An aggregate multi-step model of the urban freight restocking tours

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1 Introduction

Most of the proposed modeling systems for the simulation of the urban freight transport focus on the estimation of the level and spatial distribution of commodity exchanges both in terms of quantity and delivery Origin-Destination (O-D) flows. In particular, the quantity O-D flows are required because they allow us to capture the mechanisms underlying the generation of freight transport demand [1, 2], while the delivery O-D flows to follow the decisional and logistic process of restocking [3, 4, 5]. Furthermore, starting both from quantity and delivery O-D matrices, the O-D vehicle flows should be estimated. The vehicle O-D matrices, interacting within the assignment model, allow us to obtain the link flows and then to estimate and evaluate performances and impacts of a given city logistics scenario.

The vehicle O-D matrices are quite different from delivery O-D matrices as it happens that the same vehicle can move through different destinations along the same tour, as each restocker jointly chooses the number and the location of deliveries for each restocking tour trying to reduce his costs (e.g. using routing algorithm; 6, 7). Both aggregate and disaggregate models have been proposed. The disaggregate ones (e.g. microsimulation or agent-based) focus on the behavior of single restocker. The aggregate models consider the average behavior of all restockers (or categories of restockers) starting from the same warehouse zone. Within this class, two approaches have been proposed: incremental growth and multi steps. The former studies [8, 9, 10] propose to obtain the number of stops per tour 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 because there are different behaviors depending on the number of stops/deliveries within the tour. The multi steps approach [11] estimates the freight vehicle O-D matrices through the definition of the trip chain order (that is the number of stops in a tour departing from a given origin zone – warehouse location zone) and the choice of the delivery locations.

The paper refers to the vehicle O-D matrices estimation using a restocking tour model within the aggregate multi-step approach, and presents some improvements of recent works developed by the authors in previous studies [4, 12]. In particular, based on survey data carried out in the city center of Rome, different behavioral modeling structures are investigated and the results are also compared with the revealed data.

This model is a part of a general model system, described in the following section 2, while section 3 reports the general structure of the proposed aggregate multi-step model of the urban freight restocking tours and section 4 is relative to the capability of the model to assess city logistics policies.

2 The general model system architecture

The general model system has been developing at University of Rome Tor Vergata in order to define a useful tool for assessing the effects of the city logistics policies/measures pointing out on each decision-maker's choice that could be influenced. It consists of different steps aggregated into three model sub-systems that allow us to estimate the quantity, delivery and vehicle exchanges within the urban area. In the following sections, the sub-systems are reported, while in the full paper, more details and the responses of the general modeling system for reproducing the goods movements in the study area will be briefly reported, too.

Even though, each sub-system allows us to characterize the commodity flows for freight types *s* (e.g. foodstuffs) and time period *h* (e.g. day), for simplicity of notation, the class indexes *s* and *h* will be taken as understood.

2.1 The quantity model sub-system

The average quantity flow of freight attracted by zone *d* and coming from zone *o* by transport service type *r*, $Q_{od}\left[r\right]$, is estimated 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 quantity of freight attracted by zone *d* obtained by an *attraction model*;
- *p[o/d]* is the probability that freight attracted by zone *d* comes from zone *o* (e.g. production place/firm, warehouse) obtained by an random utility *acquisition model*;
- *p[r/od]* is the probability to be restocked by transport service type *r* (e.g. retailer in own account or by carrier) obtained by a random utility *transport service type model*.

2.2 The delivery model sub-system

The average number of deliveries performed by service transport type *r* on *od* pair in time slice τ, $ND_{od}\ [\tau r]$, is determined as follows:

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

where

- $Q_{od}\ [r]$ is the average quantity flow of freight attracted by zone *d* and coming from zone *o* with transport service type *r* (see eq. *1*);
- *q[r]* is the average freight quantity delivered with service type *r* obtained by a random utility *shipment size model*;
- *p[τ/d]* is the probability of having deliveries in time slice τ obtained by a *delivery time model*.

2.3 The vehicle model sub-system

In the paper, it is proposed to obtain the O-D vehicle matrices using an aggregate multi-step restocking tour model that considers the average behavior of all restockers (or categories of restockers) starting from the same warehouse zone. The number of tours (i.e. number of vehicles) with n stops/deliveries departing from origin zone o at time t of time slice τ and operated by transport service r and vehicle type v, $T_o[vnt\tau r]$, is estimated as follows:

$$T_o\left[vnt\tau r\right]=T_o\left[\tau r\right]\cdot p\left[t/o\right]\cdot p\left[n/to\right]\cdot p\left[v/nto\right] \quad (3)$$

where

- $T_o[\tau r]$ is the total number of tours departing from origin zone o in time slice τ;
- $p[t/o]$ is the probability that the restocking tours depart at a certain time t from an origin o (i.e. warehouse zone) obtained by a random utility *departure time model*;
- $p[n/to]$ is the probability that deliveries are performed by tours departing from a given zone o with n stops/deliveries obtained by a random utility *trip chain order distribution model*;
- $p[v/nto]$ is the probability that deliveries are performed by vehicle type v obtained by a random utility *vehicle type model*.

