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New trends on urban goods movement: modelling and simulation of e-commerce distribution

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Abstract

In this paper, a modelling framework to complete the recent scientific works on urban goods modelling is proposed. More precisely, we introduce a substitution procedure that estimates the number of trips and the corresponding travelled distances for shopping drive, home delivery and reception points' strategies. Moreover, an appraisal of scenarios is proposed in order to study how these three new forms of proximity delivery services impact on the overall urban goods movement distribution. Starting from four extreme situations, we introduce more realistic scenarios in order to find a suitable combination of delivery strategies. All the scenarios are simulated using the proposed framework, and the main traffic issues related to e-commerce distribution channel are discussed. The best realistic combination promotes the joint usage of home deliveries and proximity reception points and allows a reduction of about 13% of the road occupancy rates in urban areas.

Keywords: urban goods movement, modelling, shopping trips, e-commerce.

Introduction

In the last decades, city logistics has been developed to deal with the main problems of urban freight distribution, studying freight movements in urban areas and proposing solutions to reduce congestion and pollution as main problematics (Crainic, 2008; Danielis *et al.*, 2010). Recent studies have defined and characterised the different movements of urban goods (Patier, 2002; Ségalou *et al.*, 2004; Russo and Comi, 2006). Two main approaches have been proposed for urban freight modelling: in classical modelling approaches, these movements are related to a quantity of goods (Sonntag, 1985; Ortuzar and Willumsen, 2001). However, the vehicle trip seems to be a better unit for modelling approaches which consider at once freight and passenger transportation, insofar as congestion, pollution and other problems derived from interactions between the freight distribution and the transport of people can be related to the public road sharing by the vehicles involved in both types of transportation (Routhier and Aubert, 1999; Patier, 2002; Rosini, 2005).

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The urban goods movement (UGM), commonly identified with the freight distribution flows in urban areas, is not limited to retailing supply flows as many authors defined it at the beginning of the XXIst century (Woudsma, 2000; Taniguchi et al., 2001) but includes several categories (Patier, 2002; Ségalou et al., 2004; Russo and Comi, 2004; Gonzalez-Feliu et al., 2010a). The main types of urban goods are the following:

- *Inter-establishment movements* (IEM) or classical freight distribution flows in urban areas. They represent about 40% of the total km.PCU[1] of UGM.
- *End-consumer movements* (ECM) commonly identified with shopping trips. In the last decade, other flows have been included in this category, like those derived from home deliveries, reception points or other B2C and C2C movements. Their share with respect to the total number of km.PCU of UGM is about 50%.
- *Urban management movements* (UMM), related to public infrastructure maintenance, building works, waste management and other urban space management functions. They represent about 8% of the total km.PCU of UGM.
- *Postal and express parcel delivery services* represent 1% of the total km.PCU of UGM.
- *Other flows* (less than 1% of the total km.PCU of UGM).

We intend to take a particular look at end-consumer movements and more precisely to the relation between classical shopping trips and other forms of B2C flows. The aim of this paper is to present the last trends on urban goods modelling and to propose a procedure used to replace shopping trips by other distribution approaches, like home delivery services or proximity reception points. In the second section, a brief overview on simulation models for UGM used in European cities is presented. In the third section, the simulation procedure is described. Then in the fourth section, both the overall model including the various categories of urban goods is detailed and the proposed scenarios are presented. Finally, the simulation results are given and commented, in order to study the impact of the proposed scenarios on urban goods mobility.

Literature review

Most of the modelling approaches in Europe have been developed in Germany, Italy and France (Ambrosini *et al.*, 2008). We propose a brief review on the main models that have been applied to cities in Europe, taking into account the various categories of urban goods.

In Germany the first approach to calculate UGM on the basis of an O/D model for a complete region with 300 zones was made by Sonntag (1985) and is known as the WIVER model. Developed to produce O/D matrices for the road-based UGM and other commercial related activities, WIVER is a behaviour-oriented simulation model, able to consider explicitly the complexity of urban trip chain pattern. Therefore, the model can focus on four types of vehicle classes. The calculation of the O/D matrices consists of a four step analysis:

1st step Tour and stop generation: calculation and/or description of the number of tours; number of stops per tour; tour purposes per branch, vehicle type, and zone. This volume can be further divided by traffic volume per zone (origin and destination).

[1] Private Car Unit, defined as follows: 1 private car = 1 PCU; 1 light goods vehicle = 1.5 PCU; 1 lorry = 2 PCU; 1 articulate veh. = 2.5 PCU.

2nd step: Single-trip O-D settings: determination of the destinations and modelling of the O-D interactions and single trips.

3rd step: Routes construction: their simulation is got by trip chain aggregation. The combining of trips to a tour is steered by a "savings function" (Ambrosini et al., 2008).

4th step: Assignment: each traffic volume and its related distribution are allocated into hour groups.

WIVER is suited to model or urban goods movements, providing information regarding total mileage, number of trips and tours, daily traffic distribution over time, subdivided into vehicle type and economic sectors. Furthermore, the relations between origins and destinations in terms of routes or single trips can be modelled. The model has also been used in several German and European traffic planning processes, like Hamburg 1993, Berlin 1994 (Sonntag *et al.*, 1995), Berlin 1998 (Meimbresse *et al.*, 1998), Hansestadt Rostock 1999, Berlin 2000 (Ambrosini *et al.*, 2008) and within the framework of the COST 321 co-operative action (Urban Goods Transport) for the cities of Munich, Nuremberg, Augsburg, Hanover and Trier, as well as the European project REFORM (research on freight platforms) for the metropolitan areas of Rome, Madrid and Brussels (Ambrosini et al., 2008).

Using the main approach of WIVER, Lohse (2004) developed a model called VISEVA - W to compute simultaneously and interdependently the traffic volumes of different branches and vehicle types, for both people and goods related trips. The model starts with rates for mobility, modal split and affinity to vehicle classes/transport modes (behavioural data) as well as spatial data of the involved traffic zones, networks and conditions. After the generation of O/D relations the trip generation is calculated on the basis of a series of interdependent equilibrium formulas. By this, the model avoids the complex process of calibrating the savings functions used in WIVER.

