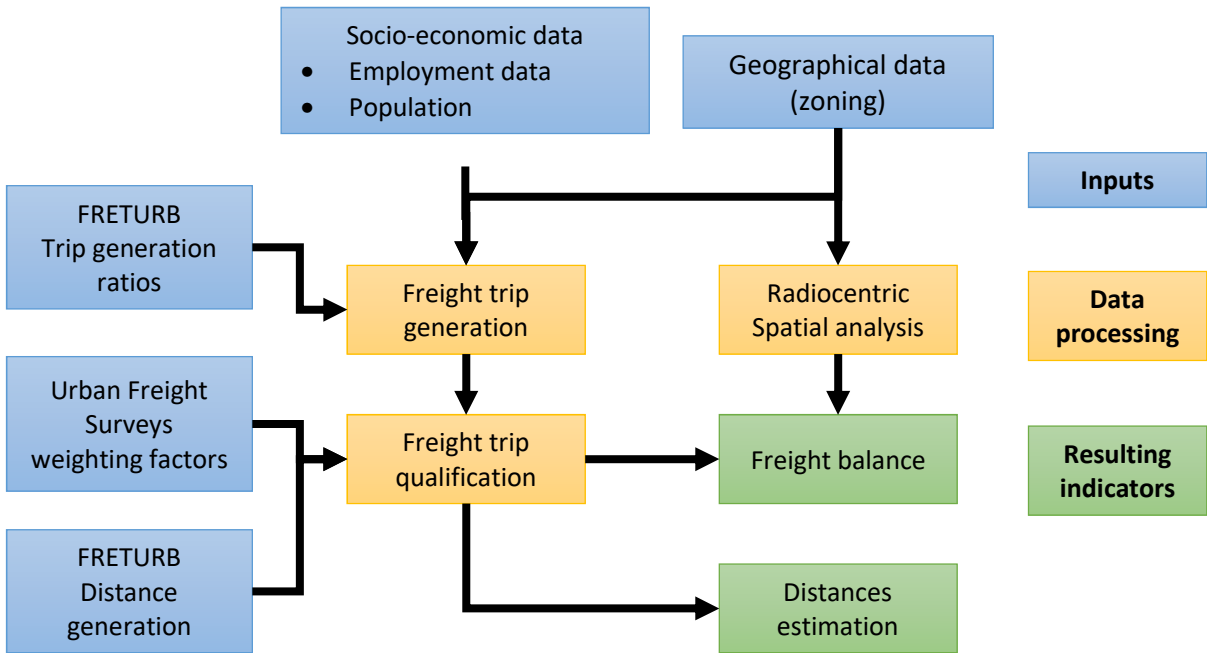
With $\partial_{z,l}$ the distance of the average trip induced by an operation generated in zone z involving logistics l determined by:

- $\partial_{z,l}^*$ the average distance of the first and last trips involved by an operation generated in zone z with logistic l . Routhier and Toilier demonstrated that this distance can be estimated by a function of the radius of the city
- $\partial_{z,l}^{**}$ the average distance between two connectors (points of successive deliveries) of the same round, the first connector being in zone z and the delivery involving logistics category l . Routhier and Toilier demonstrated that this distance can be estimated by a function of the urban density
- n_l the average number of connectors in logistics category l ,

The results of this sequence of functions will determine the effects of urban growth on total vehicle kilometers travelled (VKT) and corresponds in equation (1) to the L term. For more elements on distance generation, please read the relevant reference (Routhier and Toilier 2007).

Data processing, analysis and displays have been carried out using the R programming language (R Core Team 2017) and sp, rgdal and aspace packages (Bivand, Pebesma, and Gomez-Rubio 2013; Bivand, Keitt, and Rowlingson 2014; Bui, Buliung, and Rimmel 2012).

The next graph (Figure 2) summarises the methodology used to produce the analysis presented in the next



sections.

Figure 2: summary of the methodology used in this paper

This method is transferable provided data on establishments exist and are accessible, which is at least the case for most of the works cited in this paper, including North America, Europe, Asia and South America (Alho and e Silva 2015; Sakai, Kawamura, and Hyodo 2016; Malik et al. 2017; Oliveira, Nóbrega, and Ebias 2017; Gonzalez-Calderon et al. 2018; Singh 2018; KOREAN Statistical Information Service 2020).

4. Urban growth and logistics distension: the case of Lyon

The analysis of urban growth, economic activities and freight mobility will rely on the case of the urban area of Lyons (eastern France, with a population of 1.8 million in 2012, 6,000 km²). The analysis of the evolution of urban activities is essentially based on the processing of five establishment^{**} files (called SIRENE^{††}) for the conurbation of Lyons in 1982, 1990, 1999, 2005 and 2012. For each establishment of a territory, these files describe its industry sector, number of employees, nature and size of premises, address, legal status, date of creation and other organisational elements. The industry sectors used in the SIRENE file is a five-digit code (NAF^{‡‡} code) related to the four-digit United Nations' ISIC^{§§}. Given the nature of these files, our analysis will mainly focus on freight flows between economic activities, discarding end-consumer behaviours, e-commerce and urban management flows for better comparability. These files were archived by the LAET throughout the years for various studies with its own resources. More recent SIRENE files exist, however this database has only been freely and openly accessible since 2017 and its format changed with the temporary deletion of certain variables concerning the employment of establishments we need to make this research possible. Since the national institute for statistics and economic studies does not distribute past databases, we could only for availability and reliability reasons work on files dated 1982-2012.

The analysis of the SIRENE files over several years involves several risks (change of the data structure, of activity classifications) and heavy data processing had to be done in order to produce reliable information, in this paper we will not however describe the method used to control and adjust the SIRENE data. For further elements on the data processing of these types of files, please read the adequate references (Gardrat, Gonzalez-Feliu, and Routhier 2013; Gardrat et al. 2014). These data are fundamental to identify spatio-temporal trends and to understand the changes in the urban freight mobility system in a territory but also to model freight transport.

We will now expose the results of the spatio-temporal analysis of economic activities in the urban area of Lyons. Our first result is that the total number of establishments (all types of activities) in the studied perimeter increased significantly between 1982 (85 000 establishments) and 2012 (125 000), a proof of an attraction dynamic and the development of activities in the area of study.

