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Connecting demand estimation and spatial category models for urban freight: First attempt and research implications

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Abstract

This paper proposes a combination of models to estimate in a mesoscopic and microscopic way different patterns of urban goods demand according to the area within the city. The two proposed models are a category classification model for demand estimation and a spatial-based typology model defining different elementary zone within a city based on urban forms characteristics. Both models are applied to the same dataset for the city of Angers (France).In case of the identification of general rules, this new approach will help the transferability of goods practices in urban freight from a zone of a city to the same zone of another city.

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Keywords: Spatial modeling; demand-estimation model; urban freight; urban planning; transferability

1. Introduction

Over the past twenty years urban logistics has become a shared issue in several big cities around the world (Dablanc, 2011). One of the main topics of urban logistics research is that of modeling, mainly motivated by the need of public (and private) stakeholders to support their decisions by quantitative estimations of impacts of urban logistics actions (Gonzalez-Feliu et al., 2013). However, we observe that for the most part, urban goods transport is neglected by the field of urban planning; this could be said to contrast with the centrality of the study of urban

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passenger transport. As a result, modeling tools for urban freight based on geographical analyses and urban modeling are scarce. Most of urban freight models have few connections to cities' characteristics or spatial criteria (Anand et al., 2012). However, spatial approaches could complement technical approaches because city characteristics influence urban goods transport organizations in various ways (Dablanc, 2009; Allen et al., 2012; Lindholm, 2012; Tozzi et al., 2014; Ducret et al. 2015).

This paper is an attempt to connect a demand-estimation model and a spatial modeling classification in order to identify the possible connections and interactions between urban form characteristics and freight movements. We are trying to identify relations and links between the spatial organization of the city and the demand for freight transport, in terms of deliveries and trucks. In case of the identification of general rules, this new approach will help the transferability of goods practices in urban freight from a zone of a city to the same zone of another city.

The paper will be structured as follow: first, after a brief review of the link between spatial studies and urban freight modeling, we will develop in detail the research questions analyzed in this paper. The case study developed in this paper will be also described. In a second part, we will describe in detail the methodology constructed in order to connect demand-estimation model and spatial modeling for urban freight. In a third part, we will develop the main results of the connection between spatial analyzes and demand-estimation. Finally, we will discuss those results and the research implications and perspectives of this work.

2. Research questions and case study

2.1. Urban freight modeling and spatial studies: a review

Among disciplines that have tried to understand logistics organizations and the distribution of urban goods, geography and spatial studies have always taken a backseat compared to economy, management and especially transport engineering sciences (Woudsma, 2001; Hesse and Rodrigue, 2004; Macharis and Melo, 2011; Hall and Hesse, 2012). Contrasting with the fact that relations between urban transport and urban planning have been studied since the 1970s and modelled in various ways since then through successful land-use and transport interaction models (LUTI, De la Barra, 1989), links between spatial organization and goods distribution in urban areas have been overlooked.

Several literature review papers aimed to synthesize the modeling efforts of the last 40 years (Anand et al., 2012; Comi et al., 2012; Gonzalez-Feliu and Routhier, 2012; Taniguchi et al., 2012). We observe three main types of models: demand estimation models, which mainly aim to define commodity or trip O-D matrices related to truck in urban areas; route construction approaches that aim to build those routes from commodity O-D matrices and behavioral and multi-agent models that aim to simulate a realistic behavior of the involved stakeholders in urban logistics.

With the exception of models based on LUTI frameworks (De la Barra, 1989), most of urban freight models, have few connection to cities' characteristics or spatial criteria (Bonnafous et al., 2014). Anand et al. (2012) have analyzed the descriptors of a great number of city logistics models and have shown that the most commonly used descriptors are traffic flow and commodity flow, freight and trip generation, loading rate, pollution level and transport cost. Location and land use, which are more spatial oriented descriptors, are used comparatively little (Anand et al., 2012). Even planning models are not always based on spatial oriented descriptors. In that context, we would like to open urban freight modelling to spatial data and generalize spatial study for urban freight, providing a decision-making tool based on spatial data and territorial analysis (Gonzalez-Feliu et al., 2013).

Nevertheless, from our point of view, spatial approaches could complement technical approaches because city characteristics influence urban goods transport and distribution. According to Allen et al. (2012), urban transport activities are affected by spatial and geographical factors and certain "urban form prerequisites", like the city's size and density, layout and urban form, street design, urban morphology, the location of activities, land use, and the position of the city in the supply chain just as well as economic factors. The authors also note that the interactions between vehicle trip, urban form and land use have been under-researched. Thanks to a precise study of urban areas in the United Kingdom, they subsequently demonstrated that several geographical, spatial and land use factors such as the facility's location, the city's size and location in the city network, street design, settlement size and density, city layout, and commercial and industrial land-use patterns are likely to influence the efficiency and intensity of freight journeys. In her PhD. monography, Ducret (2015) emphasizes and details those conclusions for a large number of French cities thank to a large survey. She shows that the form of the urban development, the density gradient of inhabitants, the density of the street network as well as the street profile are important factors of productivity and efficiency of the last-mile delivery and that freight providers daily adapt their organization to those factors (Ducret, 2015, Ducret et al., 2015).

2.2. Research questions

Based on those theoretical recent conclusions, the aims of this research is to evaluate if there is a link between urban form characteristics, freight movements and freight vehicles. In other words, the paper evaluates if it is possible to understand urban freight from a spatial analysis of a city or area.

