DEMAND MODELS FOR THE ESTIMATION OF URBAN GOODS MOVEMENTS: AN APPLICATION TO THE CITY OF ROME

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Abstract

This paper presents a specific modelling system which simulates the commodity, delivery and vehicle goods movements, developed in order to support ex-ante assessment of city logistics measures.
A review of models developed to simulate the urban freight transport demand is also reported. The review analysis highlights the limits of models for the ex-ante assessment of city logistics measures. For this reason this paper proposes a new modelling system made of different steps approaching problems related to: quantity OD flows, service-type OD flows, delivery OD flows, delivery OD flows for delivery time and vehicle type, and vehicle OD flows. This modelling system has been specified and calibrated using some surveys carried out in the inner area of Rome, where more than 500 truck drivers and more than 600 retailers have been interviewed.

1. INTRODUCTION

According to the latest statistics, about the 75% of European population lives in urban areas, and 40% lives in large urban areas of over 200.000 inhabitants. The share of urban population will increase arriving to 80% in the 2020. Urban areas consume about 70% of energy and produce about 80% of GHG emissions (ISPRA, 2009). Urban mobility accounts for 32% of energy consumption and for 40% of all CO_2 emissions of road transport and up to 70% of other pollutants from transport. In this context, great importance assumes the urban freight transport. In fact, it has been estimated that the total of urban freight transport accounts for 14% of vehicle-kilometers, 19% of energy use, and 21% of CO_2 emissions (Schoemaker *et al.*, 2006). Urban freight is more polluting than long-distance freight transport owing to the frequency of short trips and stops. Fuel consumption increases sharply if lorries have to stop very often: with five stops in 10 km, fuel consumption increases by 140% (Martensson, 2005).

Thus, in order to make urban mobility more sustainable, measures to reduce the environmental impact of freight transport have to be implemented. Several ex-post evaluation highlight that many implemented measures have generally been quite unsuccessful. Consequently, it is fundamental to have methods and models in order to analyze measures before their implementation for an ex-ante assessment of impacts. Several authors agree that the proposed approaches have not yet fully validated and in any case they do not provide the expected results. The lack of interest demonstrated by local authorities for this segment of mobility implies a shortage of data, for which only few experiences are supported by comprehensive surveys (Browne *et al.*, 2007).

In any case, the need of finding solutions for the forecasting and management of freight vehicles in urban areas is stimulating the investigation of models to estimate freight OD matrices and vehicle flows road networks. Most proposed models have been developed within the sequential modelling approach by considering three different categories of models based on truck, commodity and delivery.

Truck-based models consider the trip of freight vehicles as reference unit. These types of models have been proposed by Ogden (1992), Spielberg and Smith (1981), Hunt and Stefan (2007), and Wang and Houlguin-Veras (2009). Models developed within the commodity-based approach consider the commodity as reference unit and have initially been proposed by Ogden (1992) that provided some applications to the city of Melbourne. Other applications of this class of models have been proposed by Oppenheim (1994), Munuzuri *et al.* (2004), Nuzzolo *et al.* (2008) and Russo and Comi (2010). Finally, the delivery approach focuses on movements/deliveries and has been introduced by Routhier and Toilier (2007), and Nuzzolo *et al.* (2009).

Many of these studies propose models that present some limits for use in an ex-ante assessment of city logistics measures. For example, truck-based models estimate directly trips of freight vehicles but they are difficult to be used for forecasting analysis. They do not allow to follow the mechanism that determines the freight demand and, secondly, these types of models could well reproduce round trip (one origin – one destination), but fail in the trip chain simulation.

Commodity-based models allow us to capture the mechanisms by underlying the generation of freight transport demand, and new studies proposed to modify the general modeling approach in order to include the possibility to simulate the restocking process (Nuzzolo *et al.*, 2006), the vehicle holding choice (Russo and Comi, 2009) and to follow the journey within the urban area (trip-chain; Raothanachonkun *et al.*, 2007; Wang and Houlguin-Veras, 2008).

Delivery approach focuses on movements/deliveries (pick-ups and deliveries); the use of delivery as reference unit allows to easily identify the movements for each economic activity (origin and/or destination) of study area, as well as it allows to have a direct link between producers and transport operators.

A detailed analysis of advantages and disadvantages of these three approaches are given by Nuzzolo *et al.* (2009).

The modelling system features have to be identified in order to develop a modelling system able to support ex-ante assessment of city logistics measures. The following section 2 analyses the urban freight transport and resumes some features required to reach this aim. Thus, the paper provides a modelling system to simulate goods movements at an urban scale combining commodity, deliveries and vehicles flows. Quantity allows us to follow the mechanism underlying freight demand, and delivery allows us to follow better the decision process of trip-chain definition. In fact, for a better conversion of quantity into vehicles, we propose an intermediate step which estimates freight OD matrices in terms of deliveries. This approach allows us to follow the sequence of activities undertaken during the journey (deliveries and pick-ups) and, thus, to define a system of models that allows the ex-ante assessment of city logistics measures (section 3). It should be noted that the third level allows to overcome the limits of commodity based approach when considering empty trips. Although, in general, within the commodity based approach some researchers have proposed to overcome the disadvantages due to empty trips by applying the load factor (Chin and Hwang, 2006), by including the empty trip for the return trips or by considering them as a trip of a given trip chain (Houlguin-Veras and Thorson, 2003), we develop a modelling system able to estimate both loaded trips and empty trips based on trip chain (tour) behaviour. In the estimation of the vehicle OD matrix, two types of truck trips are considered: round trips and tours in terms of both empty and loaded trips.
The proposed modelling system has been specified, calibrated and validated for the city of Rome (section 4), while section 5 reports some conclusions of this work.

