



## **A trip chain order model for simulating urban freight restocking**

**Nuzzolo Agostino, Crisalli Umberto and Comi Antonio\***

*Department of Civil Engineering, Tor Vergata University of Rome, Italy*

---

### **Abstract**

This paper proposes a trip chain order model for simulating retailer restocking within urban and metropolitan area. It is part of the general modelling system developed by the authors for simulating urban freight demand which considers both demand and logistic sub-systems. The former allows us to obtain the freight Origin-Destination (OD) matrices in quantities and deliveries per transport service type, time slice and vehicle type. The latter allows us to obtain the vehicle OD matrices according to the journey characteristics (i.e. number and sequence of delivery points) in order to restock economic activities located within the study area.

This approach, known in literature as tour-based approach, aims at reproducing the choice structure of the restocking process and the sequence of delivery points (stops) for vehicle journeys, considering dependences existing among subsequent trips of the same journey. It implies that each destination zone to be delivered is chosen depending on the previous and the next destination ones. The logistic subsystem of the proposed modelling system can be divided in two parts: the first which defines the trip chain order (i.e. the number of deliveries made during a tour); the second one which considers the choice of the stop locations.

This paper focuses on the specification and calibration of a trip chain order model using data collected in the city centre of Rome.

*Keywords:* city logistics, trip chain order, tour-based, urban freight transport.

---

---

\* Corresponding author: Antonio Comi (comi@ing.uniroma2.it)

## 1. Introduction

Commercial vehicle movements represent the 15% of all urban vehicle trips, and produce even larger impacts in key areas such as congestion, emissions, road wear and industrial area traffic (Hunt and Stefan, 2007). The role of freight transport as an important part of the day-to-day activities for business and people is still increasing, especially if we analyse the recent trends of e-commerce, economic globalization, high-tech warehousing and just-in-time production systems. In addition, the partial replacement of the traditional demand for lighter and/or higher-value goods with the on-line shopping has been increasing; it implies an increase in the amount of freight transported by trucks. Moreover, when compared with the passenger vehicle fleet, trucks can have significant impacts in road congestion, greenhouse gas and pollutant emissions and pavement wear.

Consequently, it is fundamental to have methods and models to analyze urban freight transport and to assess the relative impacts. These tools should allow us an *ex-ante* assessment of measures that can be implemented by local administrators in order to make urban freight mobility more sustainable and, in particular, to reduce the environmental impacts due to lorries driving within the city. Urban freight measures implemented around the world can be classified in the following three classes:

- *governance*; in this class we can find 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;
- *material infrastructures*; this class includes measures related to areas that can be reserved for freight operations (e.g. logistic nodes to optimize freight distribution in metropolitan/urban areas like urban consolidation centres);
- *Intelligent Transportation Systems (ITS)*; this class includes traffic information systems, route optimization systems, as well as tracing and tracking ones.

The need of finding solutions to forecast and manage freight vehicles in urban areas is stimulating the investigation of models to estimate freight OD (Origin-Destination) matrices and vehicle flows on road networks. Most of the proposed models have been developed within the sequential modelling approach by considering three different categories of models based on *trucks* (Ogden, 1992; Spielberg and Smith, 1981; Hunt and Stefan, 2007; Wang and Holguin-Veras, 2009), *commodities/quantities* (Ogden, 1992; Oppenheim, 1994, Nuzzolo *et al.*, 2006; Russo and Comi, 2004 and 2010) and *deliveries* (Routhier and Aubert, 1998; Routhier and Toilier, 2007; Nuzzolo *et al.*, 2009).

Truck-based models consider the trip of freight vehicles as reference unit. The advantage of this class of models is the ease of data gathering (e.g. using automatic traffic counts), which facilitates the calibration and validation, but they are not able to account properly for changes underlying demand generation.

Commodity-based models consider the goods movement as reference unit. They allow us to capture the mechanisms underlying the generation of freight transport demand, but they fail in the simulation of the restocking process.

Delivery-based models have been proposed to better simulate the decision process underlying the definition of urban freight trips focusing on movements (pick-ups and deliveries); the use of the delivery as reference unit allows us to easily identify the

movements to each economic activity (origin and/or destination) of a study area, as well as it allows us to have a direct connection between generators and transport operators.

