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Abstract

This communication presents four contrasted and near-caricatured scenarios of retail location and distribution, and compares them on the bases of both road occupancy rates and greenhouse gas emissions. Two main families of scenarios are defined: retailing land-use scenarios, based on the location of the different retailing activities of a city, and end-consumer delivery organisational scenarios, based on the definition of new services to deliver end-consumers, at home or to reception points. Those scenarios are simulated using an integrated approach combining inter-establishement goods transport flows, shopping trips and end-consumer deliveries. The simulation approach is able to show the relation between several aspects of retailing deployment (store location, catchment area's supply, urban retailing planning policies) and both upstream distribution of goods to retailers and downstream usage of private vehicles for shopping. Although scenarios are extreme and near-caricatured, they are able to identify the limits and forces of the different retailing strategies in urban zones.

1. Introduction

City logistics aims to study the urban part of the logistic chain and more precisely freight movements (in their different form) in order to reduce costs, externalities and nuisances related to urban goods transport. Several methods and approaches are found in literature (Taniguchi et al., 2001; van Binsbergen and Visser, 2002; Anderson et al., 2005; Ambrosini et al., 2008; Craninc, 2008; Gonzalez-Feliu, 2008; Quak, 2008). However, most works focus on final deliveries to retailers, and not on the other part of the urban supply chain, that of end-consumer movements (Russo and Comi, 2006; Gonzalez-Feliu et al., 2010). Three main types of flows can be related to goods transport in urban areas (Ségalou et al., 2006): *inter-establishments movements* (IEM) are related to freight distribution between the different activities, i.e. the exchange of goods between establishments; *end-consumer movements* (ECM) can be defined as the trips where the purchased goods are transporter near the consumer's location, and *urban management movements* (UMM) include all flows related to the logistics activities of the city and its infrastructures (waste management, building, road and network construction and maintenance, postal services, household and enterprise moving actions, etc.). The first group of urban freight movements has been one of the most studied subjects in city logistics research. The second group, commonly studied in other fields but often not modelled as a part of the global urban freight distribution chain, is however an important component in terms of traffic volumes. According to Gonzalez-Feliu et al. (2009a), shopping trips represent in France between 10% and 25% of the total person trips, depending on the day of the week, and almost half of the total rad occupancy issues (in km.PCUs, i.e. Private Car Units) of urban goods transport flows. In terms of pollution, the urban transport of goods, including end-consumer movements, produces about 25% of the total CO_2 emissions for transport, 35% of the NO_x emissions and 40 to 50% of the solid particles [14].

Moreover, shopping trip behaviour is directly related to retailing land-use policies and to new services to consumers, like e-commerce and proximity delivery distribution services. Furthermore, those actions have also a direct impact on deliveries to retailing activities, showing that the link between IEM and ECM is crucial in urban logistics. It is then important to estimate the impacts of such policies and actions on the overall urban goods transport system, i.e. that which combines IEM, ECM and UMM flows. However, UMM being indirectly related to the other two flows, can be studied in a second time.

The aim of this paper is to propose and examine four extreme scenarios and estimate the impacts of the actions they represent on both road traffic flows (in terms of rad occupancy issues) and greenhouse gas emissions. First, the simulation methodology used to estimate the impacts of the scenarios on urban goods flows is presented. Second, the proposed scenarios are described. Third, the four scenarios are simulated and the results compared and discussed. Finally, as a conclusion, the main strengths and limits of the analysis are presented, as well as further developments.

2. Freight transport flow estimation: a global approach

As shown above, urban goods transport includes three categories of flows (Ségalou et al., é006):

- Inter-establishment movements (IEM), which includes freight distribution deliveries and pickup trips, for all economic activities of the urban area. So, not only the retailing distribution is concerned by IEM, but all pickup and delivery operations related to commercial activities and its related transport flows. According to Ségalou et al. (2004), they represent about 40% of the total road occupancy issues of urban goods transport.
- End-consumer movements (ECM) are nowadays mainly purchasing trips by car, but with the development of new practices, like home deliveries, e-grocery, direct circuit B2C services, pickup points development, etc., they will soon include a variety of flows and can sometimes substitute IEM flows in the terminal part of supply chains. They represent about 50% of road occupancy issues (Ségalou et al., 2004)
- Urban management movements (UMM) are those related to all logistics activities of the city that are not necessarily related to commercial activities or that are linked to the development and maintenance of the city. The main flows are those of building,

road and network maintenance activities, followed by waste collection, management and recycling activities. Other flows concern household and enterprise moving actions, postal services (both official and informal), representation activities and reparation services to private or professional customers, among others. By subtraction, all those flows represent about 10% of the total urban goods transport movements, in road occupancy issues.