More specifically, we will analyze if zones of similar urban forms have similar goods needs or if details on the business characteristics of the zones are necessary to anticipate the freight profile of a zone. For example, we expect that non-commercial residential zones will have similar goods generation rates and freight movements per inhabitant. What is not so evident is that activity zones, industrial and commercial, will have similar generation rates. Moreover, mix commercial-residential zones seem interesting to analyze more precisely in order to state the possibilities of similarities in terms of urban goods needs.

In order to explore this hypothesis we will conduct the first attempt to connect demand-estimation model and spatial modeling for urban freight. In case of the identification of general rules – zones of similar urban forms have similar goods needs – the model will help to transfer goods practices in urban freight from a zone of a city to the same zone of another city.

2.3. Case study: the French city of Angers

Analyses will be conducted for the French city of Angers. Angers is a French large urban area situated in the West of the country (Fig. 1). It is a city of 148 803 inhabitants (2011). We can estimate the Freturb model (the main model used in France for urban logistics demand estimation, see Bonnafous et al., 2014 for its most recent overview) that there is around 270 000 deliveries (including both receptions and expeditions of freight) per day in the city of Angers (Ducret, 2015). Moreover, and from a political point of view the city presents, by now, little commitment to regulate and manage urban freight. In fact, traffic conditions are good, congestion is rare and traffic and parking regulations flexible.

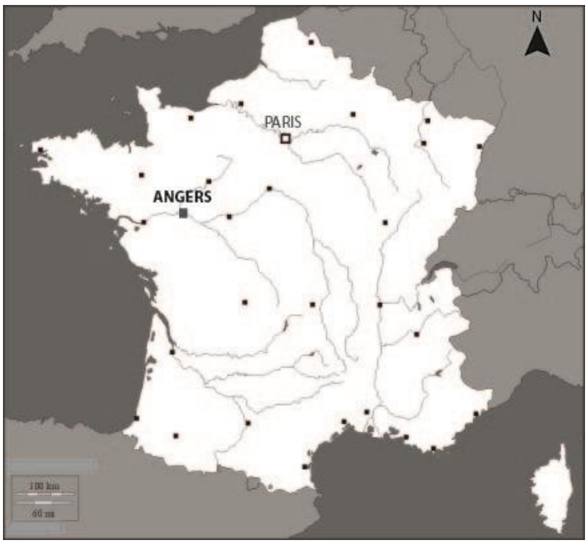

Fig. 1. Localization of the city of Angers

Two different analyses will be conducted on the case study. A first analysis, based on graphical visualizations of data, will show the possibilities of combining a spatial typology model and a category classification demand estimation model, mainly in terms of scale selection and on details in terms of the results visualized. After that, the second one will question the homogeneity of freight demand within each homogenous spatial zones of the city identified. We aim to make a dispersion analysis on a set of indicators that describe the freight needs and opportunities of each spatial zone.

3. The proposed methodology

The methodology to connect demand-estimation model and spatial modeling relies on two modeling approach.

3.1. The spatial modeling approach for urban freight

Regarding the spatial modeling approach for urban freight, this research relies on an innovative approach based on a clustering analysis of spatial and economic descriptors (Ducret et al., 2015).

The spatial descriptors of the model are: the density of inhabitant and of the linear density of the distribution points, the type of land use- residential versus professional zones-, the type of housing and its verticality -collective versus individual-, and the road network density approximated thanks to the number of street section in a small area. Some of them are half spatial and half economic descriptors like the type of land use. We have also added two descriptors specifically socio-economic which can describe the demand for freight: the age of the population and the median income. The model's descriptors rely on professional data from the French Post Office and spatial data from the French Institute of Statistics and of the French National Institute of Geography. For the most part, data are geo-localized.

With respect to the modeling approach, we have realized multidimensional analysis based on principal component analysis (PCA) in order to identify the axis of a spatial segmentation. Then, we have carried out K-Means analysis according to the identified axis to provide the clustering (Ducret et al., 2015). Those methodologies are usually used for spatial statistics analysis but not properly from an urban logistics point of view. We have carried out the modeling process at a very small scale, on a 200m x 200m square grid which can provide a last-mile and precise point of view.

The model provides cities' segmentation into nine coherent and homogeneous zones. Each area is defined according to its spatial organization and economic profile and its influence on urban goods distribution (Ducret et al., 2015). The nine identified zones provide specific information about cities and translate differentiated morphological organizations at a high scale.

From a geographical point of view, we can distinguish professional areas, residential areas of various density, commercial profile and type of housing, as well as different zones of the city center (Fig. 2). The spatial modeling for urban freight gives an accurate and classical representation of the city. But the clustering also provides specific elements about the spatial and organizational constraints on urban delivery related to the infrastructure network, the density of the distribution point and the verticality of the housing.

Regarding the city of Angers (Fig. 2), the city center is relatively dense and constrained and presents high population and distribution point density levels which are represented by zones 4 and 5. Those areas are thus defined by high level of urban freight constraints such as traffic congestion (even if the city center is defined by a high level of accessibility), short but dense delivery tours, regulated measures and areas, mix of residential and professional deliveries. On the contrary, low density residential areas are described by zones 8 and 9. In those areas, the parcel provider is confronted to higher delivery failure rates, long tours linked with GES emission and pollution, low efficiency delivery routes. The model also provides information about the type of housing which is relevant when considering the duration of the delivery and the tour. For example, areas defined by zone 1, which are industrial and commercial areas, are easier and faster to deliver compared with residential areas. Within the residential areas, the types of housing (collective housing -zone 2 and 3- or horizontal individual housing) are also relevant information to estimate the duration and the density of the tour.

The socio-economic information of the description of the zones is more relevant in order to imagine new delivery services able to fit the freight demand and its requirements.