Another approach is that of IVV Aachen, a company that included a "goods and special transports" model in their urban transport planning software VENUS (Janssen and Vollmer, 2005). This model is also differentiated by vehicle types but the differentiation of the trip reasons is based on "trip purposes" e.g. industry-trade connections, trade-end user. The approach originates clearly from the calculation of individual traffic. The trip distribution is carried out by a gravitation model. The modal split (only for commercial used cars) is based on network and spatial resistance. Available time budgets, daily courses, distribution of stop time lengths and number of stops are used for the generation of trip chains.

In France the urban freight model FRETURB has been developed by the LET, (Routhier *et al.*, 1999, 2007). It is a land use and tour-based model of urban goods transport. It consists of three modules which interact with each other:

- a "pick-up and delivery model" including commodity flows between all the economic activities of a town;
- a "town management module", consisting of transport of goods and raw material for public and building works, urban networks (sewers, water, phone), and removals;
- a "purchasing trips model", modelling shopping trips by car (that represents the main last kilometre trips to consumers).

The pick-up/delivery model is a regression-based model fed by thorough coupled 4,500 establishments and 2,200 drivers surveys carried out in three different sized towns. Those surveys brought to light relevant relationships between the behaviour of the shippers (spatial and economic data) and the behaviour of the hauliers (operations of transport). The modelled data is the movement of goods (defined as a delivery or a pick-up associated to a given establishment, vehicle size, mode of management and logistic behaviour). It is derived from the empirical survey data resulting from statistical validation. The average number of truck movements (deliveries/pick-ups) is a function of 45 industry types *a*, the nature *p* of the premises (store, warehouse, office, headquarter) and the number *o* of jobs of the establishment. With the help of the national public registers of establishments, each zone is informed about the various types of generators according to its size (number of jobs) and its industry category.

As regards the flows distribution, the aim is to build a non-oriented O-D matrix of goods transport. A macro-network is performed between the centroid of the zones. The average speed on each link between adjacent zones depends on a density indicator (average of population and employees of zones *i* and *j*) and on the road performance between *i* and *j*. A typology of routes is performed (25 types) in order to match the delivery stops of each zone, according to the type of vehicle, the type of connecting trip, the type of operator (public transport, haul by forwarder or consignee) and the number of stops of the round. An average distance and an average time are allocated to each type of trip. The choice of the itinerary is obtained by the "shortest path" Dijkstra algorithm. A probabilistic method is implemented in order to calculate the distribution of the flows between *i* and *j*. At last, a trip assignment can be carried out in order to calculate the total distances for a given state of the network. Since 1995 the model has been increasingly improved. It has been available as software since 2000 and is implemented in about 20 French towns (among which Paris, Lyon, Lille, etc.).

The purchasing trip module has been developed in various phases. The trip generation (Ségalou, 1999a; Gonzalez-Feliu *et al*., 2010a) is obtained by linear regression from survey data on several French cities, for each shopping destination zone. The main factors that influence trip generation are the population, the number of commercial activities of each zone (per type), the presence of a peripheral commercial centre, and the motorization rate. The part of the private car in the total trip generation is also calculated. Then, a catchment area (Gonzalez-Feliu *et al.*, 2010b) relates each destination zone with the potential household locations, using a probabilistic gravity model based on the work of Ségalou (1999b).

The town management module models the transport flows related to goods and raw materials for public and building works, urban networks maintenance (sewers, water, phone) and removals. This is made using surveyed and estimated data using an empirical procedure (Routhier and Toilier, 2007).

In Italy, Russo and Carteni (2006) propose a regional modelling procedure based on the simulation of the dependence existing between successive trips of the same distribution channel. They make the distinction between trip-based and tour-based modelling. In the first case, the choice for each trip between two transhipments is independent of the choice carried out for other possible trips belonging to the same journey. In the second case, the choice for each trip affects the other trips belonging to the same journey. The authors have a preference for the tour-based modelling approach. The proposed freight distribution model consists of three macro-models:

- The Distribution Strategy Model (DSM) determines the trips set for a given distribution channel strategy. For each manufacturer market and customer market, a distribution channel is chosen, as well as the logistics schema related to it (e.g. manufacturer-logistic centre-wholesaler-retail-customer),
- The First Trip Model (FTM) simulates the choice of the first transit destination d1, of the loading unit u1, of the departure time h1 and of the freight mode m1,
- The Subsequent Trip Model (STM) simulates the choice of the various subsequent trips and the related freight modes from each trip destination.

Those three models are specified by a nested logit model which brings into play various local socio-economic data (time, population, employment, number of firms of each zone, …). According to loading units' o-d_i demand, a loading unit choice model allows to convert tons/year to vehicles/day. The aggregated data from a transport national count (2001) demand matrix by province and 41 traffic counts (2002) is used for calibration of the demand function and of the assignment matrix estimation for each loading unit. This model was applied for the simulation of freight distribution within Campania region (gathering 5 provinces of Southern Italy), comprising a total of 551 municipal districts, with 62,516 firms. The model system allows an estimation of: the origin-destination choice probability matrices, the O-D freight matrices referred to a fixed period time, the vehicle link flows on the network through an assignment model.

In order to integrate the consumer behaviour in the supply chain, Russo and Comi (2004) propose a conceptual analysis of the end-consumer movements between the shops zone (d) and the consumption zone (o) on the one hand, and the inter establishment movements between retailers and warehouses (w) (re-stocking) on the other hand. This approach is useful to analyse freight mobility in a global planning process in two parts. The first one is carried out by a round trip or a trip chain. The second one is performed through a supply chain or tour-based approach. The authors propose a model structure, at a commodity level, divided in an attraction macro-model which concerns the demand in freight quantity for each o-d (end-consumers) and an acquisition macro-model concerning the demand in freight quantity for each d-w (retailers and warehouses). The latter consists of a channel choice model (probability to choose a channel to bring freight for restocking in zone d and a stock model (probability that a retailer take the freight sold in his shop, arriving from the zone w).

Russo and Comi (2010) extend their analysis adding modules to the modelling system in order to convert goods quantity flows into freight vehicle flows. At this level are distinguished: - a service macro-model, which receives as input the demand in quantity for a macro-area and gives as output quantity for each consignment, zone and vehicles needed for restocking; - a path macro-model, which receives as input the demand in vehicles and gives as output the departure/arrival time and path used. Both models belong to discrete choice theory and implement random utility functions.