2. MODELLING SYSTEM NEEDS

The main objective of this section is to identify all components of urban freight transport in order to develop a tool supporting ex-ante assessment of city logistics measures. For this reason we have to analyse:

- the structure of urban freight distribution for each identified freight type;
- the decision-makers involved in the distribution process and their choice dimensions;
- the measures to be evaluated and the influenced choices.

In urban and metropolitan areas, freight transport is mainly related to the distribution of final products from producers, wholesalers and restocking centres to the economic activities located in the area (e.g. shops). In particular, urban distribution can be characterized for freight type and can be represented through the functional scheme of freight distribution as pictured in Figure 1. This paper will deal with the bold part of Figure 1, that is the case in which the freight passes through a retailer before arriving to end-consumer.

Referring to the retailer restocking, urban freight transport is characterized by different decision-makers which act to move freight from producer to end-consumer. It implies that freight models have to consider the choice of how and where freight must be moved. In particular, decision-makers (actors) can be grouped according to who influences the level and composition of freight transport demand, defining three classes:

- retailers, that sell goods to end-consumers and can decide, for some freight types, how much and how to restock, from where, what time, which vehicle, which restocking tour and which path has to be used;
- wholesalers or logistics operators, that are all actors responsible for planning and management of physical distribution of products; they include producers (which decide how to produce, how much and where to sell), wholesalers/distributors (which provide to consolidate/deconsolidate freight during the transportation chain up to consumers); this class of actors can decide the choice sequence of: retailer restocking type, time, used vehicle and possible intermediate facilities (e.g. urban distribution centres), as well as delivery tour and path;
- carriers or transport operators or express companies (couriers), which include all actors responsible of transport that decide how to provide transport.

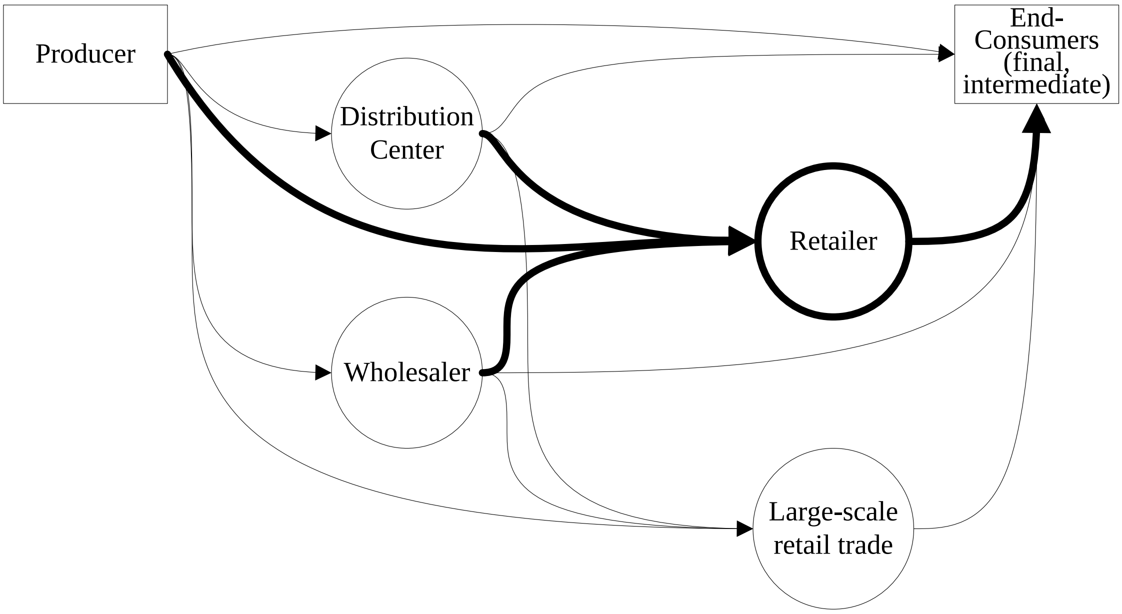

Figure 1 – Structure of urban freight distribution

Referring to the choice dimensions, we can identify two sets of choices: one related to demand and one related to supply/logistics. The former class includes choice relative to: how much to be restocked daily, where to take freight sold in her/his shop, how to do the restocking (e.g. by himself or third parties), what time to do the restocking journey. Latter class includes choices relative to: which vehicle to be used, which restocking/delivery tour (e.g. sequence of pick-ups/deliveries), if to use or not an urban distribution centre, and which path to be used.

Each of the previous choices can be modified by the implementation of city logistics measures. In particular, city logistics measures can be classified as follows:

- infrastructures; this class includes measures related to areas which can be reserved for freight operations (e.g. logistic nodes to optimize freight distribution in metropolitan/urban areas like urban consolidation centres);
- governance; this class includes traffic regulations (e.g. time windows, heavy vehicle network, road-pricing, maximum parking time, maximum occupied surface and

specific permission, incentives to switch from own account to third parties), and measures related to the introduction of new standards for transport units (equipment measures), such as low-emission vehicles;
- Intelligent Transportation Systems (ITS); they provide traffic information, route optimization, freight capacity exchange, tracking and tracing.

Starting from this classification, the following section proposes a modelling system for urban freight transport and logistics able to assess impacts generated by the implementation of some city logistics measures.

3. THE PROPOSED MODELLING SYSTEM

The analysis of literature in this field highlights the limits of current models for the ex-ante assessment of city logistics measures. The proposed modelling system allows to integrate the advantages of three recalled approaches: commodity (to capture the mechanisms underlying the generation of freight demand), delivery (to follow the decision process of trip-chain definition) and truck (ease of data gathering and link vehicle flows in terms of both loaded and empty trips).

For this reason, this paper proposes a new modelling system approach for the assessment of city logistics measures. It consists of two sub-systems (see Figure 2): the first related to the demand and the second related to the logistics.