Moreover, the sum of those three types of flows (so the total urban goods transport flows) represent about 20% of the total road occupancy Km.PCU and 25% of greenhouse gas emissions (Ségalou et al., 2004).

As seen above, IEM and ECM represent about 90% of the total urban goods transport flows and about 18% of the total urban transport flows. They are of different nature (IEM are mainly trucks of 3.5T or more, whereas most ECM are nowadays trips of inhabitants by private car), but they share the same space (urban roads and streets) for both running and parking. It is then important to combine them in a unique model to simulate the impacts of urban logistics planning actions, as shown in Russo and Comi (2006). However, current works remain conceptual, with few real applications. For that reason, we have recently proposed an approach to include ECM into existing IEM frameworks (Gonzalez-Feliu et al., 2010). We present here the integration of both tools (an IEM and an ECM model), as the continuation of the work presented in Gonzalez-Feliu et al. (2009a).

The integrated framework is then composed of two modules, one for IEM simulation (FRETURB) and one for ECM simulation (STG).

FRETURB is data production and diagnosis framework for decision support in urban freight distribution that presents different functionalities (Gérardin Conseil and LET, 2000). It is able to estimate the IEM demand for a given urban area. Then, it can estimate road occupancy rates by running vehicles. More information is given in Gérardin Conseil et LET (2000) and in Ambrosini et al. (2008). The model has been calibrated from logistic behaviours observation, for several surveys in the late 1990's (Ambrosini et al., 2008). Organisation and management of the logistic chains have been analysed according to a large typology of establishments (116 types according to the nature of their activity and their size).

The STG framework is a new shopping trip estimation model built from the following definition of private car shopping trips: for each purchasing activity, two related trips are defined, one ending at the shopping activity and the other starting at it. First of all, the demand is estimated considering that the shopping destination is chosen according to the commercial zone attractiveness, which depends on the commercial supply, the type of purchase and the available modal choices (Gonzalez-Feliu et al., 2010a). The novelty here is that the trip distribution is not made using a classical trip estimation method (like in

Gonzalez-Feliu et al., 2009a,b, 2010a) but using a catchment area model based on the notion of attractiveness (Gonzalez-Feliu, 2010b).

The integrated simulation framework works as follows. Consider a city, divided into representative zones. Each zone is defined by two data sets: one defines the economical activities of the zone and the other characterises its population. From the first data set, the FRETURB tool calculates the IEM vehicle flow exchanges between zones for freight distribution and collection, and gives to the STG model the composition of each commercial area. The STG module calculates analogously private cars shopping trips. After that, these flows are integrated in order to calculate the road occupancy issues of running vehicles, for both IEM and ECM flows, in total number of km.PCU for freight-related vehicle trips, to calculate the congestion level. Finally, CO_2 emissions and local pollution rates can be also obtained by considering the characteristics of the different vehicles (professionals and individuals) in the considered city.