In order to overcome the limits of the above mentioned approaches, Nuzzolo *et al.* (2009) provide a new modelling framework to simulate urban goods movements combining commodities, deliveries and vehicles flows. Quantities allow us to follow the mechanism underlying freight demand, while the delivery allows us to better reproduce the decision process which defines the trip chain. In fact, for a better conversion of quantities into vehicles, they propose an intermediate step which estimates freight OD matrices in terms of deliveries. The modelling system consists of two sub-systems: the first related to the demand and the second related to the logistics. The demand sub-system allows us to estimate the OD matrices in terms of quantity and deliveries for different freight and transport service types. The logistic sub-system allows us to estimate the OD matrices in terms of vehicles used for restocking the study area. Given the complexity of representing the restocking phenomenon (estimation of vehicles OD matrices from given quantity and/or delivery OD matrices), the literature only reports some applications to test cases (Raathanachonkun *et al.*, 2007; Wang and Holguin-Veras, 2008) or to real cases under strong assumptions (Nuzzolo *et al.*, 2009). The former studies propose to obtain the number of stops (delivery points) per journey by an incremental *growth* for which, at each stop, the option to come back to the base (warehouse) is considered. This approach implies relevant approximations in some real cases, especially when restockers behave planning journeys with a pre-fixed number of stops. Referring to the latter case, in order to obtain vehicle OD matrices, Nuzzolo *et al.* (2009) propose to use a particular zoning of the study area that allows us to assume that all deliveries of the same journey are done in the same traffic zone (*average quantity approach*). This assumption is based on some survey results that pointed out a restocking strategy for which decision-makers organize tours trying to serve all customers closely located.

In order to define a modelling system that allows us to take into account the pre-trip definition (i.e. before starting journey) of trip chain order (i.e. number of delivery point or stops per tour) and to overcome the strong assumption that all deliveries are done within the same destination zone, this paper proposes a model developed within the tour-based approach to support the estimation of vehicle OD matrices from given delivery OD matrices. The tour-based approach aims at reproducing the choice structure of freight transport; it simulates the dependences existing among successive trips of the same journey, which implies that each destination is chosen depending on the previous and the next destinations.

This approach is suitable to be used by transportation planners as it allows to simulate the behaviour of decision-makers (e.g. retailer, wholesaler and producer) in an aggregate way, and it is capable to capture the underlying decision-making process which generates vehicle operations and, hence, freight tours in urban and metropolitan areas.

This paper is structured as follows. Section 2 describes the general modelling system, while section 3 presents the results of calibration and validation of the trip chain order model using data collected in the city centre of Rome. Finally, section 4 reports some conclusions and further developments of this research.

## 2. The general framework

In this paper we refer to the assumptions of Nuzzolo *et al.* (2009) who propose a modelling framework that allows us to integrate the advantages of the three recalled simulation approaches: commodities/quantities (to capture the mechanisms underlying the generation of freight demand), deliveries (to follow the decision process of trip-chain definition) and trucks (ease of data gathering and link vehicle flows).

The modelling system consists of two sub-systems (Figure 1): the first related to the demand and the second related to the logistics.

