A General Coordinated Model to Simulate Urban Freight Distribution

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1 Introduction

Freight demand models are one of the key components of transportation planning at the strategic, tactical and operational levels. Public agencies need to forecast future transport needs for both people and commodities in order to provide the infrastructure and human resources that make such movement possible. The private sector needs forecasts of demand for transportation services in order to anticipate future financial commitments, equipment acquisition and labour requirements.

One of the greatest difficulties in analyzing freight mobility is the identification of decision-makers involved in the process. In the case of freight, there is no sole decision-maker who chooses trip characteristics, but rather a complex set of decision-makers responsible for production, distribution and marketing who, in turn, operate in different fields as producers, who have an economic function and deal with the production of goods, or as consumers, who are freight consumers and become producers of semi-finished goods, destined for the markets and hence towards end-consumers.

Freight transportation is commonly measured and described by either commodity movements or vehicle movements. Freight demand is derived from the socioeconomic system in which raw materials, intermediate inputs and finished products are needed at specific locations at specific times. Therefore the primary focus of freight transportation demand modelling should be commodity movements because vehicle movements are triggered by the need to move commodity.

The models have been developed to simulate freight transport at different scale: *national* and *urban*. It is not possible to extend the models at national scale to urban scale because one of the hypothesis on which the models are based is that the system must be closed or at least the relations with outside must be known and constant.

This paper focuses on urban freight transport and logistics. In the following a brief state of the art of urban freight demand models is reported. In section 2 the attention is directed to a general integrated system of models developed to analyze urban freight movements: before the general structure then the attraction, distribution and acquisition models.

In recent years, in the industrialized countries, studies on urban freight movements have increased because freight transport is a major source of traffic congestion and nuisance including air pollution and noise. So some models and many empiric methods were developed.
One of the first studies on urban freight movements is provided by Ogden (Ogden, 1992). He presents the first classification of urban freight models, reviewing models which have been actually developed for each freight category. This classification wants the models aggregated in: *commodity-based* and *truck-based* (Ogden, 1992; Taniguchi and Thompson, 1999; Holguín-Veras and Thorson, 2000). He also reports the first results of some case studies in many cities of the world, especially cities in the USA and Australia.

A general framework for freight demand models is given by Garrido and Regan (2000); an international comparison of methods developed and results obtained in urban goods movements is made by Routhier et alii (2001).

Another classification of urban freight demand models, proposed in literature, is the following: *gravitational models*, similar to those used for urban passenger travel analysis (Hutchinson, 1974; Ogden, 1992; List and Turnquist, 1994; Taylor, 1997; Fridstrom, 1998; He and Crainic, 1998; Gorys and Hausmanis, 1999); *input-output models* by Harris and Liu (1998); *spatial equilibrium of the prices* (Oppenheim, 1994).

The models developed present some limits. They do not start from end-consumer and so it is impossible to consider the connection with passenger models that have had a great development. In fact, the models developed analysing mainly the restocking process of urban activities (*dw* link).

2 General models

Model structure

A specific study has been developed in Italy to define, specify and calibrate a multi-step model to analyze urban freight transport and logistics (Russo and Comi, 2002). Urban scale models may be developed, breaking them down into parts: the first concerns calculation of the demand by freight type, by *o-d* consumption pair and *d-w* restocking pair starting from socioeconomic data, while the second concerns determination of the mode, service, time and vehicle used as well as the route chosen for restocking sales outlets. The freight transport multi-step model used concerns a medium-size city and considers a disaggregated approach for each decisional level.

First level

- *Quantity attraction and distribution models*. From the general population data (residents, number of employees, stores, etc.), we calculate the quantity for each freight category that reaches each traffic zone *o* on one day arriving from each zone *d*; in this case it is assumed that the decision-maker is the end consumer assumed in the family (Russo and Comi, 2003a);
- *Acquisition model* (or large-scale distribution). From the data on the location of logistic bases, general stores, etc., we may calculate for a general retailer in zone *d* the probability of purchasing, in the generic zone *w*, the goods that will be on sale in his/her store in zone *d*;

Second level

- *Models for the choice of service, vehicle type, time and path*. The type of vehicle used for each goods class, with the quantity that it transports and the type of service performed (Daganzo, 1991) (one-to-one, one-to-many, many-to-many, many-to-one) is obtained by means of a logistic model. For each type of service and vehicle the probability of each path is evaluated.

Quantity attraction and distribution models

The freight that is transported each day in an urban centre may be grouped into various categories. The first phase of the analysis consists in the identification of homogeneous categories for aggregating daily shopping trips. A macro-segmentation of trip types is given by: durable and non-durable goods.

The attraction and distribution macro-models, with the decision-maker as the end consumer consist of a set of elementary models that allow us to calculate, as final output, the freight quantities (disaggregated by freight typology) that are required in the shops of each traffic zone in the area (*demand in freight quantity for each od*). For the specification of the elementary models we can use two different approaches (figure 1):

- *trip-based* and
- *purchase-based*.

The difference between the two approaches consists in the estimation of the average number of user trips (trip-based) or the average number of purchases (purchase-based) made by each end consumer with origin *o* and destination shops in the zone *d*. If the end consumer purchases the freight using the e-commerce, we can introduce another model to analyse this process, because he/she buys directly from producers and not in a shop of zone *d*.