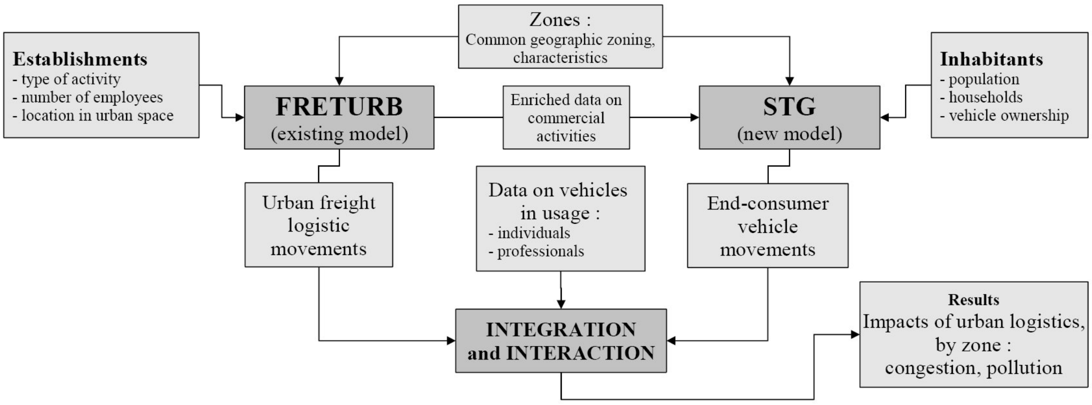

Figure 1. Chart of the integrated simulation model (adapted from Gonzalez-Feliu et al., 2009a)

This framework is applied to the urban area of Lyon (near 2 000 000 inhabitants), using the information provided by the 2006 household survey (covering 454 towns and near 830 000 households), and the 2005 SIRENE directory, the national exhaustive firm register, providing establishments NACE among other information.

3. Proposed scenarios and computational experiments

In order to analyse the impacts of different planning or management actions on urban goods transport flows, we propose to simulate four constrasted extreme scenarios. Those scenarios result from the generalization of current practices in retailing and although their deployment as on the proposed scenarios is unrealistic they represent the limits of the four actions proposed. For that reason, we think it is important to simulate and analyse them. The scenarios can be grouped into two families.

The firs family represent the action of public authorities on retailing land use. They are then two cases of pushing the deployment of different forms of retailers to the extreme. They are obtained from data extracted from the French Surveys on Urban Goods Transport and defined via conversion tables (Gonzalez-Feliu et al., 2009b). In scenario 1, we assume that all retailing activities are concentrated in 15 big peripheral commercial centres. The urban forms associated to those commercial centres are agglomerated retailing areas containing hypermarkets and supermarkets with a gallery of complementary small retailing activities. Inhabitants need then to reach those zones to make their purchasing activities, mainly by car. In scenario 2, only proximity retailers are allowed in the city. No hypermarkets or supermarkets are defined, but a wide variety of small stores and complementary retailing activities, spread in the territory at the pro-rata of the population.

The second family represents the development (in extreme situations) of different proximity delivery services already proposed by different retailing activities. To estimate them, we use the ratios of Alligier (2007), who determined the main characteristics of home delivery routes in France. Then, we suppose 15 distribution depots, instead of current hypermarkets and big surfaces. From those points, that act as intermediary logistics platforms, two main strategies to deliver the households are possible. In scenario 3, all households are directly delivered by the principle of current household deliveries. In scenario 4, a spread network of reception points were people can take their commands. Those reception points are located at the prorate of the population.

For each scenario, only one type of household supply strategy is allowed (in scenario 1 supermarkets, in scenario 2 proximity retailers, in scenario 3 home deliveries and in scenario 4 proximity reception points.

4. Results and discussion

The proposed scenarios are simulated using the presented method. We also simulate a reference situation, that of Lyon in 2006. For IEM we take into account only the last transport flows (i.e. the direct deliveries to retailing activities, which represent about 20% of IEM). We report the results in Table 1:

Table 1. Main results of simulation

	Km.PCU Last transport IEM	Km.PCU ECM	Km.PCU TOTAL	**CO_2 equivalent**
Reference	2,7 Mkm/week	26 Mkm/week	28,7 Mkm/week	**6150 t/week**
All Hypermarkets	-87%	-3%	-11%	**-16%**
All proximity stores	+90%	-87%	-63%	**-56%**
All home deliveries	-87%	-85%	-85%	**-86%**
All pickup points	-87%	-95%	-93%	**-92%**

The main results show that the decisions in urban planning and the choices of the stakeholders We observe that, in terms of traffic, scenario 1, which seems intuitively a bad scenario, allows however a total saving of about 11% with respect to the reference situation. The main contributor is the IEM family, because delocalising retailing activities in specific points in peri-urban locations has as effect a decrease of the upstream supply-chain costs (because of both the concentration of retailing activities and the fact they are closer to production and distribution activity zones); downstream transport flows have a small decrease, which is explained by the fact that shopping at commercial centres and malls is in general longer in distance but allows a concentration and a decrease of the frequency, which seem to well compensate the distance increase. Scenario 2 has a big impact on both flows, but in an opposing way. Whereas ECM flows decrease highly, IEM ones increase even more. However, since in the reference scenario the considered IEM are about 10% of ECM flows, the total decrease remains interesting (about 63%).