At the present time, the proposed modelling system has been recently calibrated from end-consumers' and retailers' surveys. An end-consumer survey was carried out for durable and non-durable goods in Giarre (30,000 inh. and about 700 retailers in southern Italy). About 450 end-consumers were interviewed and the gathered information was about the goods consumed by end-consumers, purchase trips and size of purchases, as well as socio-economic characteristics (residence, composition of the household, gender, etc.) and characteristics of purchase trips (round trip or trip chain, purchase zone, freight types, time spent in a shop before purchase, dimension of purchase, etc.).

A retail survey consisting of more than 1,000 interviews of retailers (retail shops and supermarkets) was carried out in Reggio Calabria (180,000 inh. in southern Italy) and in Palermo (800,000 inh. in southern Italy). The interviews allowed to discern some characteristics determining the choice of distribution channels, acquisition macro-area, acquisition zone, vehicle and target time, as well as general information like shop location and size, main types of goods sold, number of employees, average number of customers per day and week, storage availability, etc. Moreover information has been collected about restocking trips (own account or not, getting through a warehouse or not, quantity of goods required per restocking trip, vehicles used, etc.). Notably about 48% of interviewees choose to restock on their own account, 49% choose a third party and the remaining 3% use both possibilities.

According to the authors, the current modelling structure is easily adaptable in order to consider the possibility of e-commerce. Furthermore, it allows passenger mobility to be considered and end-consumer choices to be linked with those of other decision-makers.

Two applications of the methodology proposed above can be found in Nuzzolo *et al.* (2010a) and in Filippi *et al.* (2010). Thus, the end-consumer model of Russo and Comi (2010) is combined with the inter-establishment model proposed by Nuzzolo *et al.* (2010b).

In Filippi *et al.* (2010), the main goal is to implement the above methodology for ex-ante assessment of the effects of freight transport in urban areas. The focus is the assessment of pollutant emissions and the application is carried out on the inner urban area of Rome. It shows that an urban distribution centre can be more effective in reducing environmental externalities than policies based on vehicle fleet renewal.

In Rome, the methodology was applied to test four different scenarios: - no public intervention and a vehicle demand growth of +1.6% (current trend) (SC0); - intervention and enforcing control for access to pre-Euro vehicles and for parking (SC1); - access prohibition to vehicles that do not comply with the Euro 2 standards and market entry of Euro 5 standards (SC2); - previous scenario (SC2) with creation of an Urban Distribution Centre (SC3).

It appears that the effect of non-intervention (SC0) increases CO_2 emissions and the same (slightly less) happens in the case of SC1. The best savings come from the introduction of a multi-company urban distribution centre (UDC): about a 15% decrease of vehicle-km and about a 24% reduction in terms of CO_2. Beyond these results, the study puts forward a 26% drop in the external costs in case of UDC, from the public authority point of view.

The authors point out that the methodology proposed could be further developed in the near future with a micro-simulation traffic module. The simulation of the driving cycle in real traffic conditions would increase the accuracy of the estimates of the pollutant emissions.

Nuzzolo *et al.* (2010b), focus on the implementation of ex-ante assessment procedures to estimate the effect of city logistics scenarios in order to reduce the impacts of freight transport. For this purpose, the availability of a reliable tool for ex-ante assessment plays a key role in the decision making processes. In that way, the paper identifies the decision-makers, whose choices could be influenced by city logistics measures. The latter are also classified in such a way that it would be possible to define the decisional processes influenced by city logistics measures, that models have to simulate. The presented system allows forecasting the O/D truck flows within a study area and consists of two sub-systems: one related to the demand which gives the O/D matrices in terms of deliveries, the other, related to the logistics, permits the conversion of the delivery O/D flows into truck O/D flows. The modelling framework consists of two models that allow reproducing the commercial vehicle tours within the urban area. The former model gives the distribution of tours per number of deliveries and the latter gives the probability to choose the following destination for the next delivery.

An application of this model has been implemented in the city of Rome and provides some results. For instance, third-party freight flows amount to 31%, receiver own account to 20% and shipper own account to 49%. On average, whatever the type of goods carried and the management mode, the share of light goods vehicles (LGV) is 60% versus 40% for medium goods vehicles (MGV). The average number of stops in a tour fluctuates according to the management mode: for third-party (2.2 for LGV and 4.2 for MGV), receiver own account (1.5 for LGV and 2.8 for MGV) and shipper own account (1.6 for LGV and 3.0 for MGV).

Also in Italy, Gentile and Vigo (2006) propose a prototype demand model that has been applied to several cities of Emilia-Romagna. According to the authors, the model deals with two main questions. The first takes place when a given activity (a fortiori a given zone) generates movements belonging to different supply chains, and the second when a vehicle performs several deliveries or pick-ups in a tour. This model is able to estimate the yearly number of operations generated by each zone, following a sequential procedure similar to the well-known four steps model for the transport of people.

This model has shown a similar construction process as FRETURB, i.e., a simultaneous surveying-model architecture development (Rosini, 2005). In the years 2003-2005 an extensive survey of City logistics was carried out for all cities of Emilia-Romagna according to the same survey model (Rosini, 2005). Three main surveys: demand generation, attraction, flows per operation. This is a unique opportunity for modelling.

The demand generation is using directly the Italian standard classification of activity units (establishments). The main hypothesis is that logistic characterisation of towns is based on the construction of a "Zone-Supply Chain" grid (ZS matrix). The model explicitly uses a fine grained classification system of local units (establishments). Each Supply Chain (SC) is defined in accordance with a classification tree of the NACE. The overall model defines the total number of operations of a SC as a function of the NACE code and the number of employees in each establishment. Survey data are used to calibrate the model and to obtain the distribution of parking time, time of service, etc. for each SC. Supply chains are: fresh, dry, frozen foods, garments and other stuff. A Supply Chains generation matrix is calculated in various cities of Emilia-Romagna. The distribution and network assignment model has been tested recently (Gentile and Vigo, 2007). The preliminary results are of good quality and the model is easily transferable to different towns without specific additional surveys, like in the French Freturb approach from which it is inspired. The model has been calibrated using the rich database of Emilia-Romagna Region, which resulted on a set of models for different city typologies, from small to middle size with various urban structures. As a consequence, the CityGoods software has been implemented and is currently used by the regional authority.