Tests have been conducting in the city of Angers with operational postal teams in order to validate the reliability of the model. Spatial characteristics of each zone and logistics constraints have been evaluated. Those tests have allowed validating the descriptors of the model, the final nine zones and the urban logistics situations they describe.

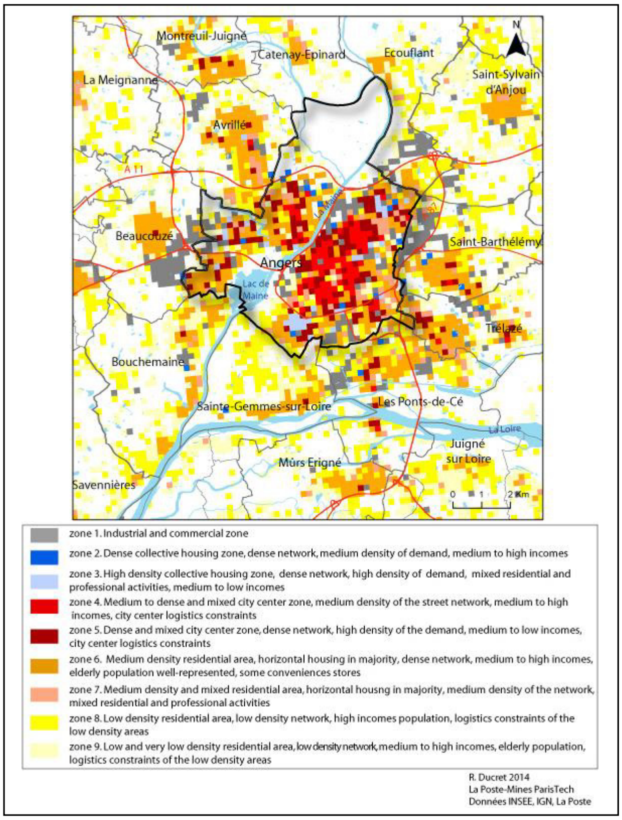

Fig. 2. The nine urban zones of the spatial-modeling approach for the city of Angers

3.2. The demand-estimation model

As for the demand-estimation model, it is related to each single establishment. According to Holguin-Veras et al., (2011) a category class model based on a typology of establishments can be deployed to generate the urban goods transport needs for each zone, but opposing to classical "average-based" models (Bonnafous et al., 2014), in this type of models each category follows different generation patterns, constant or variable. The proposed model comes also from the preliminary findings of Gonzalez-Feliu et al. (2014) that propose an emission model (i.e. based only in expeditions). Here, we will focus on a model that estimates, for each establishment of a city, the number of deliveries (including both receptions and expeditions). Those urban goods transport needs are then declined in terms of own account and third party transport and types of vehicle (light commercial vehicles, single trucks and articulated trucks).

This type of model is directly related to data quantity and quality (as stated in Holguin-Veras et al., 2013; Gonzalez-Feliu et al., 2014) and the modelling possibilities depend on both the data granularity and on the aims of the model (Gonzalez-Feliu and Routhier, 2012). For that reason, it is important to first analyze data used to build the model, in order to find the best granularity and categorization to obtain a model that would be representative of the reality we aim to quantify and at the same time easy to assess and understand.

Data used to develop and validate the model are issued from the French Urban Goods Movement (UGM) Surveys (Ambrosini et al., 2010). From those data, we make a first analysis of data availability and quality, combined by a dispersion analysis, in order to examine the variability of data, but also its availability (in terms of quantity of data that allows making significant statistical analysis). Indeed, since statistics-based results are strongly dependent on data quantity and quality, so when concluding on a relation or on a generation pattern, it is important to state on the statistical significance at the same level as we state on the validity of the methods used for model construction and calibration). Note that the data used in this research has already be used to develop the Freturb model (Bonnafous et al., 2014), based on what Patier (1999) and Bonnafous et al. (2015) call the UGM "invariances": the Freturb model is based on the assumption that the average number of deliveries per week and employee (both receptions and expeditions considered together) should be constant and with a small variability, and can be ranged on the category of "average-based models" (see Holguin-Veras et al., 2011 for an econometrics-based discussion on such type of models). But this assumption would only be valid, according to those authors, for a categorization with 116 classes (categorization defined in the French UGM surveys, see Ambrosini et al., 2010 for a large description of the surveys). However, in our context, it is very difficult to produce data inputs with this fine level of disaggregation, as the spatial model produces an establishment category in 8 classes, too aggregated with respect to the 116 categories of the French surveys. For those reasons, it is important to choose the most appropriate data aggregation for our model.

To this purpose, we propose first to examine the data of French UGM surveys via a dispersion analysis and an analysis of statistical significance, carried out as follows. Given four possible aggregations of data (a categorization in 8, 25, 45 and 116 classes respectively), we examine, for each categorization, the number of categories that are statistically significant in terms of sample size, basic statistics and probability estimators mainly based on Normal laws have a significance for a sample with at least 30 individuals). Then, we think important to estimate average and standard errors of two possible generation variables: the number of deliveries and the number of deliveries per employee. In both case, the time horizon is the week (i.e. a weekly number of deliveries is estimated). We propose in table 1 a summary of four possible aggregations of data (a categorization in 8, 25, 45 and 116 classes respectively). More precisely, we identify the number of categories having enough data to be statistically significant (i.e. at least 30 individuals according to the considerations of Wonnacott and Wonnacott, 2001). The table is organized as follows. The first column indicates the level of aggregation (categorization of the different economic activities of cities), then thee blocks of columns are presented: the first indicates the number of categories statistically significant, then the number of categories with a coefficient of variation CV[†] higher than 1, and finally the remaining categories (i.e. those that have a CV lower than one). Each block of columns contains 3 columns: the first shows the results for an aggregation where there is no distinction between receptions and expeditions, the second and the third do the same to only receptions and only expeditions respectively.