Scenarios 3 and 4 give over-dominate the other two scenarios, obtaining better results for two reasons. The first is that they concentrate all the destination of goods at retailing level in 15 points of the city’s periphery, allowing a good reduction of upstream flows (IEM). Indeed, in both cases, IEM reduction is similar to that of scenario 1. The difference is made in downstream flows (ECM). Scenario 3 allows a reduction of about 85% of road occupancy issues (at both ECM and total levels), whereas Scenario 4 allows a better reduction (95% at ECM level and a global reduction of 93%). Both results are outstanding the other two scenarios and show the potential of e-commerce and proximity deliveries. The main difference is made by the fact that in scenario 3, deliveries are under-optimised with respect to scenario 4 (since home deliveries present still big constraints that do not allow to load the vehicles to the best of their possibilities, which is not the case for reception point deliveries, which the level of goods aggregation is 10 to 20 times higher). In any case, both scenarios (3 and 4) present utopic results that have to be regarded as what they are: the simulation of extreme situations.

In terms of greenhouse gas emissions, we observe slight differences that do not change the essence of the results. The best situation remains scenario 4, and the second best scenario 3, with similar results. Regarding scenarios 1 and 2, we observe that the gains for scenario 2 are about 7% worse than for road occupancy issues, and for scenario 1 about 5% better. This is due to two main facts: the first is that the main contribution to greenhouse gas is made by trucks, which are (for small retailers) old and bad in terms of environmental and greenhouse gas emissions. Moreover, in scenario 2, the main areas of both deliveries and shopping trips are the central parts of the city and the main inhabited parts of the urban area, which have small streets where vehicles circulate a low speeds (and then pollute more than in urban highways). Concerning scenario 1, to reach commercial centres, both trucks and cars prefer using main roads and urban highways, and speeds are higher and more constant, which has a direct impact on reducing CO2 emissions. Although results show that scenario 2 is much better than scenario 1, and both scenarios are extreme, they also show that the bad vision of peripheral retailing areas has to be re-examined to promote a good usage of those structures.

The limits of those analyses are that scenarios are extreme, and non-realistic. They show however the potential of the 4 strategies tested, and show the need of combining them in a way to profit on their synergies to give an equitable offer or retailing in an urban area having a good impact on the environment.

5. Conclusion and further developments

In this communication we proposed four extreme scenarios to analyse the limits of land-use and distribution policies and their impacts on urban goods transport. Via an integrated framework that takes into account both IEM and ECM flow, we have simulated the four proposed scenarios (household supply respectively in (1) peripheral commercial centres, proximity retailers, e-grocery with home deliveries and (4) e-grocery with deliveries to proximity reception points. This is a « physical » approach; in other words, the economic and social costs have not been directly evaluated, focusing on impacts on road occupancy and greenhouse gas emissions. It is important to note that only the last transport to retailers considered, so it will be needed to extend it to all the urban goods movement field. Results show the big advantage of e-grocery strategies, which over-dominate the only retailer location scenarios. However, those scenarios are extreme, and in the case of e-grocery, they are based on a total sharing of logistics, dividing the urban area into zones and having a shared B2C distribution system, which is not realistic nowadays. This shows the potential of e-commerce (mainly e-grocery) if two conditions are met: the first is to combine e-grocery with a good location of logistics facilities; the second a total collaboration with stakeholders to share deliveries and vehicles (in the sense of Gonzalez-Feliu and Morana, 2010 and Gonzalez-Feliu, 2011). New simulations, with a more realistic configuration, need then to be made to state on the potential of those approaches and to find a synergic combination of strategies. Last but not least, it is important to obtain good quality data for both shopping trip and proximity distribution characterization.