All these models have been developed and calibrated using real data supplied by specific surveys (Ambrosini and Routhier, 2004). Moreover, these models are used by public local authorities for diagnosis and near-future estimation of urban goods movement and their relation to urban land use. However, they have not been developed to take into account the new distribution channels like those derived from e-commerce practices, because these channels are continuously evolving and few standard data related to them is available.

Concerning e-commerce, several studies have been carried out in the recent years. The most of them are related to consumer's choice or marketing and ergonomic aspects of web-based business (Rohm and Swaminathan, 2004). In supply chain management works, home deliveries have been simulated following two main approaches. We will briefly present those related to e-grocery, which potential to reduce the global nuisances of the urban freight transport has been commented in recent researches (Durand, 2010). On one hand, optimisation approaches, of which the most of them are related to the operational research (Kämäräinen, 2003; Punakivi *et al.*, 2003; Taniguchi and Kakimoto., 2003; Nemoto, 2004), are based on route construction procedures issued from combinatorial optimisation heuristics (Toth and Vigo, 2002; Golden *et al.*, 2008). These procedures take into account some of the specificities of home delivery services. On another hand, existing operations simulation approaches are empirical and based on econometric models or GIS-based data collection procedures (Cairns, 1998; Alligier, 2007). The first approach is more suitable for simulation since it can be adapted to hypothetical different situations but do not take into account the social acceptance of some solutions. The second one is more related to real practices, notably in the social field, but simulation implies that these practices do not change.

The other e-commerce distribution channels have been conceptualised recently in supply chain management (Paché, 2008), especially those related to reception points and store picking (shopping drive). However, these studies deal with managerial and strategy questions and are not related to route simulation (Durand, 2010).

The proposed method

As we have seen above, the most studied flows in urban goods movement modelling are inter-establishment movements. Moreover, some end-consumer movement models have been developed to estimate only shopping trips. Because new forms of B2C services are proposed in urban areas, we highlight the need of taking them into account in an integrated simulation approach. In this section we propose a method to empirically estimate the effects of e-commerce delivery routes in terms of km.PCU.

This method needs to refer to both IEM and ECM models, since it makes possible the interaction between them and simulates the substitution of both categories of movements by new flows related to other B2C flows. For this purpose, four types of end-consumer trips can be defined. The most known and common is traditional shopping, simulated by ECM models. Moreover, we can define three distribution channels *ch* for e-grocery and teleshopping services. These services allow the consumer to command the purchased goods in advance. However, the upstream and downstream supply schemas can change with respect to traditional store supply. In this study, we will consider the following channels:

1. Shopping drive services, where commands are prepared in supermarkets or hypermarkets without major changes on their supply strategies, then it is picked up by the consumer by car, avoiding queues and waiting times. With this service,

the shopping transaction is made virtually, but picking of the product is directly made in a supermarket or a hypermarket, mainly in periphery, by the final consumer (Routhier *et al.*, 2009).

2. Home deliveries, where commands can be prepared on a store without changing its supply strategy, or in a specific depot or warehouse, with important changes in one or more supply chains (Durand, 2010). In both cases, the ordered products are delivered to the consumption place using light goods vehicles.
3. Proximity depots, where the supply changes change to include the new proximity reception points. In these services, the ordered products are delivered to reception points near the consumption place in which they are picked up by the final consumer (Durand *et al.*, 2010).

The proposed method is a sequential algorithm that estimates the flows to be substituted by each new distribution channel then it affects to each of them its corresponding trips. First, a generation phase will calculate the number shopping trips to substitute. Second, the freight quantities associated to these trips are estimated on the basis of specific surveys made on French medium and big cities (Patier and Routhier, 2009). Then, in parallel, both IEM and ECM are simulated to substitute the flows that use other channels as detailed below. Finally, the total number of km.PCU is estimated for each section of the study.

Definitions and notation

Given a geographical zone Z (mainly an urban area), divided in *n* sections. Each zone *i* is characterised by the number of trips that it generates at origin (retailers) and destination (households), respectively for IEM (T_i^{IEM-E}, T_i^{IEM-A}) and ECM (T_i^{ECM-E}, T_i^{ECM-A}) categories. Also the O/D matrix is known for both categories, noting each trip between section *i* and section *j* $T_{ij}^{IEM}, T_{ij}^{ECM}$ respectively.

For each channel *ch*, an average channel share CS_i^{ch} is defined as the percentage of the population that uses channel *ch* for shopping purposes in retailing activities located at section *i*. These constants depend on the category of urban space (Gonzalez-Feliu *et al.*, 2010a). Three types of urban area are taken into account, following the definition of Gonzalez-Feliu *et al.* (2010), defined as follows: the main urban area, known as *central urban area* in this study, contains the main city of the urban region and sometimes other urban suburbs which can be assimilated to the main city, because of a continuity of the urban landscape. The cities of the *near periphery* are the urban zones close to the central urban area, and are usually identified with the first ring. The rest of towns of the extended urban community belong to the *far periphery*.

Moreover two modal practices are defined. The shopping trips that contribute directly to congestion and pollution are essentially those made by private cars. So, we note them with the index *PC*. The rest of the trips are aggregated under the tag *O*. In order to set the hypotheses for the substitution of the flows for each of these categories, we define a modal share (respectively $MS_i^{PC\,ch}$ and $MS_i^{O\,ch}$ for private cars and all other modes) as the percentage of usage for each of the two mode categories.

After that, we can define for each channel the number of shopping trips that will be substituted by the corresponding B2C flows, noted N_{ij}^{ch} and defined as follows:

$$N_{ij}^{ch} = CS_i^{ch}.MS_i^{PC\,ch}.T_{ij}$$

Substitution procedures

After calculating N_{ij}^{ch}, two phases are simultaneously launched. One is the substitution procedure for upstream flows (the last mile for the supplying of retailing activities), which concerns only the impact of home deliveries and proximity reception points. The other substitutions concern the downstream flows for all channels.