The demand sub-system allows us to estimate the OD flows in terms of quantities and deliveries for different freight types, as follows:

- quantity OD flows: freight OD matrices in quantity (e.g. tons per day) are estimated starting from socio-economic data;
- service-type OD flows: freight OD matrices in quantity are split in terms of who can be assumed as the decision-maker of the restocking process and which transport service is used: receiver (e.g. retailer) in own account, sender (e.g. producer, wholesaler) in own account, third party by transport company and third party by courier;
- delivery OD flows: starting from the service-type OD flows, the model gives flows of deliveries for each *od* pair; the delivery step is modelled through the evaluation of freight quantity (shipment size) delivered by different identified service types;
- delivery OD flows per time slice, as result of the modelling characterisation of the delivery OD flows for target time;
- delivery OD flows for vehicle type: the delivery OD flows are split in terms of used vehicle type (e.g. Light Goods Vehicles, Heavy Goods Vehicles).

The logistic sub-system allows us to estimate the OD flows in terms of vehicles used for restocking the study area for different freight types, as follows:

- vehicle OD flows: the delivery OD flows for vehicle type are converted in OD vehicle flows taking into account the origin of each truck trip belonging to the same journey (tour).

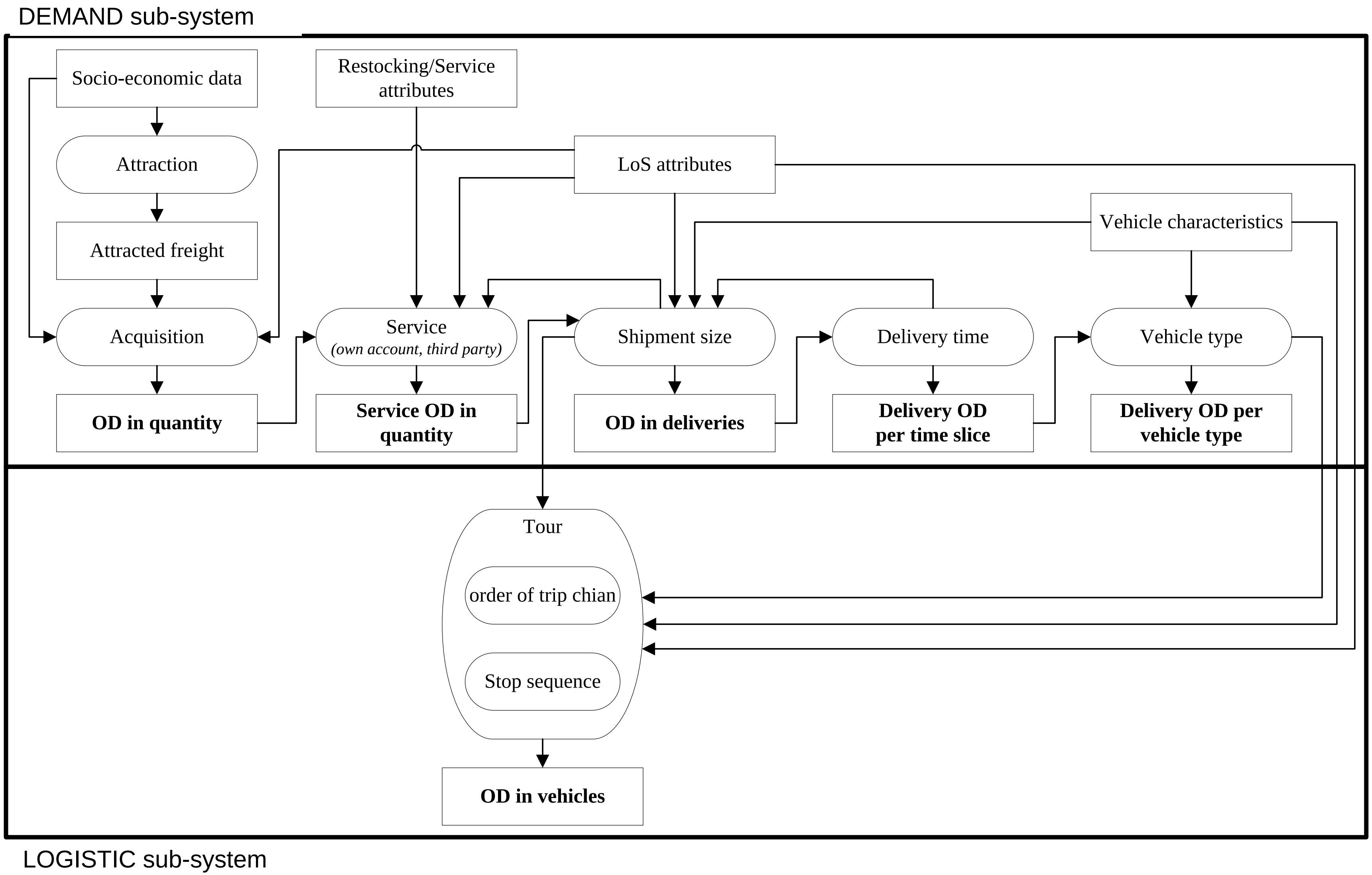

Figure 2 – Structure of the proposed modelling system

3.1 Demand sub-system

The demand sub-system allows to estimate the average flows of freight type *s* both in quantity and deliveries. Let be $Q_{od}^{sh}\left[r\right]$ the average *quantity* flow of freight type *s* attracted by each zone *d* and coming from zone *o* in time period *h* (e.g. day) with service type *r*. For simplicity of notation, the class index *s* (freight type) and *h* (time period) will be taken as understood unless otherwise stated. Thus, the average quantity flow $Q_{od}\left[r\right]$ can be determined as follows:

$$Q_{od}\left[r\right]=Q_{.d}\ \cdot p\left[o/d\right]\ \cdot\ p\left[r/od\right] \qquad (1)$$

where

- $Q_{.d}$ is the average quantity of freight attracted by zone *d* obtained by an *attraction model*;
- $p\left[o/d\right]$ is the probability that the freight attracted by zone *d* comes from zone *o* (e.g. production place/firm, distribution centre, warehouse); it represents the acquisition share (probability) obtained by an *acquisition model*;
- $p\left[r/od\right]$ is the probability to be restocked by transport service type *r* obtained by a *service type model*; the possible transport service types are (Figure 3):
    - receiver (e.g. retailer); the receiver chooses how, where and when to go to bring the goods sold in her/his shop and she/he restocks
        - in own account,
        - by third party (transport company or express company that offers small size shipment);
    - sender (e.g. wholesaler, producer); in this case, the receiver suffers the choices of other involved actors, but she/he can give some constraints regarding the delivery time; at same way, the sender can restock:
        - in own account,
        - by third party (transport company or express company that offers small size shipment).