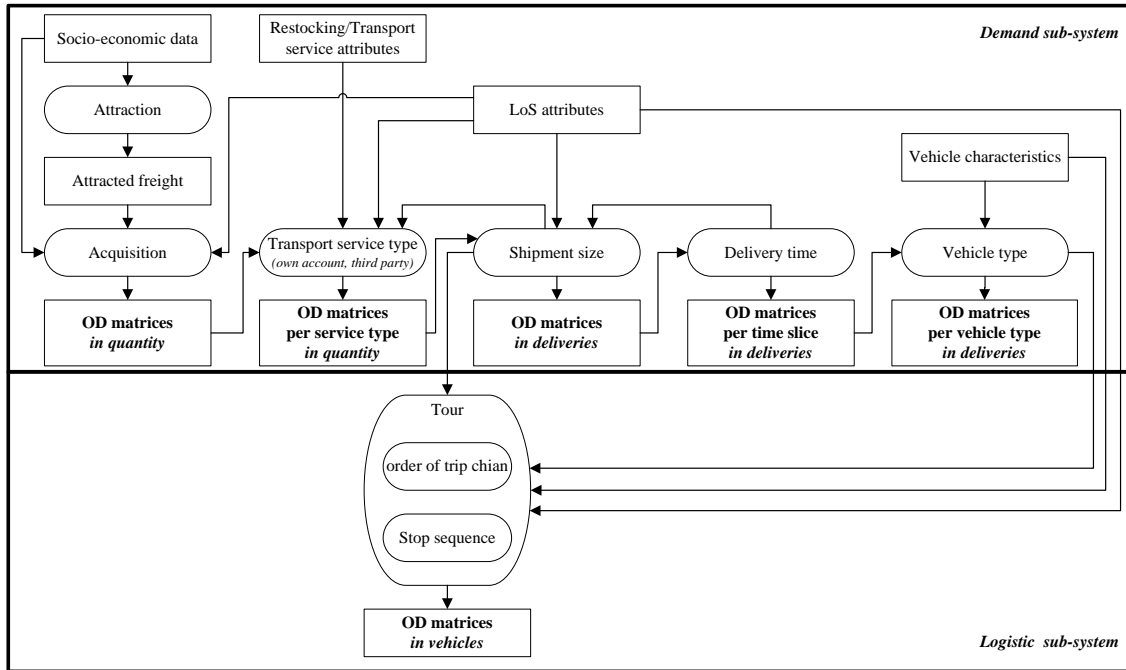


Figure 1 - System models architecture for simulating freight restocking

### 2.1 Demand sub-system

The demand sub-system allows us to estimate OD matrices both in terms of quantities and deliveries. For what concerns the OD matrices in quantities, each element  $Q_{od}^{sh}[r]$  represents the average quantity flows of freight type  $s$  attracted by each zone  $d$  coming from zone  $o$  in time period  $h$  (e.g. weekday) for transport service type  $r$ . Transport service type  $r$  plays a key role in the definition of OD quantities as it considers the transport characteristics on account of the receiver (e.g. retailer) or the sender (e.g. wholesaler) by: own account, third party (i.e. transport company or express company that offers small size shipments), as pictured in Figure 2.

In the following, for simplicity of notation, the class index  $s$  (freight type) and  $h$  (time period) will be omitted unless otherwise stated.

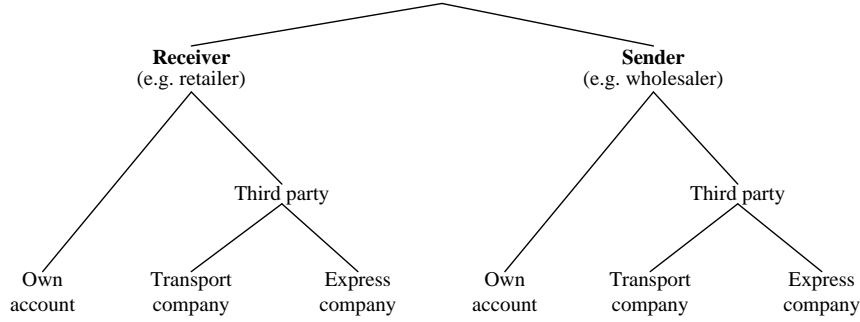


Figure 2 – Transport service type: structure of choice dimensions

The average quantity flow,  $Q_{od}[r]$ , can be determined as:

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

where

- $Q_{.d}$  is the average quantity of freight attracted by zone  $d$  obtained by an *attraction model*;
- $p[o/d]$  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) which can be obtained by an *acquisition model*;
- $p[r/od]$  is the probability to be restocked by transport service type  $r$  obtained by a *transport service type model*.

Then, the average quantity flows are converted into delivery flows. The OD matrices in deliveries are made of delivery elements  $ND_{od}[r, \tau, v]$ , which represents the delivery flow on the OD pair  $od$  for transport service type  $r$  and vehicle type  $v$  moving in the time slice  $\tau$ . It can be expressed as:

$$ND_{od}[r, \tau, v] = \frac{Q_{od}[r]}{q[r, v]} \cdot p[\tau/d] \cdot p[v/\tau rod] \quad (2)$$

where

- $p[\tau/d]$  is the probability of receiving deliveries in time slice  $\tau$ , which can be obtained by a *delivery time model*;
- $p[v/\tau rod]$  is the probability of delivering by vehicle type  $v$ , which can be obtained by a *vehicle type model*;
- $q[r, v]$  is the average freight quantity delivered by service type  $r$  and vehicle type  $v$  (*shipment size*).

## 2.2 Logistic sub-system

The logistic sub-system allows us to estimate the OD matrices in vehicles characterized by: service type  $r$ , time slice  $\tau$  and vehicle type  $v$ .

For reader convenience, it is important to introduce some definitions and notations used in the following of this paper. A *trip* is a vehicle movement between one origin and one destination for delivering at a shop (delivery point or stop). A journey is a sequence of trips starting and ending at warehouse. Journey with a single delivery is a

*round trip*. Finally, we define a *tour* or a *trip chain* (Figure 3) a journey made of a sequence of trips. A tour can also have a single destination zone but many delivery points (stops); it happens if all shops to be served/restocked are located within the same traffic zone  $d$  (i.e. stops within the same zone are considered).