Upstream flows

When using home delivery services and proximity reception points, the last mile flows for each retailing activity are modified. The new distribution schemes are simulated in the downstream flows phase. However, these flows partly substitute some inter-establishment movements. In order to make this substitution, we need to estimate the quantity of goods that is distributed by these channels. To do this, we define the total load L_i^{ch} as the total quantity of goods purchased at section i to be substituted by channel ch. This load is proportional to the number of trips $N_i^{ch} = \sum_j N_{ij}^{ch}$. According to the preliminary studies of Henriot and Routhier (2010), the following Table 1 has been established:

Table 1: Average quantity of freight per worker, according to the category of shop (in kg)

Type of retail establishment	**Weight by worker *(kg weekly)***
Hypermarket (>2000 m²)	1560
Specialised department store	466
Supermarket (>400 m²)	580
Minimarkets	535
Clothing shoes and leather	152
Butcher’s	395
Groceries, alimentation	553
Bakeries	554
Café, hotels, restaurants	64
Pharmacy	101
Hardware	161
Furniture	192
Stationer’s bookseller’s	479
Other	115
Non sedentary	451

Table 1 comes from the large urban goods movement surveys carried out in France. The average quantity of freight for each shopping trip depends on the category of shops and of the mode choice for shopping (car vs. other modes). The weight average per shopping trip is got by the ratio between the total weight of goods delivered in town and the total number of shopping trips as showed in table 2.

Table 2: Average quantity of freight per worker, per shopping trip and category of shop (in kg)

Category of shops	Weight average / worker per day	Weight average / shopping trip
Small shops (<400m²)	35	5,8
Great Distribution (>400m²)	200	11,9

The substitution of the shopping trips from car channel towards other channels has different impacts on the part of upstream supplying of the retailing activities.

Drive: The substitution of traditional car shopping trips to drive shopping trips has no impact on the upstream channels, because the number and the location of the shops do not change.

Home deliveries and reception points: The increase of home deliveries results in a decrease in the number of retail shops. The substitution is based on the weight of the delivered goods and on the average weight of the home deliveries or reception point deliveries.

Downstream flows

The downstream flows are estimated using different methods according to each channel.

Drive: Only supermarkets and hypermarkets are considered for drive schemas, since proximity retailers provide services, which are closer to proximity reception points. From the current shopping practices (Gonzalez-Feliu *et al.*, 2010a), we can estimate the travelled distances for supermarket or hypermarket shopping by private car. In this way, the distance d_{ij}^{drive} is defined as the travelled distance by car between *i* and *j* for shopping drive purposes. Then, the total travelled distance D_{ij}^{drive} for shopping drive between *i* and *j* is estimated as follows:

$$D_{ij}^{drive} = N_{ij}^{drive}.d_{ij}^{drive}$$

Home deliveries: To simulate home delivery distribution trips, we need to characterise the corresponding routes. So we followed the results of Alligier (2007), which characterised several home delivery services and their corresponding routes. We have synthesised these results into three categories (see **Table 3**). The simulation is then made empirically, following current practices.

The substitution needs to define the number of orders (i.e. the total number of delivery points for home delivery services). Not all shopping trips made by private car are related to big quantities of goods. For this reason, not all these trips will result in a home delivery order. From current practices (Alligier, 2007; Durand et al., 2010), we suppose that 60% of the trips are substituted by one order, whereas the rest will be substituted applying a 3/1 ratio (i.e., 3 shopping trips will be substituted by 1 home delivery order):

$$NO_{ij}^{HD} = N_{ij}^{HD}.0{,}6 + \frac{N_{ij}^{HD}0.4}{3}$$

In this formula we assume that the generalisation of the home delivery services implies a decrease in supplying costs and a decrease in the average weight per order of home delivery:

Once the number of orders NO_{ij}^{HD}, between *i* and *j*, has been determined, the number of delivery routes T_{ij}^{HD} are simulated as follows:

$$T_{ij}^{HD} = \left\lceil \frac{NO_{ij}^{HD}}{n_z^{HD}} \right\rceil$$

where n_z^{HD} is the number of points of a home delivery route in an urban space of category *z*.

The travelled distances are then estimated from Alligier's surveys, and are synthesised in **Table 3**: $D_{ij}^{HD} = T_{ij}^{HD}.d_Z^{HD}$

Table 3: Main characteristics of home delivery trips in each category of urban area (synthesised from Alligier, 2007)

	Central urban area	Near periphery	Far periphery	Average
Composition – individual housing	5%	25%	60%	30%
Composition – collective housing	95%	75%	40%	70%
Tour - Number of delivery points n_z^{HD}	8	12	11	10.3
Tour - Average speed	11 km/h	16 km/h	25 km/h	17.3 km/h
Tour - Average distance d_z^{HD}	17 km	36 km	80 km	44.3 km

Reception points: Proximity depot picking is simulated in a similar way than home deliveries. The characteristics of the routes are obtained by using the FRETURB model (Routhier and Toilier, 2007) on a category of shop simulating a small retailer acting as a reception point service. Because reception points are near the final customer, both big and small quantities are ordered. For this reason, each shopping trip being substituted by a reception point service is transformed into an order.

First, the number of delivery routes is estimated as follows: $T_{ij}^{RP} = \left\lceil \frac{N_{ij}^{RP}}{n_z^{RP}} \right\rceil$.

Second, the travelled distance for reception point distribution is calculated by:

$$D_{ij}^{RP} = T_{ij}^{RP}.d_Z^{RP}$$

Finally, the private car shopping trips are estimated using the model of Gonzalez-Feliu *et al.* (2010b).

Table 4: Main characteristics of reception point deliveries in each category of urban area

	Central urban area	Near periphery	Far periphery	Average
Composition – individual housing	5%	25%	60%	30%
Composition – collective housing	95%	75%	40%	70%
Tour - Number of reception points	16	20	20	18
Tour - Average speed	11 km/h	16 km/h	25 km/h	17.3 km/h
Tour - Average distance d_z^{RP}	60 km	75 km	115 km	90 km

Traditional shopping trips distance estimation: Existing shopping trip estimation models can give us both the number of trips and the total distance travelled by each O/D pair, before the substitution phase takes place. After estimating the total number of trips to be substituted, the rest of trips correspond to traditional shopping trips. In order to estimate the distances of these trips, we estimate the average distance travelled from section *i* to section *j* by private car as $d_{ij}^{PC\,small}$ and $d_{ij}^{PC\,big}$, respectively for small-medium retailers and supermarkets-hypermarkets. The total distance D_{ij}^{s} corresponding to the trips that are substituted can be estimated as follows: $D_{ij}^{s} = D_{ij}^{s-small} + D_{ij}^{s-big}$

where: $D_{ij}^{s-small} = d_{ij}^{PC\,small} . \sum_{ch} N_{ij}^{PC\,ch}$ and $D_{ij}^{s-big} = d_{ij}^{PC\,big} . \sum_{ch} N_{ij}^{PC\,ch}$

Relations with the existing models

The proposed methodology has been developed in order to be included and adapted to complete the existing urban goods models. Current models can feed the substitution procedures presented above. The required data to use the substitution procedures are:

- Geographical data (used also in urban goods models)
- IEM flows (given by models like those of Meimbresse et al., 1998; Russo and Carteni, 2004; Gentile and Vigo, 2006; Routhier and Toilier, 2007).
- ECM flows (given by models like those of Ségalou, 1999a,b; Lohse, 2004; Russo and Comi, 2004, 2010; Gonzalez-Feliu et al., 2010a,b; Nuzzolo et al., 2010).
- The channel share and the modal share for each channel defined above(this parameter is assumed by the user). These parameters, as well as other assumptions, will depend on the implemented scenario(s).