However, the sole study of the location of establishments is not enough, and we will attempt to refine our analysis by providing additional data on the structure of activity, both in employment and type of activity. Indeed, the overall number of establishments could potentially decrease, but the average size of the workforce did increase, explaining a growth in the total number of jobs^{***} in the study area. The number of establishments is therefore only a weak indicator because it only partially reflects the intensity of the activity of an agglomeration. The number of jobs is a better indicator to summarise the production capacity, but also the freight transport demand for the different

** Note that while the scope of our research includes establishments engaged in an activity, including public administrations, small and large businesses, and so on, it does not include private households. B2C trips and e-commerce flows, are therefore not considered in our analysis

†† National censorial databases of economic activities and establishments produced by the national institute for statistics and economic studies

‡‡ Nomenclature des Activités Françaises

§§ International Standard Industrial Classification

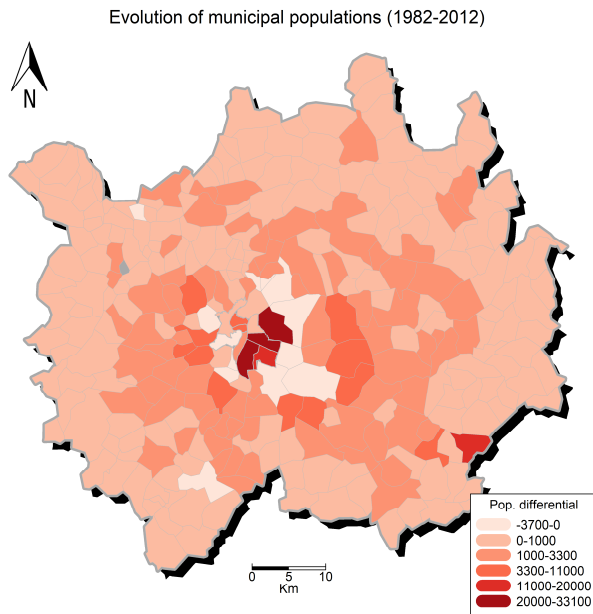
*** The number of jobs is actually an estimation in full-time jobs equivalent, in order to better represent the productivity of the urban area

classes of activities.

The total employment in the urban area of Lyons increased from 1982 to 2012 from 660,000 jobs to nearly 960,000 (Table 2) with a growth concentrated in the urban area's core. The majority of municipalities in the urban area recorded an increase in employment over this thirty-year period, with only a few municipalities registering a decline, particularly in the hyper-centre of the Lyons urban area. The population of the studied perimeter increased sharply from 1.4 million to 1.8 million. This increase occurred essentially in the centre, obviously to the detriment of the near periphery, which nevertheless experienced a relatively small decrease. The more remote peripheral areas experienced a relatively larger increase than the rest of the territory, apart from the centre (Figure 3).

Table 2: Number of establishments, jobs and establishments size in 1982 and 2012

Year	Establishments	Jobs	Estab. Size (jobs/estab.)
1982	85,855	663,623	7.72
2012	125,510	958,741	7.63



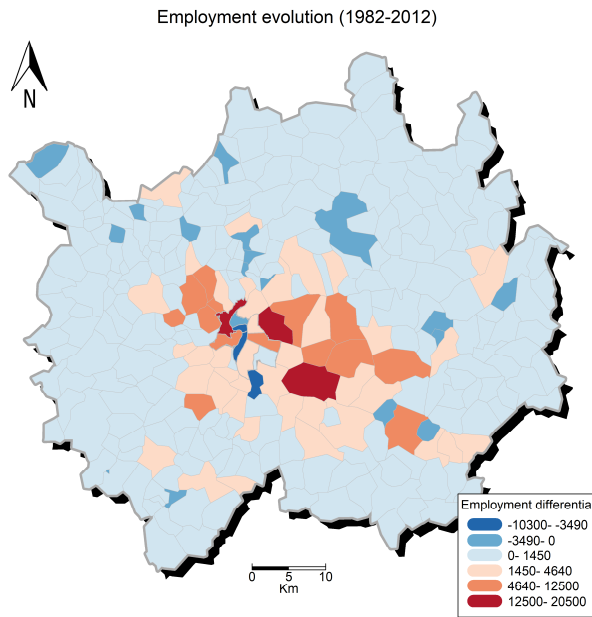


Figure 3: maps of the evolution of municipal population and employment between 1982 and 2012 in the urban area of Lyons

The loss of population in the nearest periphery is offset by increases in employment, indicating a shift in function for this area towards a kind of employment-population mix. These increases and decreases in employment are however of various natures according to the sectors of activity, which we will now study.

If we focus on the B2C retail activities, their total number fluctuated over thirty years, but the number of jobs they created increased steadily (from 87,000 to 120,000 jobs over a period of thirty years, despite the destruction of more than 2,000 establishments on the studied perimeter). This corresponds to an overall increase of the demand for consumer goods for the agglomeration, correlated with an increase of the population between 1982 and 2012.

It is mainly these commercial activities that are linked with the centripetal flows of "professional" goods transport, but also with end-consumer trips. Thus, their location has an influence not only on the mobility of households, but also on the structure of freight transport between establishments. These household supply activities are thus the central link in a chain of goods movements whose final destination is the place where households live.

Two major phases of localisation of retail businesses characterise this type of activity and find themselves intimately linked to the strategies of large retailers. We observe a phase of eviction from the city centre, until the end of the 1990s, then an urban relocation phase in a logic of constant increase in demand from the populations (Figure 4). We find on the x-axis, the distance to the centre, marked out by 1-kilometer intervals and on the y-axis, the jobs difference between each time-line (1982, 1990, 1999, 2005 and 2012). The overall number of jobs and B2C retail establishments increases, but their spatial distribution changes: this evolution is especially obvious for areas located within a five-kilometer radius of the centre of the agglomeration.

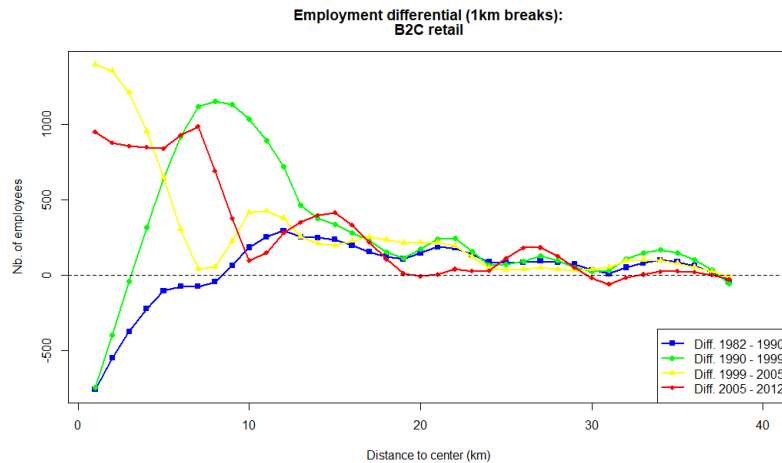


Figure 4: Difference of B2C retail jobs between dates as a function of the distance to the centre of the urban area of Lyons

On the above five curves (one for each year), we present the evolution of the number of jobs accumulated as a function of the distance to the centre (the "centre" is here formalised by the location of the "préfecture" in the third district of Lyons) (Figure 5). The first phase of localisation of retail activities corresponds to the extension of the relocation of commercial activities in peripheral areas initiated in the second half of the twentieth century (Merenne-Schoumaker 1978; Moati, Libouton, and Pouquet 2004). At that time, retail activities and specifically supermarkets experienced a period of relocation in the outskirts of large cities, favoured by the ever more intensive car use and persistent traffic and parking difficulties in the centres. These establishments were then located in large and space-consuming commercial complexes (both for sales areas and for private vehicle parking areas).