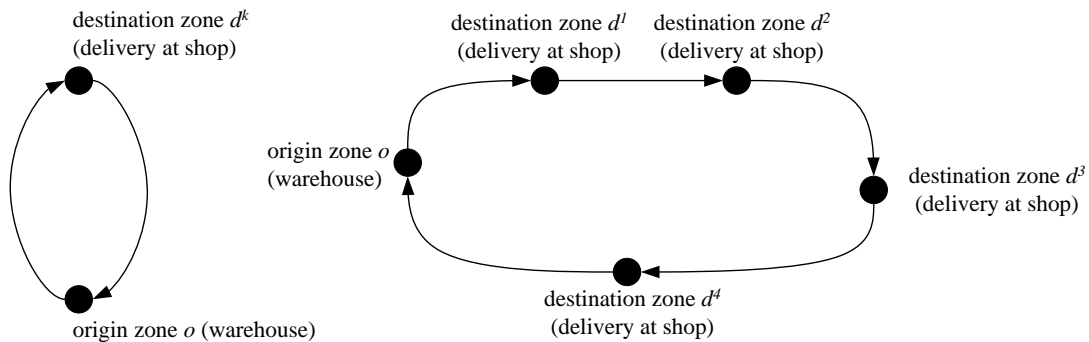


Figure 3 – Examples of *round trip* and *tour/trip chain*

Referring to OD matrices in vehicles, the reader should consider that restocking deliveries are usually planned by tours made of multiple trips among stops, and trips of a given tour are defined according to logistic decisions.

Moreover, we should consider that restocker knows the total number of deliveries for each destination zone. The deliveries are subjected to some constraints, such as number and type of available vehicles, as well as specific time windows for each customer to be restocked. Thus, the decision-maker organises the restocking tour for each available vehicle optimising the total perceived costs. This disaggregate process is generally approached through operative research methods that are suitable to be used for operative optimization of single restockers. The planner point of view is quite different, as it is not important to focus on the behaviour of single restockers but it is important to consider in an aggregate way the behaviour of all restockers (or categories of restockers) serving the study area.

In order to simulate the dependences existing among successive trips (of the same journey) according to a spatial-temporal connection among activities of different trips (e.g. with respect to time constraints), the tour-based approach can be used. The tour-based approach allows us to define trips of a journey, assuming that the choices for each trip affect other trips belonging to the same journey. Hence, tour-based models ably reproduce the choice structure of freight transport simulating the existing dependences among successive trips of the same journey (i.e. sequence of intermediate stops between restockers and retailers). It implies that each stop is chosen according to the previous and the next stops by considering the number of stops of the tour (i.e. the trip chain order). This approach is relatively new for freight modelling (Russo and Carteni, 2006) and it has been mainly developed to simulate passenger mobility (Hunt and Stefan, 2007).

This paper proposes to apply the tour-based approach to urban and metropolitan areas. The proposed modelling structure receives as input the delivery OD matrices for vehicle types and gives as output freight journeys satisfying the given OD matrices, through which the vehicle OD matrices are carried out. In fact, the OD matrices in deliveries are quite different with respect to those in vehicles. As described by Raothanachonkun *et al.* (2007) and Wang and Holguín-Veras (2008), the OD matrices in vehicles are similar to

the OD matrices in deliveries in the cases of round trips because the origin and destination of the movement of both deliveries and vehicles are the same. However, the delivery OD matrices are relatively different when the vehicles move through different stops along the tour as pictured in Figure 4. In order to better define the delivery OD matrices taking into account that deliveries are done by trip chains of different  $n$ -orders, we have to estimate the number of deliveries done in the zone  $d^k$  by a tour with  $n$  stops departing from zone  $o$  conditioned to previous stop  $(k-1)$  in the zone  $d^{k-1}$ ,  $ND_{od^k}[r, \tau, v, n, d^{k-1}]$ . It can be express as:

$$ND_{od^k}[r, \tau, v, n, d^{k-1}] = ND_{od^k}[r, \tau, v] \cdot p[n / v\tau rod^k] \cdot p[d^{k-1} / d^k nv\tau ro] \quad (3)$$

where

$p[n / v\tau rod^k]$  is the probability that deliveries on the OD pair  $od^k$  are done by a tour with  $n$  stops for vehicle type  $v$  which have to deliver in time slice  $\tau$  by transport service type  $r$  departing from origin  $o$  and doing deliveries in zone  $d^k$ ; it can be obtained by a *trip chain order model*;

$p[d^{k-1} / d^k nv\tau ro]$  is the probability of delivering in zone  $d^{k-1}$  conditioned to the fact that we will deliver in zone  $d^k$  by a tour with  $n$  stops departing from zone  $o$ ; it can be obtained by a *stop location choice model*.