Table 1. Aggregation level and data quantity requirements for statistical modelling purposes

	Number of categories with 30 individuals or more			Number of significant categories with CV<1 (deliveries per week)			Number of significant categories with CV<1 (deliveries per employee and week)		
Category of establishments	All ops.	Only rec.	Only exp.	All ops.	Only rec.	Only exp.	All ops.	Only rec.	Only exp.
8 classes	8	8	7	0	0	1	2	0	1
25 classes	25	23	13	4	4	1	7	0	1
45 classes	36	29	15	5	5	2	6	0	2
116 classes	43	38	8	13	12	1	15	8	1

We observe that the data size requirements are respected for categorizations with high aggregation of data, i.e. those that present few categories. The 116-category classification is too disaggregated taking into account the size of the overall sample, and reflects this fact in the small number of categories considered as statistically significant. Indeed, from 2970 establishments selected after data clearance, 2613 present data concerning receptions and only 1025 regarding expeditions (note that an establishment can declare both expeditions and receptions, but of different characteristics and volumes). The total number of establishment being about 20 times the number of categories, it is easy to deduce that many categories will have less than 30 individuals. Indeed, about 37% of categories (43 out of

[†] CV= Standard error/Mean value

116) are statistically significant if we consider both expeditions and receptions, 33% (38 out of 116) if we consider only receptions and less than 7% (8 out of 116) for only expeditions. Moreover, the number of significant (i.e. having 30 individuals or more) where CV is lower than one is then small. Indeed, in terms on weekly number of deliveries, about 11% of the categories present a CV<1 when not distinguishing between expeditions and receptions, and similar results are obtained and when taking into account only receptions; less than 1% of the significant categories present CV<1in the case of expeditions. For the weekly number of deliveries per employee, results are similar for the case when expeditions and receptions are not distinguished and for the case with only expeditions, but are even worse for only receptions (less than 8% of the categories are significant and have a CV<1 at the same time). In this context, making conclusions with the 116-category classification is very difficult. Two alternatives are envisaged: either reducing the threshold of statistical significance (from 30 individuals to 15, as in Gonzalez-Feliu et al., 2014) or considering a more aggregated classification and examining it in the same terms.

When examining the 25 and the 45-category classification we observe similar results in terms of dispersion. Few categories (between 10 and 25%) present a coefficient of variation lower than 1, and in the case of the number of deliveries per employee and week, when considering separately expeditions and receptions, the data dispersion is strong. The main difference between those categories arise on statistical significance: the 25-category classification presents almost all categories that are significant (except for only expeditions), as is not the case of the 45-category classification. The 8-category classification presents enough data to have significant statistical analyses but the dispersion of such data is strong, due to the high aggregation. Therefore, if we aim to have a dataset where categories present enough data for statistical representativeness purposes, it seems suitable to use a categorization in 8 or 25 classes. The 8-category classification seems too aggregated (as shown in Table 1), so the 25-category classification could be a good compromise between statistical significance needs (for what it is important to have categories with near 35 establishments at least) and homogeneity inside each category (the 8-category classification is too heterogeneous). However, it is important for the coherence and robustness of a model (in the sense of Ackoff, 1977) to develop a model in consonance of the scope of application that potential users will have (Gonzalez-Feliu and Routhier, 2012). In this context, the spatial typology integrates an aggregated categorization of establishments, from which the 8-category classification is immediately obtained, whereas the 25-category one is less direct to be obtained. Moreover, the 8-category classification is simple to deploy, since there is no need of detailed data as input. For those reasons, we will pursuit the analyses and the modelling framework with the 8-category classification.

Concerning the generation unit, the choice of the number of deliveries (including both receptions and expeditions without specifying that) seems preferable to that of generating the number of expeditions and the number of receptions separately, then aggregating them. This choice is justified mainly by the fact that this separation is not necessary when aiming to quantify deliveries to associate them to vehicles, in order to estimate road occupancy impacts or traffic-related indicators. When no relation is needed with the construction of routes (only the number and type of vehicles is needed), the number of deliveries for each establishment without specifying if they are receptions or expeditions seems enough. After that it is important to define the best declination of the base generation unit. In this context, two possibilities are envisaged: to generate the weekly number of deliveries per establishment or per employee and establishment (Holguin-Veras et al., 2011). We report in Table 2 the results of these two approaches. In both cases, we report, for each category, average values, standard errors and coefficients of variation:

Table 2. Aggregation level and data quantity requirements for statistical modelling purposes

			Weekly number of deliveries per establishment			Weekly number of deliveries per employee		
Category	Name	Sample	Average	Std. error	CV	Average	Std. error	CV
1	Agriculture	41	4.03	4.32	1.07	0.97	0.88	0.91
2	Craftsmen	375	5.47	12.99	2.38	1.94	5.43	2.80
3	Industry	623	13.82	27.36	1.98	1.43	2.31	1.62
4	Wholesalers	414	27.32	90.33	3.31	3.38	8.01	2.37
5	Stores	47	72.70	81.60	1.12	0.99	0.92	0.93
6	Retailers	1080	8.41	10.96	1.30	2.74	3.68	1.34
7	Tertiary-services	322	5.18	14.17	2.73	0.43	0.82	1.91
8	Warehousing-Transport	68	114.92	269.60	2.35	7.83	13.31	1.70

We observe that coefficients of variation for the second approach are in general smaller than for the first. However, the difference is small, and for any case (as already shown in Table 1) we cannot state on the invariant nature of the two variables, i.e. the weekly number of deliveries per establishment and the weekly number of deliveries per employee. We observe also that although those coefficients are lower for the second variable, they remain close, and those results show no indices to conclude on the better suitability of one variable with respect to the other.