The second and more recent phase (since the 2000s), corresponds to a re-urbanisation of commercial activities: implantations of small and medium-sized retail outlets in dense environments, revitalisation of city centres, and increase of urban shopping centres. This movement back to the city centre, however, does not exclude the extension of commercial concentration in the major peripheral areas.

Over the entire urban area of Lyons, jobs related to B2C retail have increased. However, we note that some zones concentrate most of the growth: centre, eastern conurbation and some municipalities in the west (Figure 6). All correspond to the locations of the most important shopping centres in the territory. These activities are relatively restricted to the most urbanised areas, with a more pronounced spread to the east, but a barycentre moving only by 1 km in this direction.

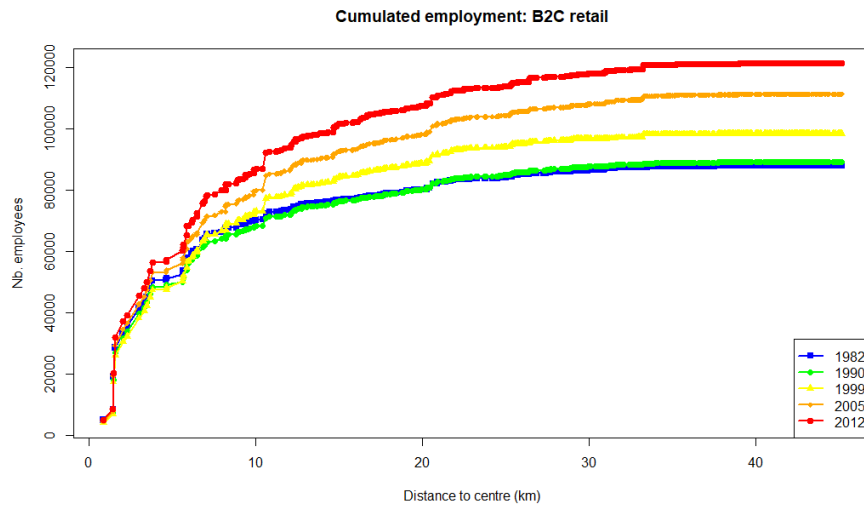


Figure 5: Number of cumulated jobs (B2C retail) as a function of the distance to the centre of the urban area of Lyons

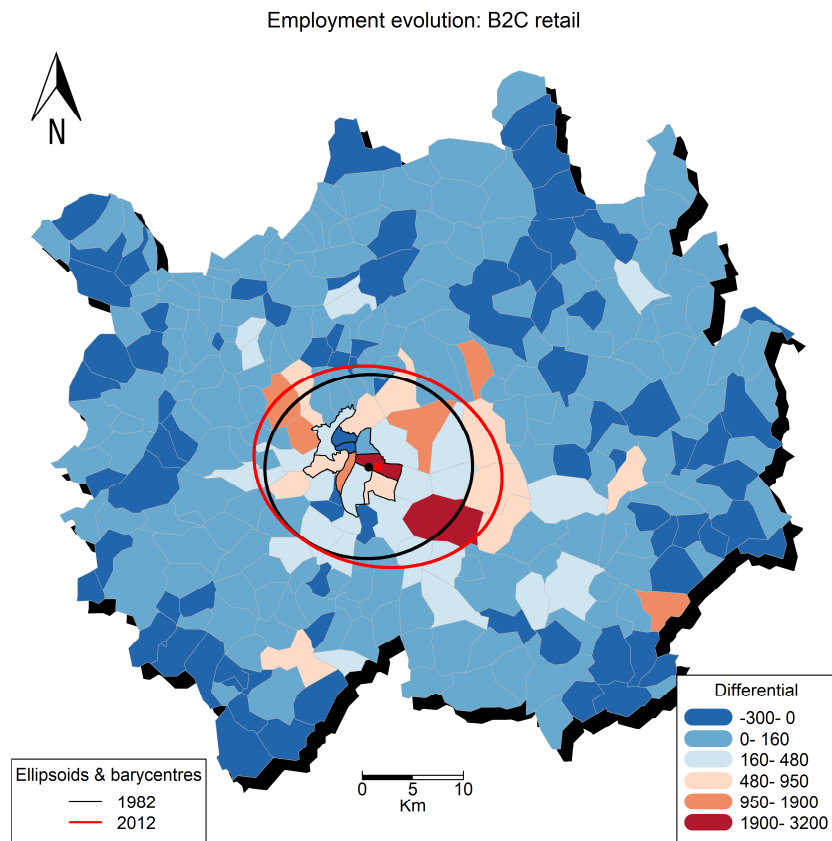


Figure 6: Employment differential for the municipalities of the urban area of Lyons between 1982 and 2012 for B2C retail activities, barycentre and dispersion ellipses

If the relocation of businesses in the city centre allows a potential reduction in the distances traveled for end-consumer movements, the relative distance of their establishments of supply, for its part, should lead to an increase in the distances traveled for inter-establishment freight transport. Indeed, these supply activities are linked to establishments whose role is to supply other urban activities: wholesale trade and warehouses. We can see that by studying the location of this sector, the relative evolutions between 1982 and 2012 favoured the most peripheral zones (Figure 7).

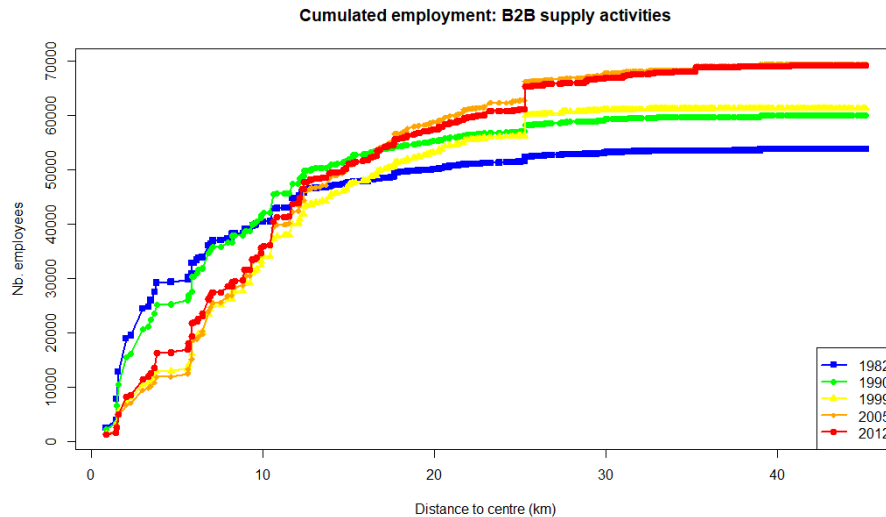


Figure 7: Number of cumulated jobs (B2B transport) according to the distance to the centre of the urban area of Lyons

B2B transport activities located in the central zone (less than 5 kilometers) is gradually decreasing between 1982 and 2005, transferring progressively to peripheral areas. It seems that the transfer boundary is located between 5 and 15 km from the formalised central point: this ring is an area below which the B2B supply activities disappear and beyond which they reappear. This movement demonstrates the phenomenon of logistics sprawl. The radius of this "logistics boundary" is also increasing little by little, as the years go by. Radial distribution curves show sharp inflection points about ten kilometers from the centre of the agglomeration. For example, the relocation of the wholesale market is particularly illustrative of this logistics sprawl. The site in the heart of Lyons was decommissioned and relocated in the municipality of Corbas, about 10 km from its initial location in the centre of Lyons. The relocation has strongly modified the economic structure of the centre of the conurbation (Gardrat, Gonzalez-Feliu, and Routhier 2013). This exceptional event reinforced the sprawl of wholesale activities in the Lyons urban area and, more generally, the sprawl of urban B2B supply activities. This modification of the city centre summarises the current urban dynamics in three movements. Firstly, a densification of residential areas and offices; secondly a return to the centre of commercial activities and thirdly a rejection of the most "undesirable" activities towards the periphery (i.e. logistics).