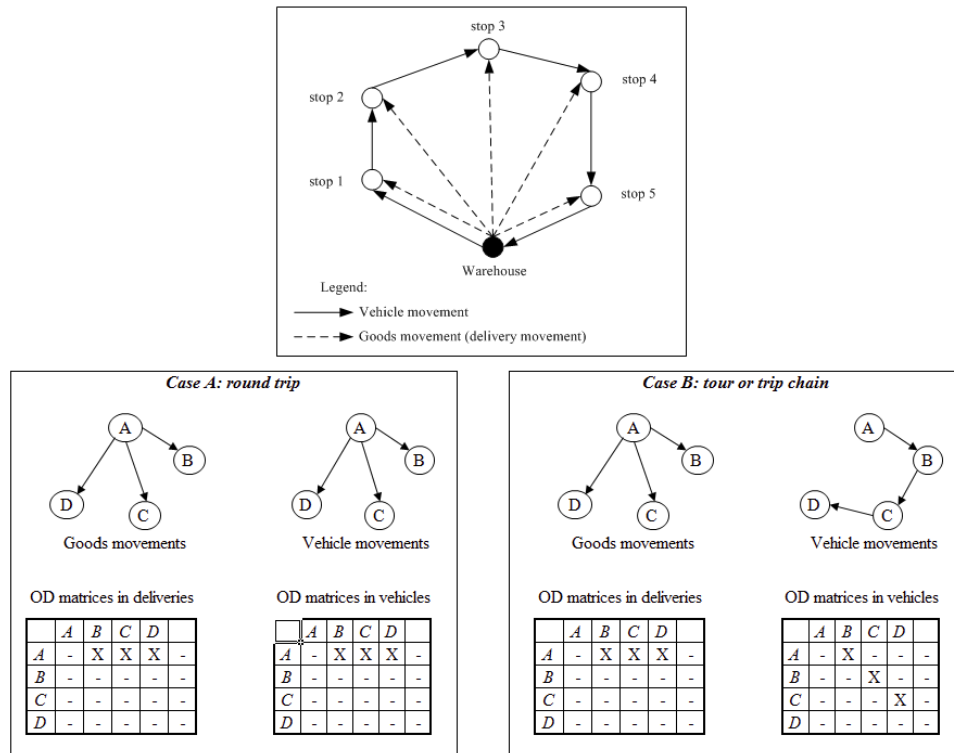


Figure 4 – Goods movements in terms of deliveries and vehicles

**Trip chain order model**

The *trip chain order model* allows us to define the probability distribution of the number of stops that characterize the undertaken journey by disaggregating the flow of deliveries  $ND_{od}[r, \tau, v]$ . The flows of deliveries with  $n$ -order trip chain,  $ND_{od}[r, \tau, v, n]$ , can be expressed as:

$$ND_{od}[r, \tau, v, n] = ND_{od}[r, \tau, v] \cdot p[n / v\tau rod] \quad (4)$$

where  $p[n / v\tau rod]$  is the probability defined in eq. (3).

The reader should consider that the trip chain order mainly depends on logistic characteristics of the warehouse. For this reason, in order to simplify the modelling structure, we can assume that  $p[n]$  depends only on the characteristics of origin zone  $o$  (i.e. accessibility), in which the warehouse is located.

### **Stop location choice model**

As previously described, a journey can be characterised by *one* or more than stops and the choice process of stop location is quite different. In the case of a journey with only one stop (round trip), the choice of location becomes the choice of single destination  $d^1$ . In the case of several stops ( $n$ -order trip chain), the *stop location choice model* gives the probability  $p[d^{k-1} / d^k nvro]$  to have done the delivery ( $k-1$ ) in the zone  $d^{k-1}$ , conditioned to have to do the delivery  $k$  in the zone  $d^k$  for a trip chain with  $n$  stops by transport service  $r$  departing from zone  $o$ .

### **3. Trip chain order model: specification and calibration**

This section illustrates the first results of the trip chain order model for the city of Rome.

The calibration has been carried out by a dataset of more than 500 interviews to truck drivers. These interviews are part of a survey campaign in the city of Rome consisting of traffic counts and interviews to retailers and to truck drivers (Nuzzolo *et al.*, 2010).

The municipality area has been divided into 99 traffic zones with a higher level for the inner area, which has been derived by aggregating 760 census parcels.

The traffic counts have been carried out for 14 hours (from 7 a.m. to 9 p.m.) in a typical work-day. The daily flow of freight vehicles is about 14,000 vehicles, which represents the 6% of total vehicle flow. The freight traffic is composed of goods vehicles with gross laden weight of:

- less than 1.5 tonnes (57%);
- within 1.5 and 3.5 tonnes (33%);
- more than 8.5 tonnes (10%).

The questionnaire used for truck driver interviews consists of 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 allows us to reveal the technical characteristics of vehicle, e.g. fuel, weight, equipment, emission standards;
3. *characteristics of transport*; this section allows us to investigate the service type (own or third account), and the scope of transport (loading or unloading), and frequency;



4. *delivery journey*; this section allows us to know the origin of journey, the type of sender and receiver, and to characterise each stop in terms of delivered/collected freight quantity, freight type, time spent, etc.;
5. *type of stop*; this section allows us to investigate the types of stop for loading and unloading operations; it also allows us to evaluate the percentage of use of space dedicated to loading/unloading and, in case of not using this dedicated space, the main reason of this choice;
6. *suggestions to improve freight distribution within the study area*.