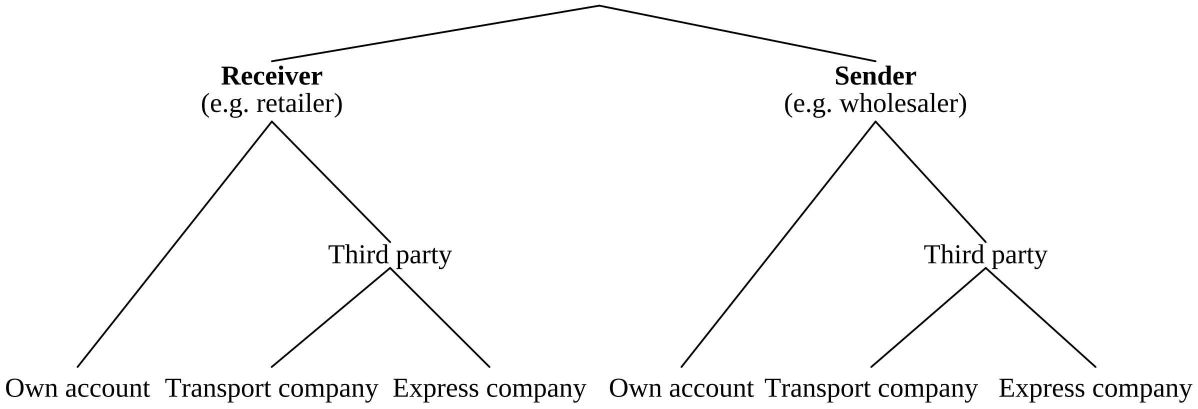

Figure 3 – Transport service type: structure of choice dimensions

Let be $ND_{od}^{sh}\left[v\tau/r\right]$ the average *delivery* flow of freight type *s* carried out by transport service type *r* on *od* pair in time slice τ by vehicle type *v*. For simplicity of notation, the class index *s* (freight type) and *h* (time period) will be taken as understood unless otherwise stated. Thus, the average delivery flow $ND_{od}\left[v\tau/r\right]$ can be determined as follows:

$$ND_{od}\left[v\tau/r\right]=\frac{Q_{od}\left[r\right]}{q\left[vr\right]}\cdot p\left[\tau/d\right]\cdot p\left[v/\tau rod\right] \qquad (2)$$

where

- $p\left[\tau/d\right]$ is the probability to be delivered in time slice τ obtained by a *delivery time model*;
- $p\left[v/\tau rod\right]$ is the probability that deliveries are carried out by vehicle type *v* obtained by a *vehicle type model*;
- $q\left[vr\right]$ is the average freight quantity delivered with service type *r* and vehicle type *v*.

The average freight quantity $q\left[vr\right]$ is the result of a complex decisional process depending on several attributes that can be modified by policy measures (e.g. interventions that modify travel costs); it can be expressed as:

$$q\left[vr\right]=\sum_{y}y\cdot p\left[y\right] \qquad (3)$$

where $p\left[y\right]$ is the probability of delivering the quantity *y*. This probability can be expressed as a function of attributes related to freight type, service type, LoS (e.g. travel costs) attributes and vehicle type. The delivered quantity *y* is a discrete variables and different classes of shipment dimensions can be identified (e.g. *y* is less than 0.5 tons). It is widely accepted that the choices of shipment size, frequency and transport service are done simultaneously, not in sequence. In literature, we find some models developed for this scope, but they mainly refer to intercity transport. Examples of these model types are given by Meyburg and Stopher (1974), McFadden *et al.*, (1986), Abdelwahab and Sargious (1991). Recently, de Jong and Ben-Akiva (2007) propose a micro-simulation model to analyze the joint choice between size and transport chain, but always at national scale.

3.2 Logistic sub-system

The logistic sub-system allows to estimate the OD flows, and using suitable path choice model, the link flows on the road network for different vehicle type (*v*). In fact, delivery movements can happen by using different vehicle types (e.g., Light Goods Vehicles, Heavy Goods Vehicles).

Starting from the outputs of previous modelling sub-system (delivery OD matrices per service types, time slices and vehicle types), in order to obtain the link flows on the road network, the estimation of vehicle OD matrices and the relative used paths for each *od* pair are required.

Let be $VC_{od}^{sh}\left[v\tau r\right]$ the average *vehicle* flow of freight type *s* carried out by transport service type *r* on *od* pair in time slice τ by vehicle type *v*. For simplicity of notation, the class index *s* (freight type) and *h* (time period) will be taken as understood unless otherwise stated ($VC_{od}\left[v\tau r\right]$).

The estimation of vehicle OD matrices can be carried out by using two different approaches (Nuzzolo *et al.*, 2009): the tour-based approach (it is an aggregate approach which provides a sequence of behavioural models that allows to simulate choices of decision-makers involved in the definition of the sequence of trips - tour/journey) and micro-simulation approach (based on micro-simulation and optimization models, which simulate the urban freight distribution strategies of a generic decision-maker belonging to a group of players with same characteristics located in a traffic zone).