With this data, the substitution procedures estimate the flows corresponding to the new distribution channels. The proposed methodology is the easy to adapt to the existing models. In order to illustrate these connections, a chart is presented in Fig. 1. Given the scenario input data, an inter-establishment movement model feeds the substitution procedure with these flows (aggregated by Origin-Destination pair), then in an analogous way, a shopping trip estimation model feeds the procedure with the corresponding flows. Then, using the equations presented above, the different categories of flows to be substituted are defined. Using the substitution procedure, each channel's movements are estimated. Finally, the remaining shopping trips are calculated and all the flows are integrated.

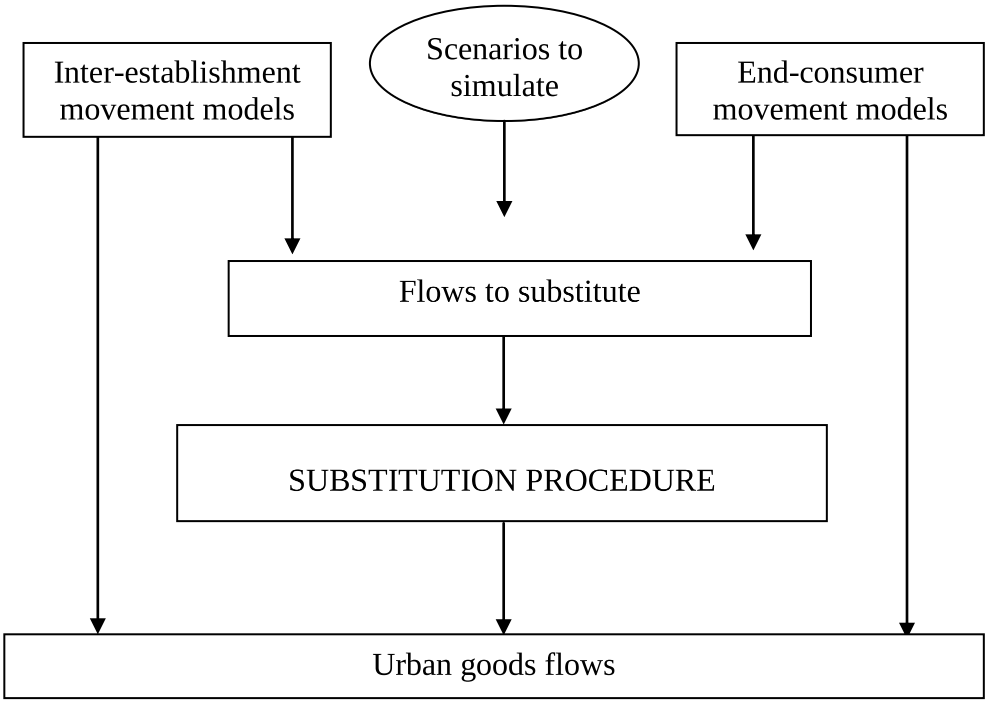

Fig. 1: chart of the integrated simulation procedure

Beyond the relations presented above, two other connections with the existing frameworks can be considered:

- For the existing models, these procedures allow to include a scenario simulation component by providing a key breakdown for substitution.
- For the proposed method, the relation with other models allow to complete and/or to update the assumptions and parameters concerning the new distribution channels. Indeed, the existing models can be used to estimate new route organisations by adapting their route construction algorithms to the new channels proposed in our method.

Global simulation and proposed scenarios

The proposed system urban goods movement simulation approach

The proposed simulation method integrates two urban goods movement models, included into the FRETURB framework, and the substitution procedure described above. From the input data, the inter-establishment flows module (Routhier and Toilier, 2007) calculates the vehicle flow exchanges between zones for freight distribution and collection, and gives to the traditional shopping trip module (Gonzalez-Feliu *et al.*, 2010b) the retailing composition of each section (in number of stores and employees, by type of commercial activity). This module estimates private cars shopping trips. After that, the shopping trips that have to be substituted are estimated using the new substitution procedure. All these flows are then integrated in order to calculate the total number of km.PCU for freight-related vehicle trips, to calculate the congestion level. We use the inter-establishment flows and the traditional purchasing flows modules in order to simulate respectively the inter-establishment and the end-consumer flows.

Reference and real data for simulation purposes

In order to simulate several scenarios we have chosen the urban area of Lyon (France). In 2006, this urban area was consisting of about 2.000.000 inhabitants and 800.000 households. In order to build a reference scenario, we worked on the following databases: the register file of companies (SIRENE file) of the chosen area, the corresponding census database (INSEE file), and the 2006 household trip survey (EML-2006 file), which follows a French standard (CERTU, 2008). In this survey, the urban community of Lyon is divided into several small zones, grouped into macro zones. The reference scenario (S0) is directly based on this survey data.