This survey also allows us to characterize the freight quantity moved within the study area. The composition of freight flows in tonnes has been estimated on the basis of counts and truck-driver surveys. The study area is a trading area which is mainly interested by attraction freight flows. The analysis highlights freight movements in the study area for about 15,000 tonnes per day. Considering the revealed freight segmentation, the 36% consist of food (about 16% is directed to restaurants and bars, and 14% to retailer) and the remaining 70% are made of other end-consumer products (e.g. household and health products).

Collected data have been used to calibrate and validate the trip chain order model. The results of this activity are reported in the following.

Referring to transport freight types of Figure 2, available data allowed to investigate the joint share in terms of: receiver in own account, sender in own account and third party. For these three transport service types, Figure 5 reports the distribution of revealed number of stops. We note that the average number of stops is about 2 and that it is quite sensitive to freight segmentation. The retailer tends to undertake tour with less stops per tour. The detailed analysis pointed out a higher value of stops per tour for foodstuffs (about 2.4 stops per tour), while the lower values refer to home accessories and building materials (about 1.8 stops per tour).

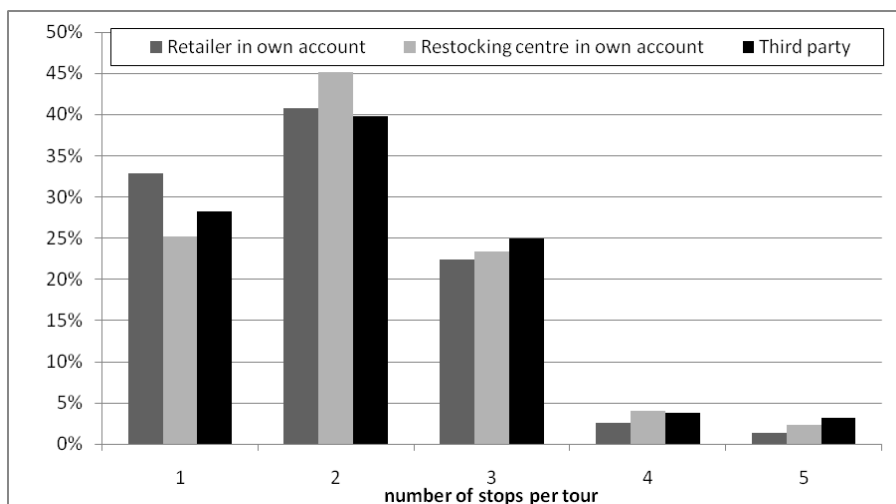


Figure 5 – Number of stops per revealed tours

In order to define the relevant attributes which characterise the restocker behaviour, a detailed analysis on socio-economic and level-of-service attributes has been carried out. The analysis pointed out that restockers prefer to undertake round trips if they are located in a zone with high level of accessibility because round trips allow them to

reduce journey operation planning. Thus, each restocker, having a pre-fixed working time, could do many trips without losing time for travelling if he was located in a zone with high accessibility. Figure 5 also points out that the retailer prefers round trips, but third party prefers long tours (more than 2 stops). The survey analysis also allowed us to understand that the trucks moving foodstuffs are interested by tour with many stops. It is strictly related to the freight type that is characterised by daily consumption products coming from different companies. For what concerns the vehicle type analysis, survey highlights the use of light goods vehicles for tours with few stops.

The calibrated model considers three alternatives: one stop (1), two stops (2) and more than two stops (2+). The data analysis pointed out that the probability to have tour with  $n$  stops does not depend on destination zone attributes. Thus, the systematic utilities of each alternative have been expressed as a function of attributes relative to origin zone, freight and vehicle types:

$$V_1 = \beta_{IAT_1} \cdot IAT_o + \beta_{r_1} \cdot RET + \beta_{v_1} \cdot VEH + \beta_1 \cdot ASA_1$$

$$V_2 = \beta_{q_2} \cdot q + \beta_2 \cdot ASA_2$$

$$V_{2+} = \beta_{q_{2+}} \cdot q + \beta_{ct_{2+}} \cdot CT + \beta_{f_{2+}} \cdot FGT + \beta_{v_{2+}} \cdot VEH$$

where

- $V_1$  is the systematic utility for a tour with one stop (i.e. round trip),
- $V_2$  is the systematic utility for a tour with two stops,
- $V_{2+}$  is the systematic utility for a tour with more than two stops,
- $IAT_o$  is the accessibility index of zone  $o$ , from which the tour departs (e.g. warehouse location),
- $q$  is the average quantity of freight delivered at each stop along the tour,
- $RET$  is a dummy variable equal to 1 if the transport service is *retailer in own account*, 0 otherwise,
- $CT$  is a dummy variable equal to 1 if the transport service is *third party*, 0 otherwise,
- $VEH$  is a dummy variable equal to 1 if the used vehicle is a *light goods vehicles*, 0 otherwise,
- $FGT$  is a dummy variable equal to 1 if the delivered freight belongs to the *foodstuffs* class, 0 otherwise,
- $ASA_1$  is the Alternative Specific Attribute equal to 1 for a tour with one stops, 0 otherwise,
- $ASA_2$  is the Alternative Specific Attribute equal to 1 for a tour with two stops, 0 otherwise.