Moreover, and to straighten our analysis, we propose an econometric analysis to study the correlation between the number of deliveries per establishment and the number of employees, as on Holguin Veras et al. (2011). Two linear models are tested: one of type $y = a + b.x$ (linear regression with constant) and one of type $y = c.x$ (linear regression without constant) as shown in table 3:

Table 3. Aggregation level and data quantity requirements for statistical modelling purposes

			Linear regression with constant		Linear regression without constant	
Category	Name	Sample	R^2	Critical value of F	R^2	Critical value of F
1	Agriculture	41	0.17	4.88E-03	0.39	4.76E-06
2	Craftsmen	375	1.87E-05	0.93	1.13E-03	0.52
3	Industry	623	0.41	2.67E-74	0.46	1.38E-85
4	Wholesalers	414	0.04	8.11E-09	0.09	1.71E-10
5	Stores	47	0.71	6.11E-14	0.81	1.84E-19
6	Retailers	1080	0.11	1.14E-29	0.22	1.18E-61
7	Tertiary-services	322	0.03	6.37E-04	0.08	2.94E-07
8	Warehousing-Transport	68	0.02	0.12	0.11	2.38E-03

The results confirm that in the 8-class categorization, a linear relation between the number of deliveries and the employment is not significant (only for category 5, stores, which is a small category with a quite homogeneous composition) a linear relation is obtained, and the linear regression without constant obtains good results (with an R^2 coefficient of more than 0.8). Moreover, the slope of the linear function is closer to the median than to the average value. On all other categories, R^2 coefficients are lower than 0.5 and in most cases lower than 0.3. This can be explained by the high dispersion of data, observed in the dispersion analysis. In this way, the combination of a dispersion-based and an econometrics-based analysis can give both the suitability of linear relations and possible statistical reasons to support conclusions of linearity. Those observations support our vision of modelling urban goods generation by a representation of its statistical distribution and not by a constant or linear function, at least for a much aggregated categorization (which can be useful when stakeholders have not the possibility of proposing a much disaggregated set of data).

For that reason, we can generate, for each category, an average number of deliveries per establishment, a minimum value and a maximum value. Those values are set in a first time as being the C05 and C95 (centiles 5 and 95 respectively) in order to cover 95% of the possible values.

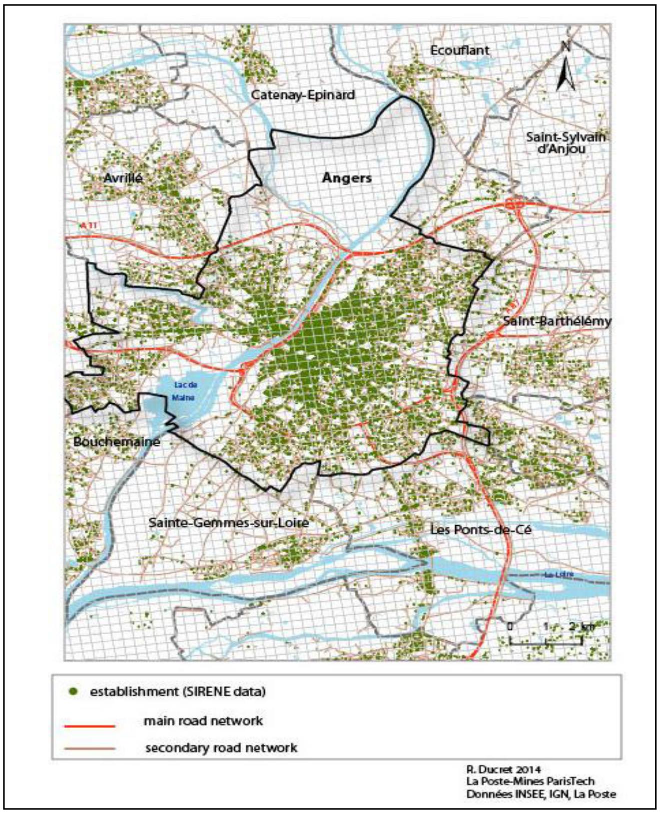

Fig. 3. Distribution of the establishments in the city of Angers and its surrounding

For the case study of the city of Angers, Fig. 3 presents the distribution of the establishments before any process has been applied. Note that the entire city is a too big territory (taken into account the spatial elementary zone given here) to see in a map the details of the modelling results. Fig. 4 shows the results of the demand-estimation model for a specific part of the territory. It especially maps the number of movements per week in Angers and its suburbs and also zooms in on the commercial and economic center of the city around the Ralliement Square and the shopping area. Those maps clearly show important urban goods recipient such as commercial zones (north and east of the city). It also emphasizes that small shops and retail stores within the city center receive frequent and divided deliveries during a week.