Future developments of the proposed research are seen in four direction. The firs concerns Modeling issues for ECM, and consists on completing the STG model with a more coherent distribution model and making it independent of the application situation (in other words, finding a model that can be applied to any context with standard data and calibrating it). The second concerns the scenarios, as stated above, to provide more realistic situations and explore the different combination of strategies. The third is that of socio-economic issues, including in the simulation framework outputs as economic and social costs, rto have a sustainable development vision. The fourth concerns proximity deliveries simulation, and aims to provide more realistic simulations at both distribution system organization and consumer's behaviour. A first simulation has been made (Durand et al., 2010) and will be completed and extended.

References

[1] Ambrosini, C., Meimbresse, B., Routhier, J. L., Sonntag, H. (2008), Urban freight modeling: a review. Innovations for city logistics, Nova Science Publishing Inc, 197-212.

[2] Anderson, S., Allen, J., & Browne, M. (2005). Urban logistics—how can it meet policy makers' sustainability objectives?. *Journal of Transport Geography*, *13*(1), 71-81.

[3] Crainic, T.G. (2008), City Logistics. In Chen Z.L., Raghavan S., (eds.), *Tutorials in Operations Research 2008. State-of-the-Art. Decision Making Tools in the Information-Intensive Age*, INFORMS, e-book, pp. 181-212.

[4] Durand, B., Gonzalez-Feliu, J., Henriot, F. (2010), La logistique urbaine, facteur clé de développement du BtoC, *Logistique & Management*, vol. 18, n. 2, pp. 41-53.

[5] Gerardin Conseil, LET (2000), *Diagnostic du Transport de marchandises en ville dans une agglomération*, DRAST.

[6] Gonzalez-Feliu, J. (2008), *Models and Methods for the City Logistics – The Two-echelon Capacitated Vehicle Routing Problem*. PhD. Thesis. Politecnico di Torino, Turin, Italy.

[7] Gonzalez-Feliu, J. (2011), Cost optimisation in freight distribution with cross-docking: N-echelon location routing problem, *Promet – Traffic & Transportation*, to appear.

[8] Gonzalez-Feliu, J., Henriot, F., Routhier, J.L. (2009a), Estimating traffic flows and environmental effects of urban commercial supply in global city logistics decision support, *IV*

International Workshop on Freight Transportation and Logistics, ODYSSEUS 2009, Izmir, Turkey.

[9] Gonzalez-Feliu, J., Henriot, F., Toilier, F. (2009b), Urbanisme commercial et approvisionnement des ménages : Impacts sur la mobilité de quatre scénarios extrêmes, *Atelier Transport et Logistique : histoire(s) de durabilité*, Marne La Vallée, 17 septembre.

[10] Gonzalez-Feliu, J., Morana, J. (2010), Collaborative transportation sharing: from theory to practice via a case study from France. In Yearwood, J.L. and Stranieri, A. (eds.), *Technologies for Supporting Reasoning Communities and Collaborative Decision Making: Cooperative Approaches*, Information Science Reference, Hershey, to appear.

[11] Gonzalez-Feliu, J., Toilier, F., Routhier, J.L. (2010), End consumer movement generation in French medium urban areas, *Procedia Social and Behavioral Science*, to appear.

[12] Quak, H. (2008). *Sustainability of urban freight transport: Retail distribution and local regulations in cities* (No. EPS-2008-124-LIS). Erasmus Research Institute of Management (ERIM).

[13] Russo, F., Comi, A. (2006), Demand models for city logistics : a state of the art and a proposed integrated system. In Taniguchi, E., Thompson, R.G. (eds.), *Recent Advances in City Logistics*, Elsevier, Amsterdam, pp. 91-105.

[14] Segalou, E., Ambrosini, C., Routhier, J.L. (2004), The environmental assessment of urban goods movement. In Taniguchi, E., Thompson, R.G. (eds.), *Logistics Systems for Sustainable Cities*, Elsevier, Amsterdam, pp. 207-220.

[15] Taniguchi, E., Thompson, R. G., Yamada, T., & Van Duin, R. (2001). *City Logistics. Network modelling and intelligent transport systems*, Pergamon, Amsterdam.

[16] van Binsbergen, A., & Visser, J. G. S. N. (2001). *Innovation steps towards efficient goods distribution systems for urban areas*. DUP Science, Amsterdam.