The accessibility index  $IAT_o$  is calculated as:

$$IAT_o = \ln \left\{ \left[ ACC_o - \min_z (ACC_z) \right] / \left[ \max_z (ACC_z) - \min_z (ACC_z) \right] \right\}$$

where  $ACC_x$  is the accessibility of zone  $x$  estimated as:

$$ACC_x = \sum_j (UL_j)^{\alpha_1} \cdot \exp[\alpha_2 \cdot dist_{xj}]$$

with

- $UL_j$  the number of retail establishments of zone  $j$  to be restocked,
- $dist_{xj}$  the distance between zone  $x$  and  $j$ , calculated on the road network according the path of minimum generalised travel cost,
- $\alpha_1$  and  $\alpha_2$  calibration parameters.

Table 4 - Trip chain order model: calibration results

Attribute	Symbol	Parameter	Value
Active accessibility	$IAT_o$	$\beta_{IAT_1}$	0.103 (3.3)
Delivered quantity	$q$	$\beta_{q_2}$	-0.074 (-1.5)
		$\beta_{q_{2+}}$	-0.105 (-1.5)
Transport service	$RET$	$\beta_{r_1}$	0.191 (2.7)
	$CT$	$\beta_{ct_{2+}}$	0.232 (2.0)
Freight type ( <i>foodstuffs</i> )	$FGT$	$\beta_{f_{2+}}$	1.001 (4.3)
Vehicle type ( <i>Light Goods Vehicle</i> )	$VEH$	$\beta_{v_1}$	0.384 (-1.5)
Alternative Specific Attribute (ASA)	$ASA_1$	$\beta_1$	0.648 (1.8)
	$ASA_2$	$\beta_2$	0.792 (1.4)
Accessibility		$\alpha_1$	3.216 (2.9)
		$\alpha_2$	-4.379 (-2.1)
$\rho^2$			<b>0.57</b>

The results of the calibration are reported in Table 4. We can see that all parameters are correct in sign and most of them are statistically significant as shown by  $t$ -student values. Parameter analysis shows the important role of the accessibility; in fact, we can see that increasing the accessibility, the number of stops per tour decreases. It confirms that the restocker prefers to do round trip if warehouse is located in a zone with an high accessibility as it allows them to reduce the operation complexity of tour management. The probability to have tours with more than 2 stops increases for foodstuffs. Finally as expected, the positive sign of vehicle type parameters confirm that the probability to have round trips increases for light goods vehicles and if small quantities to be delivered. Referring to transport service type, the positive values of parameters reflect that the probability to do round trips grows for retailer in own account, while the probability to have many stops per journey increases for third party. Even though they are the first results of the calibration of the trip chain order model, the value of  $\rho^2$  is quite good.

Finally, the analysis of the variable collinearity carried out by estimating the correlation of parameters reports that the maximum estimated absolute value of covariance is less than 0.6, as reported in Table 5. It proves the absence of collinearity among used attributes.

Table 5 - Trip chain order model: correlation of estimates

	$\beta_1$	$\beta_2$	$\beta_{IAT_1}$	$\beta_{v_1}$	$\beta_{r_1}$	$\beta_{q_2}$	$\beta_{ct_{2+}}$	$\beta_{f_{2+}}$
$\beta_2$	0.49							
$\beta_{IAT_1}$	0.50	0.01						
$\beta_{v_1}$	-0.60	0.00	-0.06					
$\beta_{r_1}$	-0.24	-0.07	-0.06	0.01				
$\beta_{q_2}$	0.26	-0.14	-0.13	-0.30	0.01			
$\beta_{ct_{2+}}$	0.34	0.51	0.04	0.00	-0.16	0.00		
$\beta_{f_{2+}}$	0.33	0.57	-0.01	0.01	-0.01	0.00	0.11	
$\beta_{q_{2+}}$	0.41	0.32	-0.11	-0.26	-0.01	0.40	0.07	0.17

#### 4. Conclusions

This paper proposed a two-level modelling system for simulating urban freight restocking tours. The former allows us to obtain OD matrices in deliveries, the latter allows us to estimate freight OD matrices in vehicles that satisfies a known delivery OD matrices. The latter has been developed by using the tour-based approach which allowed us to carry out OD matrices in vehicles by considering vehicle tours through the modelling of the trip chain order. The former is used to characterise the tours serving on OD pair *od* in terms of total number of stops. The latter is used to define the delivery locations of a given journey. A dataset of urban freight data collected in the centre of Rome has been used to support the model specification and calibration. In particular, the calibration of the trip chain order model pointed out the key role of the warehouse location, for which round trips are preferred for high accessible zones.