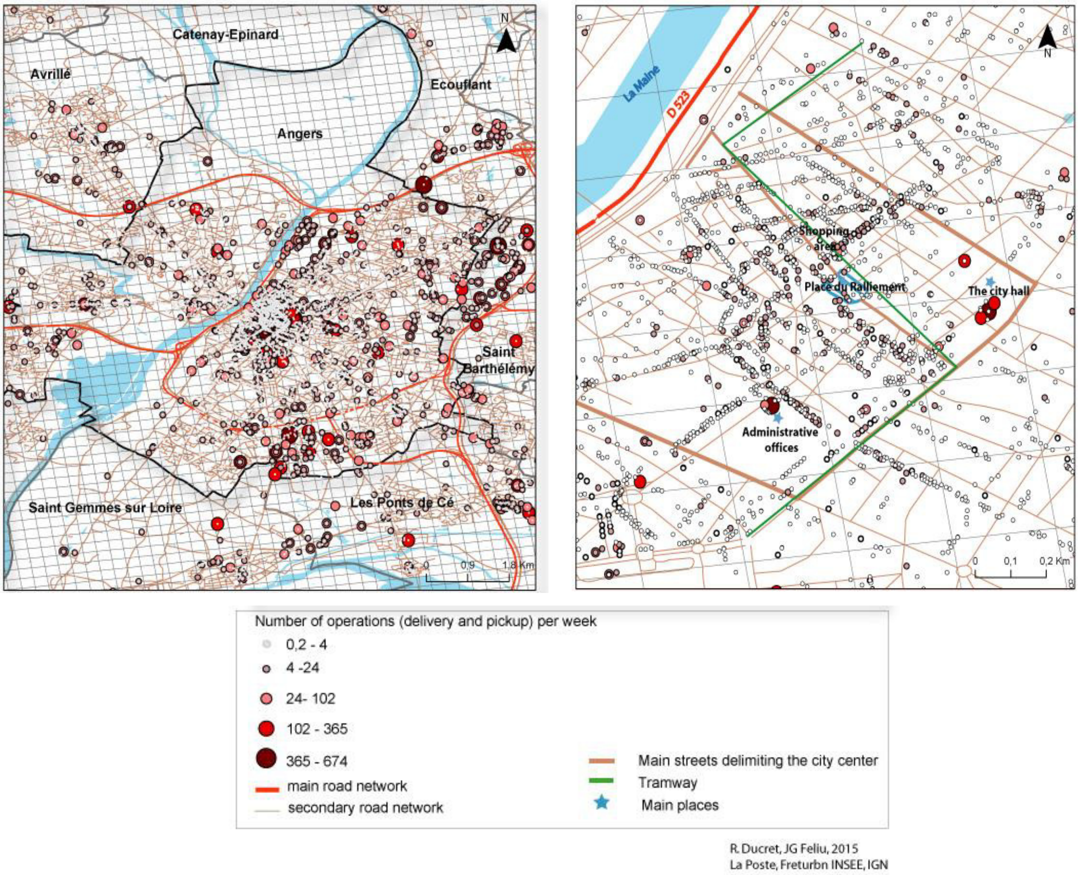

Fig. 4. Number of operations per week for the city of Angers and the city center of Angers

3.3. Modeling methodology to connect the demand-estimation model and the spatial urban freight model

Thanks to the spatial modeling tool, we are able to define the different elementary areas of a city, with their activity characteristics and urban logistics constraints. The demand-estimation model allows generating the number of deliveries per week for a city and the type of delivery vehicle. If we project the results of the demand-model above the nine areas, we are then able to estimate the number of deliveries per week at each zone as well as the type of delivery vehicle. In addition, the number of vehicles by type (light commercial vehicles, single trucks, and articulated vehicles) is associated to each elementary zone.

4. Main results

For each zone, we define the following indicators: the weekly number of deliveries per establishment, the number of trucks/day (in a min-max perspective) as well as the number of light duty vehicle and articulated truck/ day.

Fig. 5 shows the spatial distribution of deliveries in the core center of Angers (each economic activity of core city center is represented by a circle which size is proportional to the weekly number of deliveries). We can see that the most important number of delivery per week is within the shopping area around the tramway and near the Ralliement Square. Those areas are zones 4 and 5 which are the densest in distribution points (mix residential and professional) according to the spatial model. But, at the same time we can see that other zones, which are supposed to be dense in distribution points too, because of a mix of residential and economic functions, are not the place of many freight movements (zone 4).

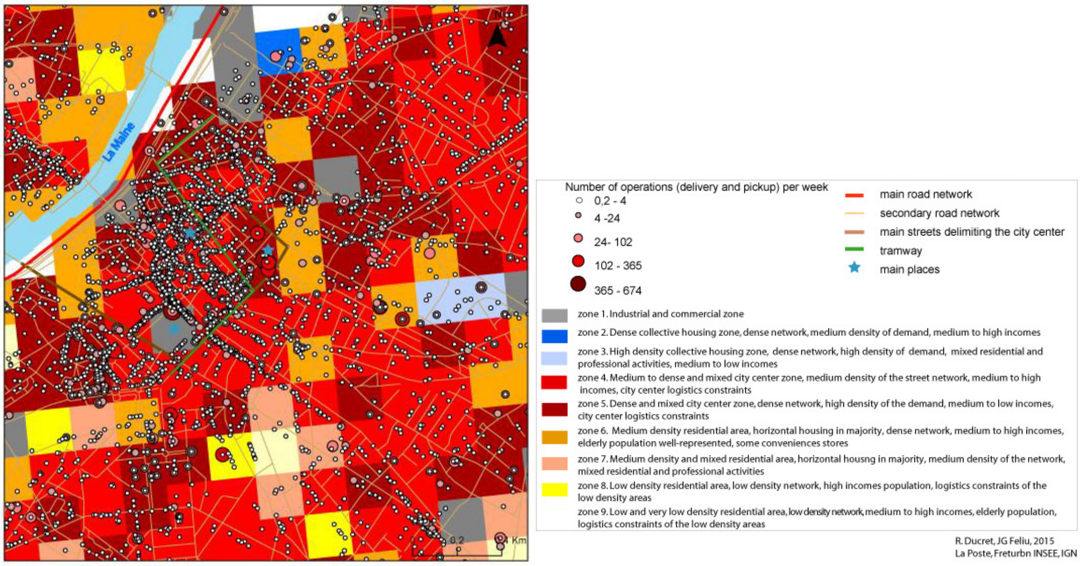

Fig. 5. Example of connection between the demand-estimation model and the spatial model: delivery operation in the city center

As for the analysis of the number of delivery by delivery vans per week, zone 6 where we have noted some convenience stores is in fact the place of a larger number of deliveries by vans because those types of establishments need more freight and more frequently. The shopping-related city center of Angers is the place of small and very small deliveries by vans as those establishments receive daily parcels. Squares of the zone number 8, which are residential for the most, show a small number of movements and those are done by small vans in the great majority.