Referring to link freight flows the solution given to this modelling problem are similar to those developed for passenger travel. The main difference between route choice models for passenger and freight is that the network might be different as there are links which have restrictions for freight vehicles.

For example, truck driver behaviour in route within an urban network is usually constrained by the vehicle size. In general, there are a number of factors that influence route choice behaviour of freight drivers in urban area and hence path models developed for passengers should be adapted for freight transport. Such models are used both for congested networks within equilibrium or dynamic models and for non-congested networks within static or pseudo-dynamic network loading models. Russo and Vitetta (2003) proposed a specification within a Dial algorithm structure for the implicit assignment of network flows that can be used for this aim.

4. APPLICATION TO THE CITY OF ROME

The described modelling approach has been specified, calibrated and validated to the city of Rome. Study area has been divided into 99 traffic zones by considering different levels of details that increase with their closeness to the inner area of the city.

The study area is the inner city area, of about 6 km^2, with more than 50,000 inhabitants and less than 24,000 employees related to trade. Access is allowed exclusively to vehicles with certain emissions characteristics (no access to pre-Euro vehicles) and with a gross laden weight of less than 3.5 tones. The access is also allowed to vehicles with a gross laden weight less than 8.5 tones only in the night hours and is restricted to some specific roads. The modelling system has been developed in order to support the municipality of Rome in the ex-ante assessment of city logistics measures to be implemented in the next future.

The study has been supported by some surveys carried out in 2008 in the inner city area of Rome: traffic counts of commercial and private vehicles, interviews to truck drivers (about 600 interviews) to investigate the supply chain of freight distribution, and interviews to retailers (about 500 interviews) to investigate the retail trade in the study area for each freight type.

In order to analyse the trend of traffic related to freight vehicles and the spatial and temporal distribution, 28 cross sections have been identified. The cross sections have been located in all access sections controlled by electronic system (boundary sections) and in some sections within the study area (internal sections).

In each section the following types of vehicles have been counted: motorcycle, car, taxi, bus, truck for waste collection, tourist bus, lorry less than 1.5 tonnes of gross laden weight, truck within 1.5 and 3.5 tonnes and tucks more than 3.5 tonnes. The traffic counts have been carried out during a week and for 14 hours (from 7 a.m. to 9 p.m.). About 480,000 vehicles (passenger and freight) have been counted daily: 43% in the morning (7 a.m. – 1 p.m.) and the remaining 57% in the afternoon.

The sample of truck driver survey consists of 502 truck drivers. The questionnaire is organized in 6 sections:

1. general information; in this section data on socio-economic characteristics of interviewee and transport firm have been collected;
2. characteristics of used vehicle; this section has allowed to reveal the technical characteristics of vehicle, e.g. fuel, weight, equipment, emission standards;
3. characteristics of transport; this section has allowed to investigate the type of operation (own or third account) and the scope of transport (loading or unloading), and other characteristics of transport as well as frequency;
4. delivery journey; this section has allowed to know the origin of journey, type of sender and receiver, and to characterize each stops in terms of delivered/collected freight quantity, freight type, time spent, etc.;
5. type of stop; this section has allowed to investigate the types of stop for loading and unloading operations and has had the aim to evaluate the percentage of use of space dedicated to loading/unloading and, in case, why this dedicated space is not used;
6. suggestions to improve freight distribution within the study area.

The sample of retailer interviews consists of 575 retailers randomly extracted within the list of CCIAA (Camera di Commercio, Industria, Artigianato e Agricoltura). The questionnaire is composed of 7 sections as follows:

1. data identifying the business (i.e. name of business, location, available surfaces both for sales and store, location of store, number of employees, type of business and type of sold goods);
2. transport in own account; it has allowed to collected data characterizing the type of transport in own account (i.e. number and type of owned vehicles, type and quantity of moved freight);
3. delivery to customers; it has allowed to collect data on frequency, quantity, time of delivery, time needed for loading/unloading;
4. supplying/restocking; it has allowed to collect data characterising the goods movements for restocking (i.e. frequency, freight type, time, used vehicle, origin type of movements – warehouse, distribution centre, producer);
5. type of stop; it has allowed to collect data on type of stops for loading and unloading operations, to evaluate the possibility to receive freight in time different from opening time, the preferred time for collections and deliveries;
6. problems; it has allowed the interviewee to report on the main problems related to loading and unloading movements;
7. suggestions; it has allowed to collect suggestions from the interviewee in order to improve the freight distribution within the study area (from both the technical and administrative standpoint).

At the end, the surveys revealed that the incidence of freight transport is about the 6%, as confirmed by several empirical studies reporting that urban freight vehicles account for 6 – 18% of total urban travel (Cambridge Systematics, 2004; Hunt *et al.*, 2004; Stefan *et al.*, 2005).

These surveys revealed that the main freight type moved in the study area is food, household, and health products (about 65%), and that distribution has two peak periods: one in the morning (8:00 to 10:00 a.m.) and one in the afternoon (3:00 to 4:00 p.m.). The incidence of freight vehicles is about 6% (about 14,000 vehicles per day) and the freight traffic is composed of goods vehicles with gross laden weight of:

- less than 1.5 tons (57%),
- within 1.5 and 3.5 tons (33%),
- than 8.5 tons (10%).

Analysis of the composition of freight flows (Figure 4) allows to define the considered freight types as:

- foodstuffs,
- home accessories,
- stationery,
- clothing,
- building materials,
- household and personal hygiene,
- other goods.

The study area is a trading area that is mainly interested by attraction freight flows. The analysis highlights freight movements in the study area for about 15,000 tons per day in attraction and only 194 tons per day in generation. The 36% consists of food (about 16% is directed to restaurants and bars, and 14% to retailer) and the remaining 70% is made of other end-consumer products (e.g. household and health products).