Through a finer spatial analysis (Figure 8), we find that most activities move from the centre to the east of Lyons. The municipalities of the eastern periphery are the main areas gathering these activities. Because of this concentration, these logistics functions show a very significant shift of the centre of gravity towards the east (i.e., the most important for the five categories of activities we are studying). With a movement of 3.5 kilometers to the east, the barycentre is getting closer and closer to the southeast ring of the agglomeration.

The sprawl of B2B supply activities has therefore been constant for twenty years, contrary to developments in the location of retail businesses. If initially the joint sprawl of supply and commercial activities seemed to limit the effects on freight transport, the commercial re-densification of city centres leads to consider significant effects on

transport and more particularly on the penetration of freight flows and delivery vehicles into dense centres. Penetration distances may gradually increase (see section 4), coupled with an increase in the volumes to be delivered and congestion due to urban freight transport. The areas most affected by these relocations are the densest (destruction of activities) and the most peripheral areas (creation of activities). Only the fringe zone (15 to 20 km from the centre) seems to be spared by deep structural change.

However, the trend from 2005 to 2012 sees the return of a limited number of urban supply activities to the core area, with the overall employment declining slightly. Is this double trend an exceptional phenomenon or a stable evolution? There are two possible answers.

First, the return of B2B transport activities towards the centre can be explained by the densification of activities in the city centre, with the return of retail to the centre as an essential element. Trends in warehouse construction (with a peak in 2007) seem to support this hypothesis, this shows that the availability of premises exists in areas close to the city centre (Gardrat 2017).

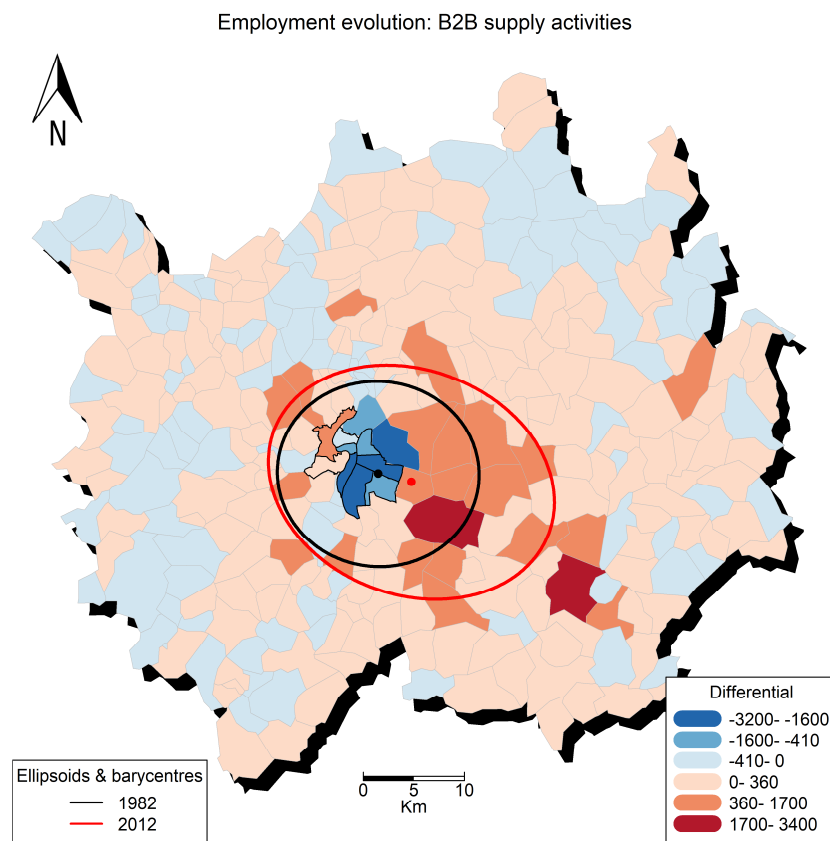


Figure 8: Employment differential for the municipalities of the urban area of Lyons between 1982 and 2012 for B2B transport activities, barycentre and dispersion ellipses

Secondly, this decrease in B2B supply jobs can be explained by other elements:

- Increased productivity of the logistics sector in recent years resulting in a lower need for an equivalent or higher demand (Bonnafeous et al. 2016).

- A tendency of the demand for direct delivery from regional or national platforms, making the local freight terminal level irrelevant, a trend that is concomitant with the concentration of platforms (increase of warehousing areas coupled with an increased catchment radius).

The industry sector is also experiencing a clear disappearance in central zones explained by the de-industrialisation of Lyons' economic environment and corresponding to the national evolution of this sector (Figure 9). The impact on freight transport should be a reduction of the heaviest vehicles in the overall structure of freight transport. Here, the centre of the agglomeration loses most of the industry-related jobs which are only partially redistributed throughout the territory.

Industrial activities are also experiencing a sprawl, but in a multi-directional manner unlike logistics functions and they are concentrated in the East and the West (Figure 10). As a result, the centroid remains relatively stable with a translation of less than 1 km to the east.

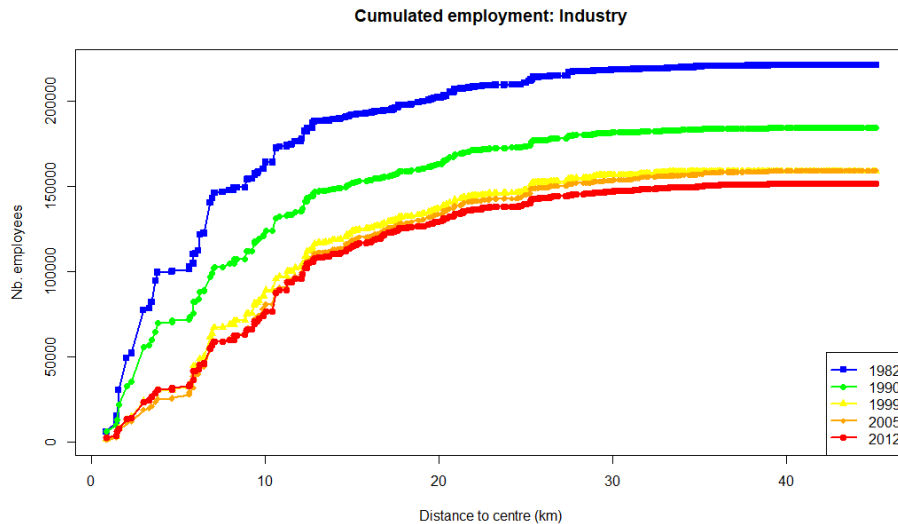


Figure 9: Number of cumulated jobs (industry) according to the distance to the centre of the urban area of Lyons

Handicraft and material services and tertiary offices (Figure 11) are experiencing a strong overall increase over the entire study area, coupled with a concentration in the central sector (a particularly strong trend for offices). These predominantly flow-consuming establishments are changing the demand for goods transport in the centres. By replacing the industrial and logistics functions, the centre area evolves into a "freight-consuming" space.