The calibrated model has been developed to test the goodness of the proposed approach, which explicitly considers the interaction between demand and logistics. Although the statistics obtained confirm the goodness of the proposed approach, further developments are required to specify, calibrate and validate the modelling system by using larger and more detailed samples.

Further developments of this research mainly regard: the calibration of the stop location model; the calibration of further trip chain order models for each transport service type; the investigation of the influence of shipment size, dimension of retail and zone to be served for the definition of the order trip chain; the modelling of choice set of stop location choice model. Finally, other developments could aim to develop this modelling system within a Decision Support System to be used for appraising impacts of urban freight transport measures and policies.

#### Acknowledgements

Authors would like to thank Chiara Danesi for her support in the analysis of the dataset.

*References*

- Hunt, J. D. and Stefan, K. J. (2007) "Tour-based microsimulation of urban commercial movements", *Transportation Research Part B* 41 (9), pp. 981-1013.
- Nuzzolo, A., Crisalli, U. and Comi, A. (2006) "A modelling system for urban freight movements", *Proceedings of the 11<sup>th</sup> International Conference of Hong Kong Society for Transportation Studies*, Hong Kong, China.
- Nuzzolo, A., Crisalli, U. and Comi, A. (2009) "A delivery approach modeling for urban freight restocking", *Proceedings of the 12<sup>th</sup> International Conference on Travel Behaviour Research (IATBR)*, Jaipur, India.
- Nuzzolo, A., Filippi, F., Comi, A. and Delle Site, P. (2010) "Ex-post assessment of city logistics measures: the case of Rome", *Proceedings of XVI International Conference SIDT 2009*, Mussone L. and Crisalli U. (eds.), Maggioli Editore, Milan, Italy.
- Ogden, K. W. (1992) "Urban Goods Movement", Ashgate, Hants, England.
- Oppenheim, N. (1994) "Urban Travel Demand Modeling", John Wiley & Son, New York.
- Raathanachonkun, P., Sano, K., Wisetjindawat, W. and Matsumoto, S. (2007) "Truck trips origin destination using commodity based model combined with an empty trip model", *Proceedings of the 86<sup>th</sup> Transportation Research Board Annual Meeting, Transportation Research Board*, Washington DC, U.S.A..
- Routhier, J. L. and F. Toilier (2007) "FRETURB V3, a policy oriented software of modelling urban goods movements", *Proceedings of the 11<sup>th</sup> World Conference on Transport Research*, Berkeley CA, U.S.A..
- Routhier, J.L., Aubert, P.L. (1998) "FRETURB, un modèle de simulation des transports de marchandises en ville", *Proceedings of the 8<sup>th</sup> World Conference on Transport Research*, Antwerp, Belgium.
- Russo, F. and Carteni, A. (2006) "Application of a tour-based model to simulate freight distribution in a large urbanized area", *Recent advances in city logistics: proceedings of the 4<sup>th</sup> International*, R. G. Thompson and E. Taniguchi (eds.), Elsevier Ltd., United Kingdom.
- Russo, F. and Comi, A. (2004) "A modelling system to link end-consumers and distribution logistics", *European Transport / Trasporti Europei*, 28, pp. 6-19.
- Russo, F. and Comi, A. (2010) "A modelling system to simulate goods movements at an urban scale", *Transportation* 37 (6), Springer Science+Business Media, LLC.
- Spielberg, F. and Smith, S. A. (1981) "Service and supply trips at federal institutions in Washington, DC area", *Transportation Research Record* 834, ASCE.
- Stefan, K., Brownlee, A.T., McMillan, J.D.P., Hunt, J.D. (2005) "The nature of urban commercial movements in Alberta", <http://www.calgary.ca>.
- Wang, Q. and Holguin-Veras, J. (2008) "An investigation on the attributes determining trip chaining behavior in hybrid micro-simulation urban freight models", *Proceedings of the 87<sup>th</sup> Transportation Research Board Annual Meeting*, Transportation Research Board, Washington DC, U.S.A..
- Wang, Q. and Holguin-Veras, J. (2009) "Tour-based entropy maximization formulations of urban freight demand", *Proceedings of the 88<sup>th</sup> Transportation Research Board Annual Meeting, Transportation Research Board*, Washington DC, U.S.A..