In those two cases it is difficult to say graphically whether there is a correspondence between the spatial organization and the demand for freight. In order to state into a possible homogeneity in freight generation inside each spatial category (in case of what we could affirm that spatial aggregation is an important determinant in freight generation), we have conducted a statistical analysis based on the notion of dispersion.

Table 3. Dispersion analysis on the number of deliveries per week and the number of deliveries per employee and week

		Deliveries per week			Deliveries per establishment & week		
Category		Av.	Std. error	CV	Av.	Std. error	CV
1	Industrial or commercial zone	126.19	509.72	4.04	5.77	16.40	2.84
2	Mixed population-activity area; medium density; high incomes	81.06	273.98	3.38	4.75	9.57	2.02
3	Mixed population and activity area; high density; low incomes	183.64	627.86	3.42	5.25	10.84	2.06
4	City center configuration ; low to medium incomes	136.06	350.52	2.58	4.00	5.11	1.28
5	City center configuration ; medium to high incomes	284.19	1412.78	4.97	6.59	18.49	2.81
6	Medium density residential area ; high incomes	85.32	251.21	2.94	4.38	8.73	1.99
7	Medium density residential area ; low incomes	370.50	1398.70	3.78	5.75	16.20	2.82
8	Low-density residential area, medium incomes	58.47	225.32	3.85	3.07	16.64	5.42
9	Low-density residential area, High incomes	41.88	180.66	4.31	3.20	8.34	2.60

First, we report average number of deliveries per week and corresponding standard errors for each category. We observe that in all cases standard errors are higher than average values, and this in both cases (absolute values and relative values with respect to the number of establishments of the zone). This first highly aggregated analysis confirms what was seen in graphical visuals and maps: the correlation between elementary urban forms and freight generation patterns is not evident. To go in-depth, we make a more in-depth dispersion analysis by detailing, for each category, average and median values of the number of deliveries per establishment in each zone, plus first and second quartiles and first and ninth 10-quantiles (Table 4).

Table 4. Dispersion analysis of the weekly number of deliveries per establishment: Average, median quartile and 10-quantile for each category

	Category of zone	Av.	Med.	Q1	Q3	D1	D9
1	Industrial or commercial zone	5.77	2.33	1.34	2.33	0.84	12.02
2	Mixed population-activity area; medium density; high incomes	4.75	2.06	1.34	4.53	0.84	10.45
3	Mixed population and activity area; high density; low incomes	5.25	2.35	1.34	5.36	0.97	11.42
4	City center configuration ; low to medium incomes	4.00	2.15	1.34	4.21	0.85	8.01
5	City center configuration ; medium to high incomes	6.59	2.32	1.34	5.60	0.84	11.42
6	Medium density residential area ; high incomes	4.38	1.54	0.97	4.03	0.57	8.86
7	Medium density residential area ; low incomes	5.75	2.23	1.34	5.04	0.95	11.42
8	Low-density residential area, medium incomes	3.07	1.16	0.65	2.30	0.39	5.71
9	Low-density residential area, High incomes	3.20	1.34	0.70	2.57	0.35	6.72

We observe that medians are in general more than twice lower than average values, which are close to third quartile values. That means that few high values are conditioning the statistical dispersion of each category, but 50% of the values (Q1-Q3) are in contained ranges (in general between 1 and 5 deliveries per week and establishment. The analysis of the (D1-D9) range is more heterogeneous. Indeed, eight ratios Q3/Q1 are between 3 and 4; the ratios D9/D1 are instead more variable, with a minimum ratio of 9, a maximum of 19 and the seven others are between about 12 and 15.

Two categories (8 and 9) characterized by low density population and mainly residential areas, present very compact results: a median number of deliveries per week and establishment near 1 and an interquartile range of about 1.7-1.9. The D1-D9 range is higher but remains limited (between 4 and 5). This is explained by the fact that residential areas are not high transport demand producers and confirms a robustness of the combined spatial and demand-based modelling approach to state on the potential goods transport demand of those zones.

Industrial or commercial zones (zone 1) have a very compact interquartile range (about 1) with a median equal to Q3 (2.33 deliveries per week and establishment). This shows a very strong robustness of the method, at least for about 2/3 of the zones: the D1-Q3 range is about 1.49 deliveries per week and establishment (this range covers 65% of the total number of zones) and this independently of a detailed composition of the zone in types of establishments (in this case, the number of deliveries per week is directly proportional to the number of establishments, independently of their type). The remaining 35% of the zones needs to be further explored, but after estimating other deciles we see that D8=6.7, so this statement can be applied to 70% of the zones of this category. Moreover, if we calculate (C05-C85) we obtain the range [0.5, 8.8] which represents 80% of the zones.