We can therefore see that over thirty years Lyons's conurbation has undergone fundamental changes in activity structure that have altered the functional nature of urban area spaces. In the framework of our study, the E term of our equation (1) changed dramatically and we will now estimate its effects on the mobility of goods using the modelling sequence described in section 2.

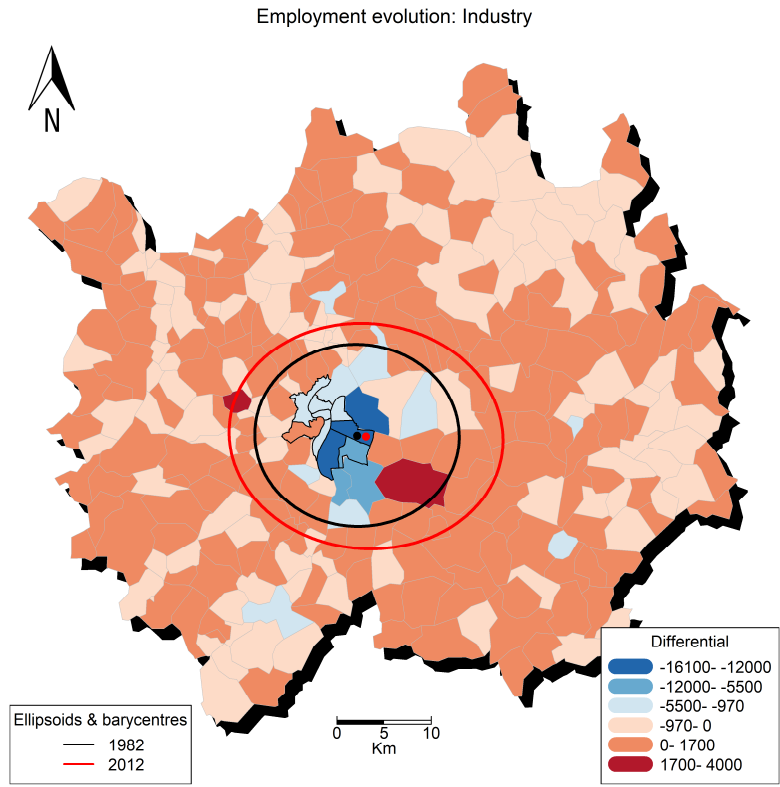


Figure 10: Employment differential for the municipalities of the urban area of Lyons between 1982 and 2012 for industry activities, barycentre and dispersion ellipses

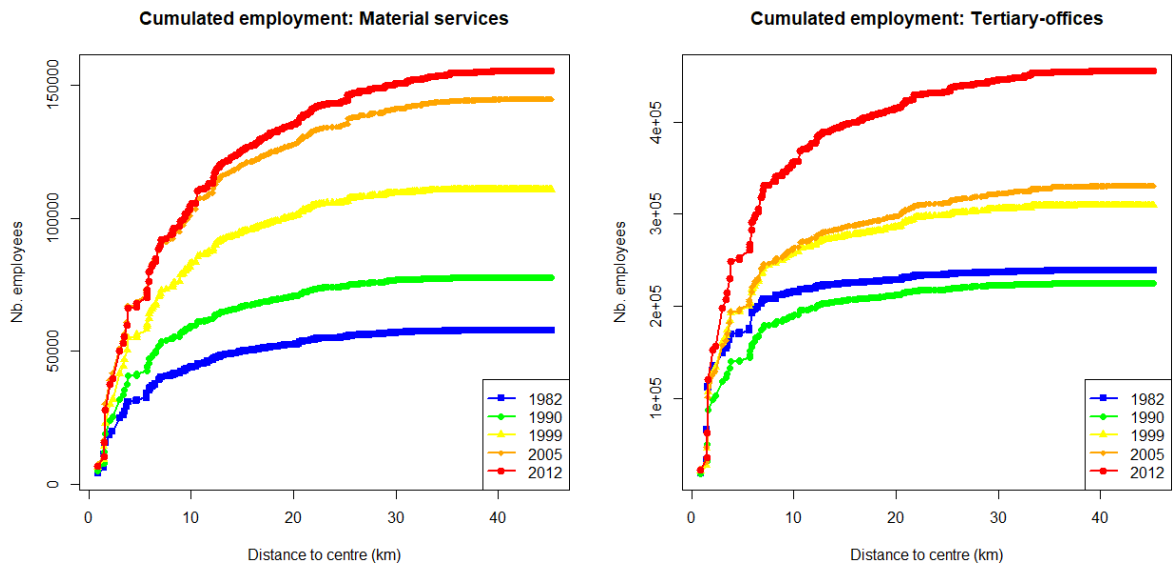


Figure 11: Number of cumulated jobs (Material services, tertiary offices) according to the distance to the centre of the urban area of Lyons

5. Effects of urban growth on freight mobility

As we have seen, most of the territorial dynamics consist in densification of freight consuming activities in already dense zones, with a sprawl of the urban supply activities they are linked to. The evolution of the figures for the distance to the centre of different types of activities illustrates these movements (Table 3). The average distance to the centre of the supply functions (transportation, wholesale trade) increases faster than for other types of activities. This distance is also important for crafts and services but this sprawl is more of a spreading nature rather than a deconcentration one, as shown by the radial distribution of this type of activity.

Table 3: Average distance (in km) of activities from the centre of the Lyons urban area between 1982 and 2012

Years	B2B supply activities	B2C retail	Industry	Material service, artisans	Offices-tertiary
1982	6.90	6.53	7.10	7.78	4.67
1990	7.98	7.07	7.20	8.95	5.51
1999	10.64	7.45	7.44	10.82	5.89
2012	11.43	8.01	8.86	11.30	6.92
2012-1982	+4.53	+1.48	+1.76	+3.52	+2.25
Employment	+20 000	+40 000	-70 000	+100 000	+200 000

The effects of this urban structure distortion alter freight mobility. The areas of Lyons conurbation and their functions have evolved into a form of logistics specialisation: the central spaces should receive more and the peripheral areas should emit more.