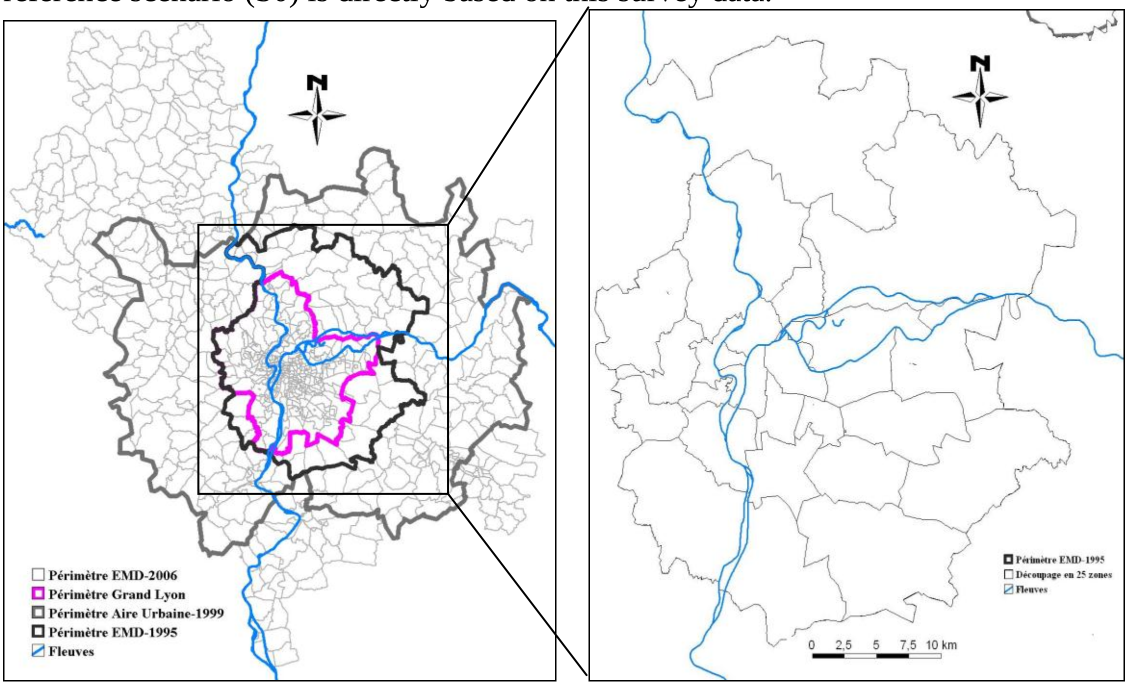

Fig. 2: Maps of the Lyon urban area and the considered zones (Bouzouina et al., 2010)

The channel shares for the reference are the following: we assume that e-commerce usage in Lyon for e-grocery is negligible with respect to traditional shopping trips and the other e-commerce flows are mostly passing through traditional postal services (which represent not more than 1% of the total UGM, according to Patier et al., 2007).

For these reasons, all e-commerce channel shares are set to zero, and the only household supply alternative is traditional shopping trips. For modal shares, we extract them from the EML-2006 survey, and synthesise the results in Table 5.

Table 5 : Private car modal share rates for each category of urban space (percentage of car shopping trips with respect to the total number of shopping trips)

	Average	Min*	Max*	Relative Std Deviation
Central urban area	23,3%	12,9%	33,4%	27,8%
Near Periphery	68,9%	52,4%	89,4%	14,8%
Far Periphery	75,5%	58,1%	87,7%	12,5%

* The minimum and maximum values are related to the corresponding section (1 to 34)

Proposed scenarios

In order to isolate the effects of e-commerce from other effects, like population growth or changes on retailing demography, we propose several scenarios built from the reference presented above by changing only the organisational schemas of end-consumer supply (with the respective inter-establishment changes if needed, but without changing the retailing characteristics of the urban area). These scenarios represent both realistic and extreme situations related to a generalisation of e-commerce distribution current trends. They are organised as follows:

- Family 1: Extreme scenarios. These scenarios are not realistic but are used to determine the limits of the development of each channel. Three scenarios are distinguished:
  - S1-1: An “all shopping drive” scenario. In this scenario, we assume that all motorised households use the shopping drive channel. Households without private car will continue to follow traditional shopping trip patterns.
  - S1-2: an “all home delivery” scenario based on the assumption that all households are delivered home. All home deliveries are carried out with light freight vehicles (up to 3.5 T.) and we assume that they are organised following the current logistic patterns.
  - S1-3: an “all proximity depots” scenarios based on the assumption that only proximity depot picking can be used by the inhabitants for supply purposes. These depots are assimilated to the existing small grocery retailers, plus several pickup points added proportionally to the population density. All proximity depots are delivered by heavy vehicles from 3.5 to 7 T following patterns similar to those of small stores.
- Family 2: Realistic scenarios implementing only one channel. In these scenarios, 50% of the population makes traditional shopping trips and 50% of one of the three channels defined above.
  - S2-1: .50% of traditional shopping, 50% “shopping drive”. For the shopping drive, only motorised households are concerned, following the same assumptions than scenario S1-1.
  - S2-2: 50% of traditional shopping, 50% “home deliveries”. Home deliveries follow the same assumptions than scenario S1-2.

    - S2-3: 50% of traditional shopping, 50% “proximity depots”. The latter follow the same assumptions than scenario S1-3.

- Family 3: A realistic scenario implementing both proximity delivery channels, i.e. home deliveries and proximity depots. This choice has been made after a few attempts in order to find the best combination of channels.

    - S3: 50% of the population makes traditional shopping trips, 15% home delivery services and 35% proximity depot picking.

Main results

The proposed scenarios have been simulated in order to estimate the reduction rates in greenhouse gas emissions for each of them. In Table 6 we report the traffic impacts of each scenario, in terms travelled distances. More precisely, we report the trends in millions km.PCU per day.

Table 6: Traffic impacts (in Km.PCU/day)

	IEM	PDM	ST	Total
S0 – Reference	4 407 471	0	3 253 563	7 661 034
S1-1 – Drive	0,0%	0,0%	37,0%	15,7%
S1-2 – HD	-8,6%	66,3%	-100,0%	-19,3%
S1-3 – RP	-8,6%	20,0%	-85,3%	-32,7%
S2-1	0,0%	0,0%	28,0%	11,9%
S2-2	-4,3%	35,9%	-40,5%	-4,4%
S2-3	-4,3%	10,4%	-33,1%	-12,1%
S3	-4,3%	13,5%	-38,0%	-13,2%

We observe a 15.7% increase of the total km.PCU/day in the first scenario (S1-1). In the base scenario (S0), we assume that e-commerce trends are the same as in 2006, of which effects on traffic are insignificant. According to the scenario S1-1, the drive following current practices (i.e., 82% of home-shopping-home trips, Gonzalez-Feliu et al., 2011) are not able to reduce significantly congestion and pollution. The two extreme scenarios (S1-2 and S1-3) show the limits of respectively home delivery services and proximity depot picking approaches. Although both scenarios result in an important reduction of total km.PCU, proximity depots seem to be a better alternative because of two reasons: first, the gain is about 1/3 of the total Km.PCU in 2006, and second, home deliveries require more time constraints for the consumer (about 2-3h per command, Alligier, 2007). In the scenario S1-2, we assume that people being delivered home do not use the car for shopping purposes, so we get a 100% in shopping trips, balanced with a 67% increase in B2C flows. In the scenario S1-3, some households will pickup the commanded products by car but the travelled distances are shorter than those of classical shopping trips (in general, less than 2 km). Moreover, the home delivery services are less optimised than the pickup depots logistics chains, because the usage of small trucks and the delivery conditions (B2B flows instead of B2C) result on a better optimisation, so a significant reduction of the total travelled kilometres.