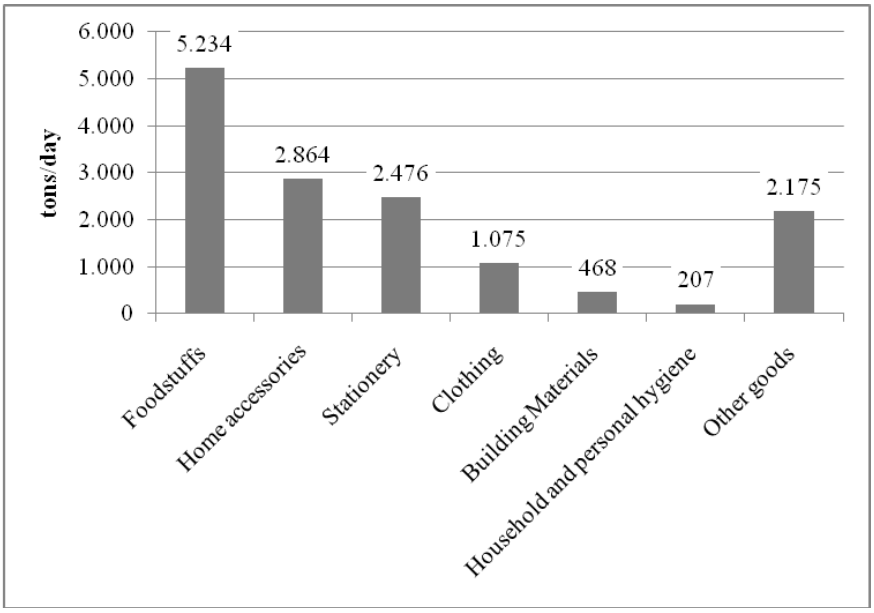

Figure 4 - Revealed freight flow distribution.

The specification and calibration of the proposed modelling system of section 3 is here reported. Models have been calibrated using the generalized least squares (GLS) estimator within the classic theory of statistical inference. For each previously recalled freight type, the OD matrices in terms of quantity, deliveries and vehicles characterised by service types, delivery time slices and vehicle types have been estimated on the basis of counts, and data from the truck-driver and retailer interviews. The presented models are the result of several specifications and calibrations based on different combinations of possible attributes. In the following models that performed the best statistical significances are reported for both the demand and the logistic sub-systems.

4.1 Demand sub-system

Referring to the general architecture described in the section 3, the first model is the *attraction model* which allows us to obtain the average flow of freight that arrives to each zone of the study area in order to satisfy the end-consumers. In general, each end-consumer can purchase the needed goods in different retailers or, in the case of some freight types, she/he can buy them in commercial concerns (e.g. bar, restaurant, and so on). The average quantity of freight type s attracted by zone d in time period h (e.g. a day) can be expressed as linear function of total number of employees in zone d related to freight type s (AD_d) and a dummy variable (ASA_d) that measures the different power of selling in zone d with high shop density (it is equal to 1 if ratio between retailer employees and resident in the zone d is higher than 35%).

Table 1 reports values of parameters calibrated for the seven freight types of Figure . All parameters are correct in sign and are statistically significant as shown by t-student values. The capability of models to reproduce the revealed values is shown by values of ρ^2 similar to those reported in the literature.

Results highlight that for all types of freight the variable ASA_d is statistically significant and its weight is not particularly high in the attracted freight estimation (especially for large zones).

In order to know the origin of freight for each attraction zone within study area, an *acquisition model* has been specified and calibrated. It simulates the choice of an origin among possible alternatives to bring the freight sold in her/his shop, including also commercial concerns (e.g. bar, restaurants, and so on).

This step allows to take into account the variation of LoS attributes (e.g. travel time and cost) due to the implementation of city logistics measures, such as Urban Distribution Centers, or governance measures (e.g. time windows, road-pricing, parking restrictions). The implementation of ITS measures could influence the origin choice, because, for example, traffic information systems as well as systems for route optimization are related to the expected generalized travel costs.

Typically the acquisition model is specified within the Random Utility Theory, but gravitational models are widely used in many applications because they give good results and are easy to be calibrated and applied. Thus, gravitational models have been specified and calibrated. The used variables belong to two groups:

- attributes of activity system located in zone *o*, or emission/generation attributes, which measure the generation/emission power of zone o (AI_o that is the number of warehouse employees of zone *o*);
- cost or separation attributes between zones *o* and *d* that measure the generalized cost for moving freight from *o* to *d* (e.g. C_{od} is the travel distance between *o* and *d*).

Table 1 reports calibration results obtained for the acquisition model. Even if acquisition models have been calibrated for all freight types of Figure 4, similar results have been obtained. Thus, only one acquisition model has been calibrated for all freight types different from foodstuffs. For this reason, Table 1 reports two set of parameters: the first for foodstuffs and the latter for other freight types. By analyzing results of calibration it is possible to point out that the number of employees has a high weight for foodstuffs, while the weight of travel cost (travel distance) plays at same way. The ρ^2 values are similar to those reported in literature.

The *service* model allows us to characterize the freight flows in terms of transport service. Thus, the service model allows to split the OD quantity flows for the previous identified transport service (receiver in own account, sender in own account, third party by transport company and third party by express company). We have to note that this share depends on the freight type because each freight type is characterized by a different distribution strategy affecting the transport service for restocking. This step allows to evaluate the impacts due to the implementation of governance measures, such as incentives to switch from own account to third parties and so on. From data collected in the city of Rome, it was not possible to obtain all these shares. In fact, it was not possible to know if the third party is due to retailer or sender. Table 1 reports the revealed shares obtained by the previous described survey.
Available data allowed to define joint share in terms of: receiver in own account, sender in own account and third party. By analyzing the revealed shares obtained in the city of Rome (Table 1), it emerges that restocking in own account by sender (e.g., producer or wholesaler) has an average share of 49%, but it strongly function of freight type. For example, this percentage increases over 60% for foodstuffs and stationery and it decrease to 22% for household and hygiene products. Note that in Rome the municipality has implemented some incentives (governance measures) to switch from retailer in own account to third parties. Thus, we have revealed that now few retailers restock in own account (less than 20%). Only for home accessories this share is higher and is about 30%.