By using equation (2), we are able to display a representation of the volume and the distribution of the operations generated in our study area in 1982 and in 2012 (Figure 12). We note that the centre was more freight generating in the 1980s than today. However, the generation of operations has shifted from the inside to the outside of the second peripheral ring (about 12 kilometers from the centre).

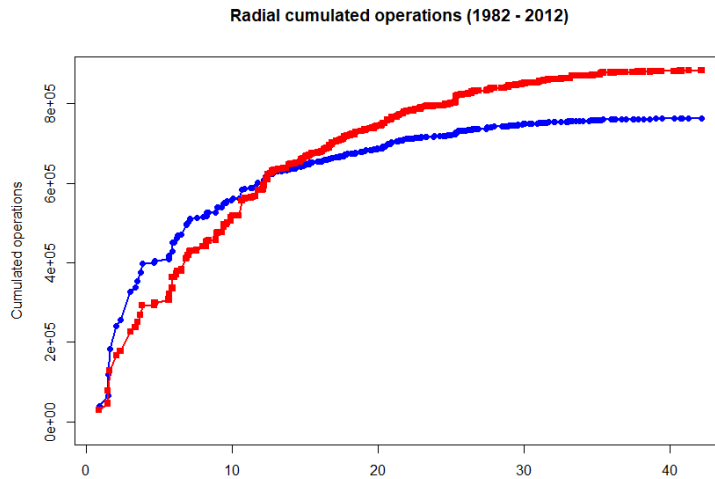


Figure 12: Number of cumulated movements in relation to the distance to the centre of the Lyons urban area in 1982 (blue) and 2012 (red)

This approach allows us to synthesise the effects of change(s) in the economic and job structure in order to transcribe it into a variable relevant to the study of mobility. This generation shift goes mainly from the centre towards the east and the industrial zones of western Lyons. The decrease in operations in the centre is due to the disappearance of industrial and wholesale activities historically located in the city of Lyons. Here again, the areas with high growth are the logistics clusters identified in the previous section. Through this analysis, we observe very clearly the concentration of activities generating operations towards the logistic and industrial clusters of eastern Lyons (Figure 13).

We can deepen this approach by studying the territory as regards its capacity to receive and emit flows. For this purpose, we will use equation (3) to calculate this indicator. This logistics potential synthesises the logistics specialisation rate of our study area and its sub-spaces and therefore the logistics imbalances of the territories. In this approach, we calculate the cumulated difference between emitted and received flows as a function of the distance to the centre. A curve inferior to 0 means that the areas represented by this curve are more receptive than emissive: these zones are therefore "freight-consuming" and depend on other emitting zones for their supply. On the other hand, a curve exceeding 0 denotes an emissive potential: these zones are therefore "freight-emitting" and emit (export) either to the consumer areas or to the outside of the agglomeration. A value of 0 means that, potentially, emissions from the area balance receptions.

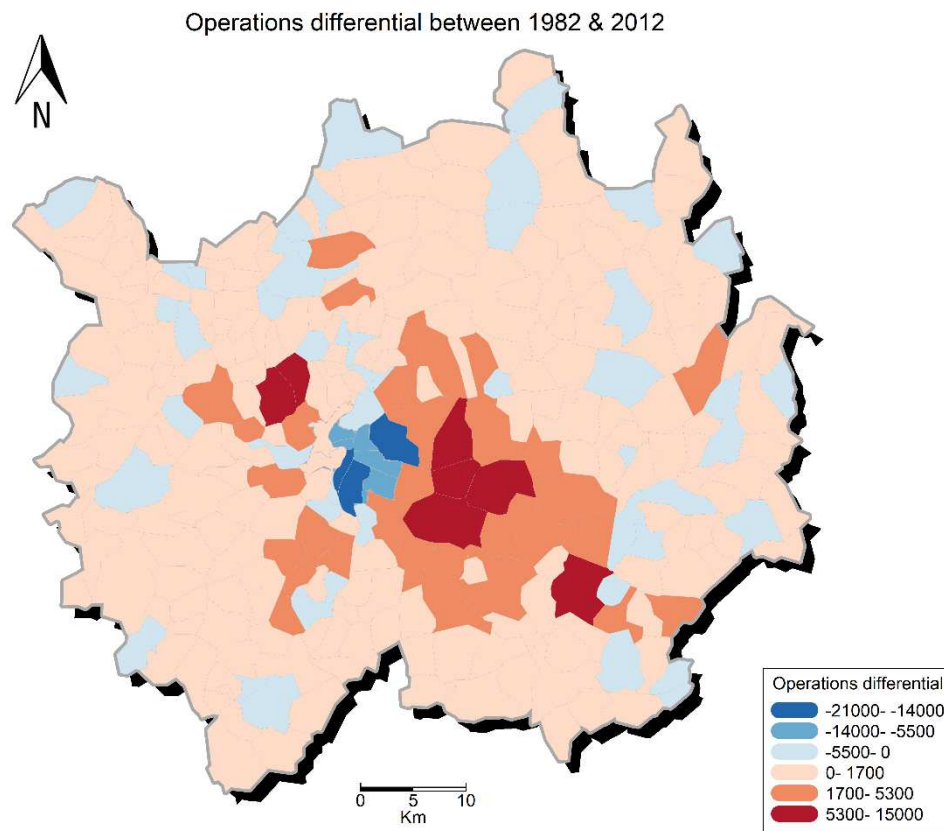


Figure 13: differential of operations per municipality between 1982 and 2012 in the Lyons urban area

The most striking difference between the two temporal limits of the study is the shift from an emissive potential towards a receptive potential in the centre, which then returns to an emissive potential beyond 17 kilometers from the centre (Figure 14). The change in the overall economic structure (logistics and industry sprawl, de-

industrialisation, densification of the centre) explains these deep changes in the logistics functions of the territory. As we have seen previously, the industry and logistics (highly emissive) initially strongly implanted in the central areas, have almost disappeared to make way for businesses and services (highly receptive).