The total number of tours $T_o[\tau r]$ can be determined as follows:

$$T_o\left[\tau r\right]=ND_{o.}\left[\tau r\right]/\bar{n}=\sum_{d'}ND_{od'}\left[\tau r\right]/\sum_n n\cdot p\left[n/to\right] \quad (4)$$

where

- $ND_o[\tau r]$ is the average number of deliveries performed by service transport type r departing from origin zone o in time slice τ;
- $\bar{n}$ is the average number of deliveries performed by tours departing from origin zone o at time t.

Being able to assume that each tour is performed by a vehicle and given $T_o[vnt\tau r]$ (see. eq. *3*), the number of vehicle $VC_{d_i d_j}$ on (d_i d_j) pair can be estimated as follows:

$$VC_{d_i d_j}\left[vnt\tau ro\right]=\sum_k VC_{d_i^{k+1} d_j^k}\left[vnt\tau ro\right]=T_o\left[vnt\tau r\right]\cdot\sum_k p\left[d_j^{k+1}/d_i^k vnt\tau ro\right] \quad (5)$$

where $p\left[d_j^{k+1}/d_i^k\, vnt\tau ro\right]$ is the probability of delivering in zone d_j the delivery ($k+1$), conditioned to have previously delivered in zone d_i the delivery k, within a tour with n stops/deliveries departing from a given zone o obtained by random utility *delivery location choice model*.

3 The aggregate multi-step restocking tour model

The above model sub-system has been specified, calibrated and validated for the city of Rome. The study has been supported by some surveys carried out in the city of Rome in 2008 and consisting of traffic counts, about 600 interviews to truck drivers and about 500 interviews to retailers. From survey data, it emerges that the departure time of tour is strictly related to the number of stops/deliveries for tour, the number of stops/deliveries for tour influences the type of used vehicle, and finally, the type of vehicle is related to the shipment size, that in turn depends on the characteristics of the shops of the destination zone. The models are structured in order to point out all these relationships, considering that the choice process can be considered as a hierarchical choice process, where each choice dimension can be influenced by each other

Based on these analyses, different model sequences, specifications and calibrations within the Random Utility Theory are tested and the results are also compared with the revealed flows.

4. The model and the city logistics policies assessment

In the current urban freight demand modeling literature, the direct relation between policies/measures and stakeholders' behaviors is not enough investigated. Then, the responses of proposed modeling system for reproducing the goods movements and how it allows us to assess city logistics scenarios will be discussed. In particular, the model seems able to assess the impacts of new Centers of Urban Distribution or Transit Points, such as accessibility variations, time and/or load and/or type of vehicle constraints, road or area pricing, retail or wholesale centers land use policies.

References

[1] J. Holguin-Veras and G. Patil, "A Multicommodity Integrated Freight Origin–destination Synthesis Mode", in *Networks and Spatial Economy 8 (2)*, 2008, 309-326.

[2] F. Russo and A. Comi, "A modelling system to simulate goods movements at an urban scale", *Transportation* 37 (6), Springer Science+Business Media, LLC, 2010, 987-1009.

[3] J. L. Routhier and F. Toilier, F. "FRETURB V3, a policy oriented software of modelling urban goods movement", in *Proceedings of the 11th World Conference on Transport Research*, Berkeley CA, 2007.

[4] A. Nuzzolo, U. Crisalli, A. Comi and S. Galuppi, "Demand models for the estimation of urban goods movements: an application to the city of Rome", in *Selected Proceedings of 12th World Conference on Transportation Research*, Viegas, J. M. and Macario, R. (eds.), Lisbon, Portugal, 2010.

[5] J. Muñuzuri, P. Cortés, L. Onieva and J. Guadix, "Modelling peak-hour urban freight movements with limited data availability", in *Computers & Industrial Engineering 59*, Elsevier Ltd, 2010, 34–44.

[6] G. Laporte, *What You Should Know about the Vehicle Routing Problem*, Les Cahiers du GERAD, G-2004-33, HEC Montreal, 2007.

[7] T. G. Crainic, N. Ricciardi and G. Storchi, "Models for Evaluating and Planning City Logistics Systems", in *Transportation Science 43 (4)*, 2009, 432-454.

[8] J. D. Hunt and K. J. Stefan, "Tour-based microsimulation of urban commercial movements", *Transportation Research Part B* 41 (9), Elsevier Ltd, 2007, 981-1013.

[9] Raothanachonkun, P., Sano, K., Wisetjindawat, W. and Matsumoto, S, "Truck trips origin destination using commodity based model combined with an empty trip model", in *Proceedings of the 86th Transportation Research Board Annual Meeting*, 2007, Washington DC, U.S.A..

[10] Q. Wang and J. Holguin-Veras, "An investigation on the attributes determining trip chaining behavior in hybrid micro-simulation urban freight models", in *Proceedings of the 87th Transportation Research Board Annual Meeting*, Washington DC, U.S.A., 2008.

[11] A. Nuzzolo, U. Crisalli and A. Comi, "A Restocking Tour Model for the Estimation of O-D Freight Vehicle in Urban Areas", in *Procedia Social and Behavioral Sciences 20*, Elsevier Ltd, 2011, 140–149.

[12] A. Nuzzolo, U. Crisalli and A. Comi, "A modelling system for urban goods movements", in *Proceedings of 11th International Conference of Hong Kong Society for Transportation Studies - Sustainable transportation*, S. C. Wong, Timothy D. Hau, James Jixian Wang, K. W. Chau and H. W. Ho (eds.), 2006, Hong Kong, Cina.