The “realistic” scenarios with one channel (S2-1, S2-2 and S2-3) represent respectively a trend situation (50% of traditional retails are kept). The shopping drive (scenario S2-1) results in a 28% increase of the travelled kilometres for shopping, and a 11.9% increase in the total travelled kilometres. In the contrary, the S2-2 and S2-3 scenarios allow respectively a 4.4% and 12.1% decrease in travelled kilometres. In the end, the mixed scenario S3 using a good combination of home delivery services and proximity depots results in an overall gain of about 13%, showing that, for the same total percentage of households using e-commerce services, the proposed combination gives better results than any situation using only one channel.

Finally, in order to make a sensitivity analysis of the method, we propose to modify the modal share rates in each zone. We observe that, for the central urban area, the car modal shares are small, as reported in Table 5. Moreover, the relative standard deviation for the central urban area is twice higher than that of the other categories of urban space. For these reasons, we propose to analyse the gains on road occupancy for peripheral zones only, on the base of scenario S3. The car modal rate is the only parameter that varies, from 5% to 80%.

Table 7 : Gains on road occupancy(in Km.PCU/day)

Car modal rate	Near Periphery	Far Periphery
5%	12.6%	12.1%
10%	12.7%	12.2%
20%	12.8%	12.3%
30%	12.8%	12.5%
40%	12.9%	12.6%
50%	12.9%	12.8%
60%	13.0%	12.9%
70%	13.0%	13.1%
80%	13.1%	13.2%

We observe that the gain variations are small (about 0.1% for each 10% increment), which can be explained by the fact that in periphery, the usage of private car for shopping is more necessary than in the central area and the e-commerce distribution flows result in a set of long urban routes. Although these routes deliver more than one household, the gains on traditional shopping trips are compensated by both the delivery routes and the private car trips for reception point pickups.

In order to illustrate these results, we report them on a graph. We observe that both curves are almost linear, as shown in Figure 3:

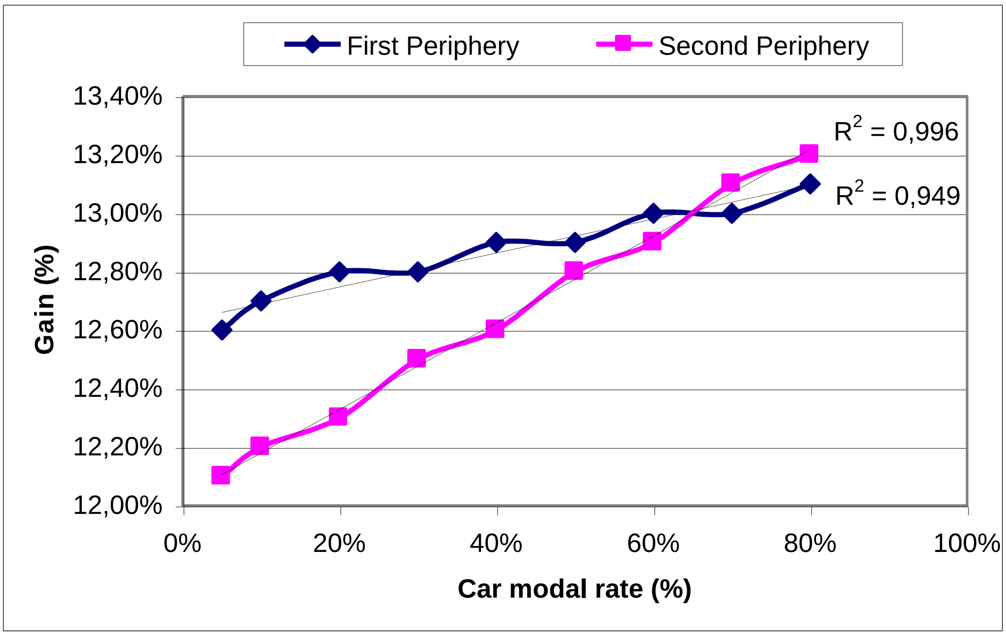

Fig. 3 : Gains on road occupancy with respects to car modal rate on peripheral areas (for a constant channel share, i.e. 50% Traditional Shopping Trips, 15% Home Deliveries and 35% Reception Points

Conclusion

This paper proposed a modelling framework coupling together the upstream inter-establishment model and the downstream purchasing trips model, in order to take into account the interaction between the supplying of retail business and purchasing households behaviour. Thanks to a substitution procedure between the different channels of distribution (traditional shopping, drive, home delivery and proximity reception points) can be included into existing urban goods models for a more appropriate simulation of a variety of scenarios. We have presented the proposed substitution methodology as well as its connection with existing modelling frameworks. In order to illustrate these procedures, we have proposed several scenarios, for both extreme and realistic situations. The simulation shows that the best realistic solution (in km.PCU/week) is brought by a mix consisting of home delivery and proximity reception points.

However, due to the lack of data, a number of approximate estimates have been made (for instance, home delivery routes are estimated from 2007 data and proximity depots routes are assumed to be similar to those of small stores supply). So the results have to be improved. To that purpose, ongoing French surveys (Patier and Routhier, 2009) will allow, in 2011, an appreciable gain in accuracy.

Finally, further developments are ongoing, more precisely about the relations between the improvements on route optimisation and the impacts of trip substitution. In this way, a in-depth study of new distribution trends, such as collaboration, logistics sharing and the usage of route optimisation tools will allow us to connect the method also to operations research tools. Another further development deals with shopping trip behaviour in order to include typologies of shoppers in the modelling framework.

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