In order to convert the OD flows from quantities to deliveries, the *average delivered quantity*, $q[vr]$, has been estimated. It also allows to take into account how governance measures can influence the composition of truck loads, such as restriction on vehicle type access (e.g. gross laden weight more than a given value). Table 1 reports the different delivery size (shipment size) revealed by surveys for the considered freight types. The average quantity varies from about 0.5 tons for retailer in own account to 0.35 tons of carrier (third parties); this result is justified by the fact that retailers in own account are characterized by a lower number of stops/deliveries. In fact, survey data highlights high values (2.4 stops) for foodstuffs and household and personal hygiene products (daily consumption products).

The delivery OD flows can be characterised for time slice τ. In many cities around the world, including our test case, time is constrained by governance regulations: the public authorities define one or two time windows (e.g. one in the morning between 9:00 – 11:00 a.m. and one in the afternoon). Referring to data collected in the city of Rome, it emerges that for many freight types more than 70% of deliveries refer to the morning period.

Table 1 – Calibration results: Quantity level

	Foodstuffs	*Home accessories*	*Stationery*	*Clothing*	*Building materials*	*Household and personal hygiene*	*Other goods*
ATTRACTION MODEL [tons/day]							
Retailer employees (AD_d)	0.06	1.6	2.9	0.1	0.1	1.3	1.2
(t-student)	*(1.89)*	*(2.52)*	*(1.85)*	*(2.99)*	*(1.85)*	*(8.93)*	*(3.48)*
Dummy Variable (ASA_d)	599.7	240.7	311.3	134.5	41.7		191.1
(t-student)	*(5.96)*	*(2.53)*	*(4.90)*	*(3.18)*	*(2.35)*		*(3.53)*
ρ^2	**0.91**	**0.79**	**0.89**	**0.75**	**0.59**	**0.89**	**0.80**
ACQUISITION MODEL							
Warehouse employees (AI_o)	*2.1*	*0.13*					
(t-student)	*(1.94)*	*(2.63)*					
Trip length (C_{od})	*-0.05*	*-0.08*					
(t-student)	*(1.85)*	*(2.80)*					
ρ^2	**0.45**	**0.52**					
SERVICE TYPE MODEL							
Receiver in own account	15%	31%	11%	11%	6%	8%	28%
Sender in own account	61%	46%	65%	42%	40%	22%	21%
Third party	24%	23%	24%	47%	54%	69%	52%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Movements of deliveries can happen by using different types of vehicles (e.g. Light Goods Vehicles, Heavy Goods Vehicles). The vehicle choice is a typical example of a travel choice that can be influenced by the implementation of city logistics measures. This choice depends on the characteristics of the delivery (e.g. freight type), characteristics of involved decision-maker, as well as on features of the urban transport system (LoS attributes and constraints to city access).

The vehicle type choice model allows to assess impacts due to the implementation of some governance measures related to the equipment in the field of city logistics, such as access restrictions to some classes of vehicles subject to environmental standards or laden weight.

The vehicle type share for goods vehicles with transportable quantity less than 1.5 tons (LGV) and goods vehicles with transportable quantity more than 1.5 tons (MGV) has been estimated by collected data (Table 2). Analyzing data, we can see that about 60% of the whole transport pertains to trucks with capacity higher than 1.5 tons, by moving an average load of about 0.76 tons per vehicle (load factor near 50%). Other type of trucks represents about 40% of the whole but their average transported quantity is about twice more (1.44 tons) than light goods vehicles. Analyzing results in terms of service types, it is possible to highlight that more than 60% of retailers and carriers use light goods vehicles, while restocking center uses at same way light and medium goods vehicles.

Table 2 – Delivery level: revealed values

	Foodstuffs	*Home accessories*	*Stationery*	*Clothing*	*Building materials*	*Household and personal hygiene*	*Other goods*
AVERAGE DELIVERED QUANTITY [tons]							
Receiver in own account	0.389	1.197	0.569	0.238	0.141	0.300	0.423
Sender in own account	0.367	0.982	0.632	0.306	0.395	0.129	0.394
Third party	0.232	0.611	0.412	0.275	0.787	0.196	0.497
Average	**0.320**	**0.902**	**0.547**	**0.279**	**0.424**	**0.180**	**0.320**
DELIVERY TIME MODEL							
Before 9am	30%	30%	34%	23%	38%	47%	27%
9am–11am	40%	37%	50%	51%	42%	32%	31%
11am – 1pm	24%	17%	9%	15%	10%	19%	21%
1pm-4pm	6%	13%	7%	11%	4%	2%	20%
After 4pm	0%	3%	1%	1%	5%	0%	0%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
VEHICLE TYPE MODEL							
Light Goods Vehicle *(less than 1.5 tons)*	70%	51%	62%	65%	35%	95%	51%
Heavy Goods Vehicle *(more than 1.5 tons)*	30%	49%	38%	35%	65%	5%	49%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

4.2 Logistic sub-system

Starting from the outputs of previous steps (delivery OD matrices per service types, delivery time slices and vehicle types), the estimation of vehicle OD matrices can be carried out by using two different approaches (Nuzzolo *et al.*, 2009): tour-based approach and micro-simulation approach.

The former is an aggregate approach which uses a sequence of behavioural models that allows to simulate choices of decision-makers (e.g. retailer, wholesaler, carrier/courier) involved in the definition of the sequence of trips (tour/journey); the latter is based on micro-simulation and optimization models, which simulate the urban freight distribution strategies of a generic player (decision-maker) belonging to the group of players located in a traffic zone; then standard procedures that extend results of individual simulation to the whole population are used.