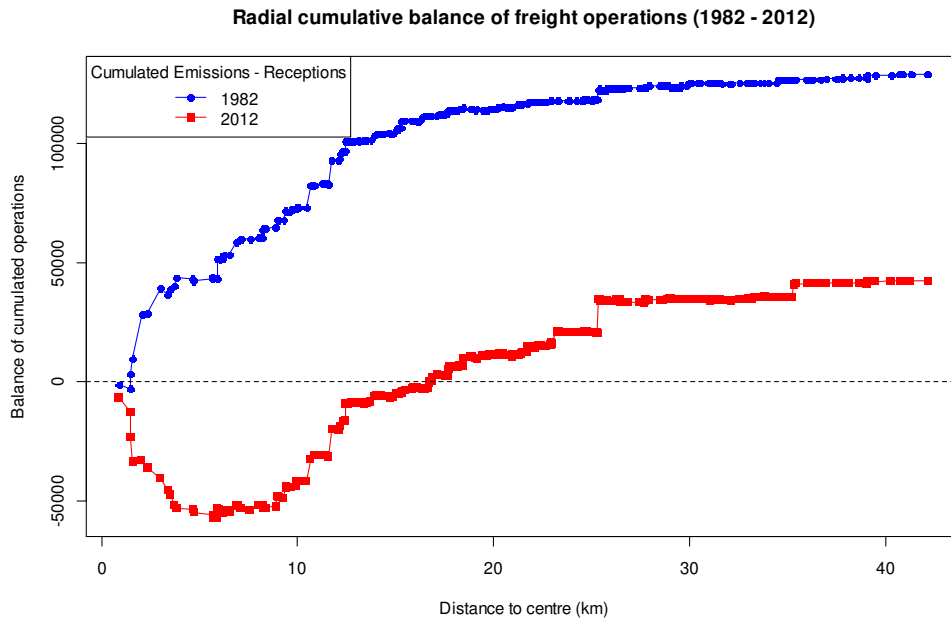


Figure 14: cumulated balance of operations in the Lyons urban area in 1982 and 2012

These elements allow us to identify the "logistics boundaries" of the Lyons urban area. In 2012, the equilibrium zone (balance = 0) corresponds to the beginning of the plateau zone in 1982, where the curve has a reduced growth trend. As shown before, this change in structure happened mainly between the centre of the agglomeration and its eastern region, resulting in an important increase in the emissive potential for the east and in the receptive potential for the centre (Figure 15). The evolution of the operation balance brings out the territories for which the logistics profile specialises.

We can infer from this freight mobility perspective that the distances of penetration in dense zones increased and the dependence of central zones on their periphery increased strongly because of these territorial modifications. By using equations (4) and (5), we therefore model the distances travelled by vehicles (Table 4) in order to assess the impact of urban growth on freight transport.

Table 4: number of weekly operations and distances travelled in 1982 and 2012

Year	Number of weekly operations	Veh.km per week	Veh.km (PCU per week)	Km/operation
1982	780,948	8,318,042	16,333,423	10.65
2012	822,851	11,035,119	21,066,080	13.41

We can observe that if the number of operations has increased by a factor of two, the distances travelled increased threefold. The effect of urban growth and the subsequent evolution of activities is therefore more

important for distances than it was for freight generation, showing the important effect of the logistics specialisation of urban territories. This conclusion is similarly illustrated by an increase in the average distance travelled for each operation from 10.6 to 13.41 kilometers. This evolution of distances has a direct impact on the intensification of congestion and pollutant emissions. In addition, the functional evolutions of the centre and its densification have modified the constraints on these spaces: the number of operations has globally decreased and serves lighter activities, requiring smaller vehicles.

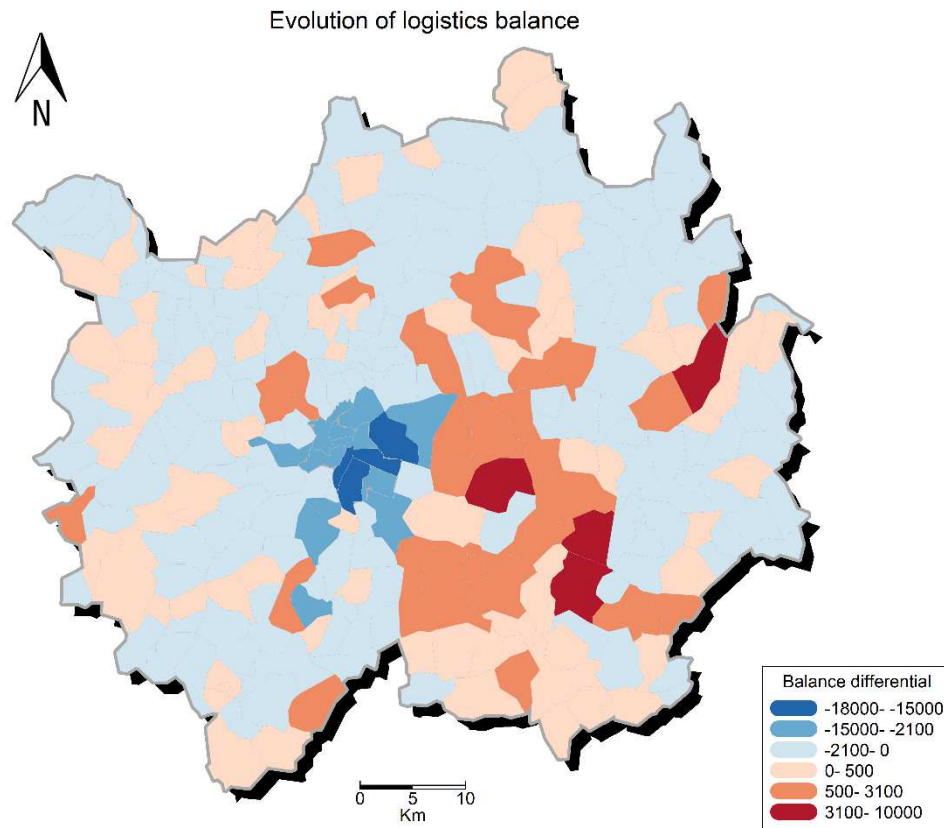


Figure 15: difference in the balance of operations in the urban area of Lyons between 1982 and 2012

We can therefore formulate that a *distension* is occurring, resulting in relocation of heavy flows to the periphery. The term *distension* is borrowed from the medical and geological communities (in the latter case however, “rifting” is the privileged term). In biology, *distension* describes an extension of a tissue in opposite directions, be it of digestive organs or articulations (sinews).