This reasoning is also applied to city center configurations (categories 5 and 6), and, in a minor way, to medium density residential areas. Indeed, in those four categories, the interquartile range is between 3 and 4 and the D1-D9 range about 8 to 10 (a little higher than for the three categories shown before). The remaining two categories (2 and 3) seem more heterogeneous. The mixity of establishments and functions (not only residential, industrial or commercial) makes the zones more heterogeneous but the interquartile ranges remain between 3 and 4 (showing that finally, in all zone types, 50% of the zones have a generation rate of number of deliveries per week and establishment comprised between 1 and 5). However, the inter-decile ranges remain between 8 and 10, i.e. with the same dispersion patterns as city center zones.

It remains to explore the generation patters when the type of vehicle is taken into account. Indeed, those results would be more robust if we split the overall number of deliveries them into three categories, one per type of vehicle. We report in Table 5 the results of this analysis for category of space 1 (commercial or industrial zones) and for light commercial vehicles and single trucks:

Table 5. Main dispersion indicators for the weekly number of deliveries per establishment, by category of trucks (light commercial vehicle and single truck)

	Number of deliveries per establishment	
	Light commercial vehicle	Single truck
Average	2.9	0.4
Standard error	7.7	0.2
Median	1.2	0.5
Q1	0.7	0.3
Q3	2.8	0.6
Interquartile	2.1	0.3
D1	0.4	0.2
D9	6.3	0.6
Inter-decile range	5.9	0.4
C05	0.2	0.2
C95	10.9	0.6
Range 90%	10.6	0.4

Both data distributions are more compact than when analyzed together (without specifying the vehicle). We observe that, although 90% of the zones are on a range of 10 in terms of number of deliveries per establishment, 80% is on a range of about 6 (40% smaller) and 50% of the zones have a number of deliveries per week and establishment comprised on the range [0,7; 2,8], i.e. only a range of 2. Although those results are exploratory and remain for one category, they seem relevant to us because, in fact, the choice of the vehicle, which is an important part of the logistics organization, can have a strong connection with the spatial organization of the city (street design, accessibility, connectivity, regulations). Further works will go in this direction, in order to analyses those data more in-depth and for all categories, and find the most suitable level of disaggregation.

Note that this research is in an initial step and the results remain exploratory. More precisely, both models (the spatial and the generation ones) have been calibrated separately and would allow a simulation (on the basis of probabilistic distributions) of freight generation in Angers (where real data on urban goods generation is not available). So to analyses more in-depth the relations between the urban forms and the urban goods generation patters two possibilities would be envisaged: either to apply them to a city where an Urban Goods Survey is available (Bordeaux, Dijon, Marseille or Paris) or use the generation model to make a simulation of generation (replicating it in a certain number of times, like in Monte-Carlo simulation) and combine both the analysis above and a linear regression analysis. Both approaches would need a high research effort and will be envisaged in future researches. However, current results can still lead us to general conclusions and practical implications.

Concerning the practical implications of the proposed methodology, we can address several considerations. The first derives directly from the conclusions of the analyses carried out above. We observe that each category of urban space present zones with similar characteristics in terms of goods generation processes. The second is related to the nature of the goods demand generation model. Since it has been developed to be deployed with few data (the categorization of establishment is simple and friendly, so of easy application), it can be applied easily to different urban areas. Stakeholders (both public and private) can then estimate the number of vehicles in a fast way and having results which are of the same order of magnitude than those of other goods generation models (Holguin-Veras et al., 2011, 2013; Gentile and Vigo, 2013; Bonnafous et al., 2014). Moreover, this model is related here to land characteristics. The analysis show that if generation is often related to only establishment characteristics, elementary aggregations of those establishments can also be modelled, giving the generation patterns of those elementary urban forms. The combination of those urban forms will constitute neighborhoods or cities. So the proposed methodology can be used in urban planning for (re) designing territories, more precisely for estimating the impacts on urban goods transport of different land use choices or for identifying the freight transport needs when defining a new urbanistic zone in a city.

Other potential uses of the proposed methodology include the estimation of number of trucks in different zones of the city (for parking and access policy decision support), the quantity of goods to be delivered to the different elementary zones of a city (for goods demand estimation in the context of urban logistics platform) and, with further research, the definition of indicators of land accessibility and attractiveness to goods transport.

5. Conclusion

From an academic point of view, the study is a first step in order to bring urban analysis and urban freight closer. This attempt to connect demand-estimation model and spatial modeling raises numerous research questions: what type of mathematic formalization to connect urban form and urban good needs, does urban and spatial patterns help understand urban good needs, does it exist general rules between the spatial organization of the city and the demand for freight. Moreover, this integrated approach proposes to be a first tool for spatial analysis of urban goods generation rates, and connect the wide literature of urban goods demand modeling to urban planning literature, subjects which are in general little connected.

Results show that an apparent non-correlation between a spatial typology and freight trip generation patterns can be affined by a statistical analysis of dispersion and distribution. Indeed, the results of this analysis show that industrial and commercial zones, as well as residential zones, have generation patterns where the data dispersion is small, whereas mixed zones (city center or not) have a higher dispersion but present characteristics that confirm the robustness of the spatial typology aggregation.

This new academic and operational position can help local authorities to better understand logistics from an urban planning point of view and could even provide operational responses to tackle urban freight organizations. Moreover, the definition of indicators that show those connections can be useful for practitioners in order to identify goods needs or limits of the current urban deployments and even anticipate in a situation of future urban developments.

Other further developments include the extension of the analyses to freight generation (quantity of goods), types of vehicle, and an aggregated category class generation model to be used by practitioners with a small quantity of input data and with an aim of transferability to different cities, at least in Europe. An in-depth analysis of interactions between urban forms and goods generation patterns based on iterative simulation would also be part of future researches.

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