In order to test the goodness of the proposed approach we have used a particular zoning of the area that allows us to convert the delivery OD flows for vehicle type to vehicle OD flows assuming that all deliveries are done in the same traffic zone (average quantity approach). This assumption is based on the hypothesis that who restocks, organizes her/his tours trying to serve all customers closely located. For example, in order to organize their restocking tours, Italian restockers usually use a zoning map related to zip codes. This assumption means, in terms of both loaded and empty trips, that:

- the retailer brings all the freight sold in her/his shop within the same acquisition zone *o*; in this case the flow from zone *d* to zone *o* are due to empty trips and the flow from zone *o* to zone *d* are due to loaded trips;
- the wholesaler (or distributor) delivers the freight within the same attraction zone *d*; the flow from zone *o* to zone *d* are related to loaded trips and the flow from zone *d* to zone *o* consists of empty trips;
- the carrier brings all the goods inside the same acquisition zone *o* and delivers them within the same attraction zone *d*; in this case the analysis of empty trips requires more attention because the carrier could be located outside the study area and the destination of back trip should be investigated.

The number of vehicles of type *v* on the *od* pair in time slice τ with service type *r*, $VC_{od}\left[v\tau r\right]$, can be expressed as:

$$VC_{od}\left[v\tau r\right] = ND_{od}\left[v\tau r\right] / nd\left[vr\right] \qquad (5)$$

where

- $ND_{od}\left[v\tau r\right]$ is delivery flow on the *od* pair for service type *r* and vehicle type *v*, eq. (4);
- $nd\left[vr\right]$ is the number of stops (deliveries) per trip undertaken by restocking type *r* using vehicle type *v*; this number of stops can be expressed as:

$$nd\left[vr\right] = QMT\left[vr\right] / q\left[vr\right] \qquad (6)$$

with

- $QMT\left[vr\right]$, the average quantity transported by vehicle type *v* with service transport *r* that (for example) can be directly estimated by driver interviews;
- $q\left[vr\right]$, the average delivered freight quantity (shipment size), eq. (3).

Table 3 reports the revealed number of stops for each freight types. We can note that the high value is related to foodstuffs and clothing, but building material one presents lower values.

Finally, referring to the aggregate results of the validation phase, the modelling system allows us to reproduce the actual situation of freight transport in the inner city area of Rome, as summarized in the following:

- commodity flows: revealed about 14,499 tons/day *vs* 14,296 tons/day by model application (-1.4%);
- delivery flows: revealed about 34,246 deliveries/day *vs* 34,190 deliveries/day by model application (-0.2%);
- vehicle flows: revealed about 15,773 trucks/day *vs* 15,718 trucks/day by model application (-0.3%).

Table 3 – Vehicle level: revealed values

NUMBER OF STOPS ($nd[vr]$)	*Foodstuffs*	*Home accessories*	*Stationery*	*Clothing*	*Building materials*	*Household and personal hygiene*	*Other goods*	***Average***
Receiver in own account								
Light Goods Vehicle *(less than 1.5 tons)*	1,93	1,02	1,62	2,23	3,90	1,43	1,39	**1,50**
Heavy Goods Vehicle *(more than 1.5 tons)*	2,90	1,99	2,36	4,08	6,45	1,03	3,97	**2,84**
Sender in own account								
Light Goods Vehicle *(less than 1.5 tons)*	2,04	1,24	1,46	1,73	1,39	2,19	1,50	**1,60**
Heavy Goods Vehicle *(more than 1.5 tons)*	3,08	2,42	2,12	3,17	2,30	1,58	4,26	**3,03**
Third party								
Light Goods Vehicle *(less than 1.5 tons)*	3,23	2,00	2,23	1,93	1,00	2,19	1,19	**2,20**
Heavy Goods Vehicle *(more than 1.5 tons)*	4,87	3,90	3,25	3,53	1,16	1,58	3,38	**4,17**

5. CONCLUSIONS

This paper presented a modelling system developed in order to support ex-ante assessment of city logistics measures. The freight modelling system has been specified and calibrated on the basis of a real test case (the city of Rome). Models have been specified within the commodity-based modelling approach because it allows us to capture quite well the mechanisms underlying freight transport demand. In order to convert the quantity freight flows to vehicles, a further unit of reference has been introduced. This unit of reference concerns deliveries and it allows us to support and follow the definition of tours/journey undertaken for restocking and to take into account loaded and empty trips.

The modelling system has been specified through easy-to-capture variables (especially for its forecasting use) represented by Level-of-Service attributes and aggregate socio-economic variables, such as number of employees.

Regarding the calibration, attraction and acquisition models have been calibrated, but for the other models only the revealed shares have been reported. The calibration results show that all obtained parameters are statistically significant in both expected sign and validation statistics.

This system of models can be successfully used for the estimation of urban freight flows by road in the initial assessment of future scenarios, as well as to calculate the impacts due to new city logistics measure implementation.

Further developments of this research mainly regard three main topics: the possibility to analyze how city logistics measures can influence the shipment size (delivery OD flow step), the possibility to develop and test other approaches in order to convert freight flows into truck tours, as well as to move the modelling framework from the proposed descriptive approach to the behavioural one. In particular, the attention can be focused on service and vehicle type choice models. The service models could be useful tools to investigate how a choice of service types can influence the definition of tours (trip-chains) and the used vehicle as well as the shipment size. In fact, the use of a particular transport service type could influence the average size of shipment and, hence, the type of vehicle to be used. It will be investigated the possibility to develop the vehicle type model within the Random Utility Theory where the systematic utility could be considered as a function of some attributes related to the dimension of wholesaler (e.g. employees), shipment (e.g. frequency, length of journey) and vehicle features (e.g. payload). Other developments could aim to develop this modelling system within a Decision Support System which could be a useful tool for appraising impacts of urban freight transport measures and policies.

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