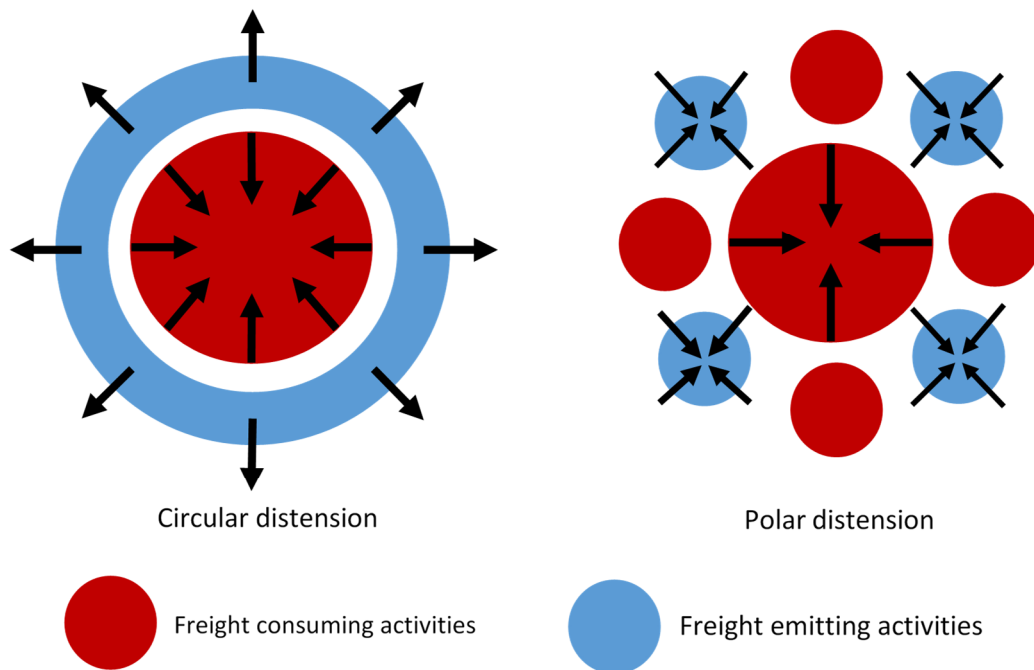


Figure 16: models of logistics distension

Very much like living tissues, the urban logistics structure as we presented it, is also undergoing a tension due to activities moving in opposite directions: *a distension*. In order to lay the basics of this concept, we suggest a model of logistics distension and its alternative form, whether we are confronted to a circular distension or to a polar distension (Figure 16). In the first case, activities undergo a homogeneous sprawl that forms a ring around the city's freight consuming area. It is archetypal and therefore illustrates the model more efficiently, but the case of Lyons corresponds better to the second "polar" or "polycentric" distension type since most logistics activities concentrated towards the East of the conurbation.

The concept of distension also extends to the general notions of territorial tensions and inequities regarding freight mobility. Producing indicators of inequities adapted to an urban freight mobility perspective could be beneficial to further support the concept of logistics distension. In this paradigm, functional mixing is a possible answer to logistics distension in order to limit its negative effects. An opposite movement to distension could therefore be a contraction of the logistics functions, possibly driven by the use of another well-discussed object: urban consolidation centres (Allen et al. 2012; Boudouin, Morel, and Gardrat 2014).

6. Conclusion

Through the spatial analysis of activities and population locations between 1982 and 2012, we confirmed for Lyons the dynamics of logistics sprawl which is happening in many cities worldwide, but also highlighted the movements of other types of activities and outlined their potential effects on freight transport.

We showed that logistics sprawl is not the only sub-effect of urban growth which has an impact on freight mobility and that it needs to be confronted to the densification or sprawl of other activities. Indeed, densification and

concentration of freight-consuming activities in city centres (shops, HoReCa, offices, services...) opposed to the sprawl of other activities (industry and logistics) has an important consequence on the capacity of cities to sustain their own supply. We therefore call this conjugated opposite movement of the localisation of various types of activities *logistics distension* and illustrate the growing dependence of urban territories on their logistics functions. Between the densification of goods-consuming activities in the centre on the one hand, and logistics sprawl on the other hand, the territory is undergoing the effect of a logistics distension that stretches the articulations of urban freight mobility.

Through freight movements modelling derived from the works on urban freight surveys and FTG models, we assessed the impact of this distension on urban freight mobility and highlighted its negative impacts on VKT with an average increase of four kilometres per operation over a thirty-year period.

Although the results do not show counterintuitive trends and effects, we produce original indicators allowing the estimation of land-use impacts on freight transport. In turn, these indicators can be translated into operational indicators (for example distances generated allow pollutant emission estimation) and offer a baseline for decision support in a quantifiable way. The methodology developed in this paper can be considered as a tool for planners in order to monitor the evolution of urban freight transport and land use, to apply quantifiable indicators designed to set targets for urban planning policies.

As an original concept, logistics distension allows us to discuss the evolution of urban freight mobility through the relative localisations of the entirety of urban activities and widens the current discussions on logistics sprawl. This systemic approach seems fundamental in the present research trends on logistics sprawl and freight landscape (Rodrigue, Dablanc, and Giuliano 2017; Sakai et al. 2018; Aljohani and Thompson 2016), bringing a more systemic and dynamic conceptualisation. This study calls for a generalisation of analyses pertaining to logistics distension in the international context and its key explanatory factors regarding urban morphologies and public policies.

By offering a global vision of the key components of freight transport and urban growth (economic activities and population), logistics distension brings decision makers and local authorities to reconsider freight mobility using a broader approach. In this case, commercial, tertiary or residents' localisations become as important as logistics facilities. The growing imbalance of freight operations described in this paper highlighted specific zones where the need for logistics infrastructures or urban consolidation centres were the most relevant. In this sense, the methodology presents indicators that can help decision makers on land-use policies and zoning characteristics, focusing on the most relevant solutions. As well as for passenger mobility, freight mobility needs a systemic approach and examination in land-use and mobility master-plans as all types of human activity generate freight transport. The findings of this work also argue for a better use of long-term modelling and decision-making tools.

The limits of this work, as an exploratory approach to define a new concept still eludes some components inherent to the evolution of urban freight mobility. One of the main points lacking in this work is the influence of e-commerce on urban freight transport, which also strongly modifies logistics behaviours. This phenomenon is still poorly assessed and no FTG models compatible with our approach exist for e-commerce yet, but current researches might help filling this gap. But since e-commerce represents 15% to 20% percent of freight flows, we can however assume that e-commerce deliveries, since they are closely linked to the population, should emphasise logistics distension because of the high concentration of residents in city centres (Ding and Lu 2017; Gardrat et al. 2016).

A corollary methodological problem has to do with the assessment of the evolution of logistics behaviours and freight trip generation over a thirty-year period, driven by new technologies and new business models. Preliminary studies have been carried out for the French case (Bonnaïfous et al. 2016) but are yet to be developed in order to be integrated into our approach. Other international data sources that could make this assessment possible are today extremely scarce not to say non-existent. This paper, of course, accurately describes the French case of Lyons but should extend the question of logistics distension to other contexts. A first step would be to generalise this work on the French territory and find similarities and divergences between territories.

Another limit to this work is the lack of insight concerning regulatory measures for freight vehicle accessibility (dimensions, vehicle weight ratings, motorisations, time windows). These actions subtly influence the organisations

of freight flows but vary significantly from one zone to another and call for heavy data collection. Moreover, regulations are not always efficiently enforced and their impacts can strongly vary according to the territory. Recent researches on low emission zones and time-windows shed some light on the effects of such measures but highlight predatory difficulties due to the variability of observations and causal links (Figliozzi 2011; Deflorio et al. 2012; Dablanc and Montanon 2015).

Furthermore, by focusing mainly on the concept and its description, this work does not provide explanatory elements on the sources of logistics distension. Urban economics and quantitative geography models can provide some clues, but more qualitative approaches related to policies and practices in urban planning can also offer valuable inputs. Additionally, the effects of distension could be explored further, either in terms of congestion, environment or economics, e.g. using the method carried out on the Paris region (Coulombel et al. 2018).

Lastly, the indicators and radiocentric methods we present here work rather well in a monocentric approach but would be hardly adaptable to polycentric approaches. Supporting a discussion on logistics distension therefore calls for multi-disciplinary and systemic approaches in order to propose relevant indicators designed to measure the phenomenon and further substantiate the concept.

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