In the trip-based approach the models that permit to calculate the *od* matrices in trips (highlighted in fig. 1) can be substitute with the passenger models (Russo and Comi, 2003a).

Having obtained the *od* matrixes, in trips or in purchases, a new model must be introduced (*purchase choice model*) that allows a dimension to be given to each trip or purchase. The output of this model is similar but the input is very different because in the trip-based approach the input consists of trips, but in purchase-based approach the input consists of purchases. Figure 1 reports the sequence defined above .

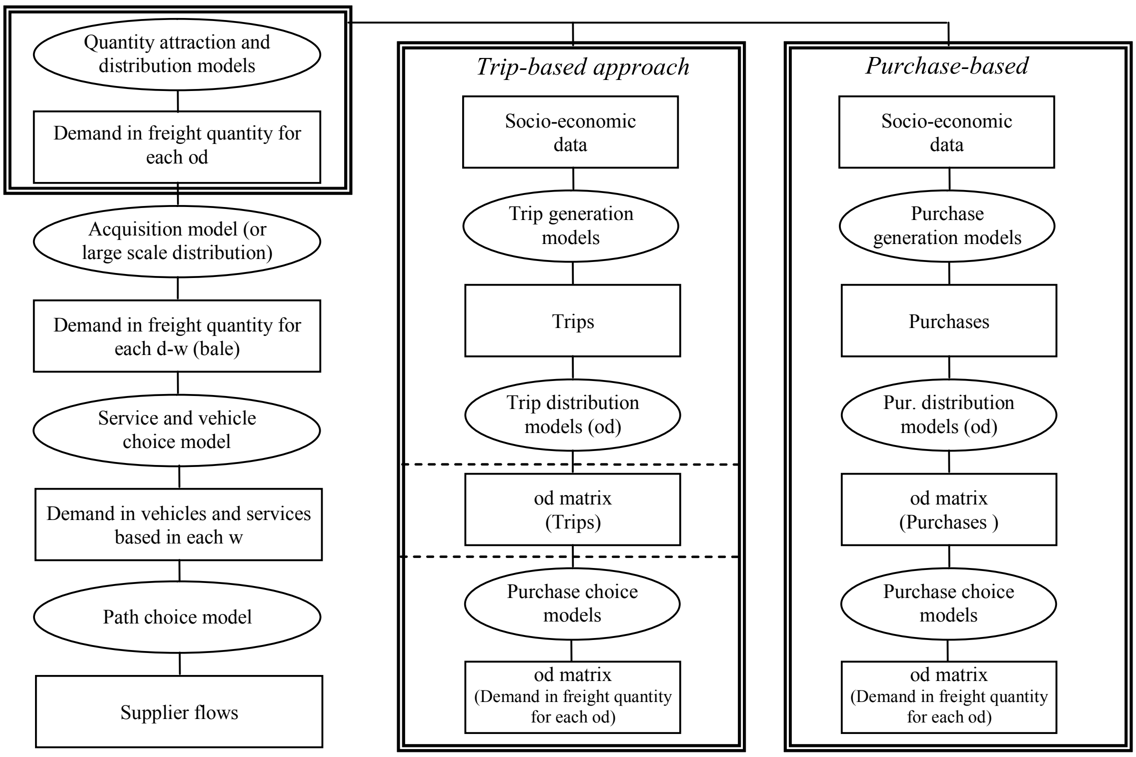

Figure 1: Compared structures of quantity attraction and distribution models.

In the following the models of trip-based approach, when the end consumer does not purchase directly from producers (firm) are reported.

For estimating the quantity of goods attracted by each zone the decision-maker in question is the family. According to the number of families in each zone, the number of trips affected from/to the same zone may be estimated, classifying the attracted goods in homogeneous typology *k*. From the data relative to the families and the shopping trips undertaken and from the goods classification, the quantities purchased may be estimated.

For each family *f*, the number of trips with origin *o* and typology *k* can be calculated as:

$$d_o^f(k) = n^f(o)\ m^f(ok)$$

where $n^f(o)$ is number of families resident in zone *o* and $m^f\ (ok)$ is the mean number of trips undertaken to purchase goods of typology *k*, departing from *o*, and it can be expressed as:

$$m^f(ok) = \sum_x x\, p^f(x/ok)$$

where $p^f\ (x/ok)$ is the probability of undertaking *x* trips with *x* equal to *0*, *1*, …, *n*. This probability can be determined as:

$$p^f(x/ok) = prob(U_x^f > U_{x'}^f) = prob(V_x^f + \varepsilon_x^f > V_{x'}^f + \varepsilon_{x'}^f) \qquad \forall x' \neq x, x' \in \{0,1,...,n\}$$

To know where each trip is directed we can use a distribution model. It expresses the probability $p^f\ (d/ok)$ of trips undertaken by family *f* going to destination *d* from *o*. If D_o^f is set of alternatives, for a family *f* resident in *o*, the probability can be expressed as:

$$p^f(d/ok) = prob(U_d^f > U_{d'}^f) = prob(V_d^f + \varepsilon_d^f > V_{d'}^f + \varepsilon_{d'}^f) \qquad \forall d' \neq d, d' \in D_o^f$$

It may be noted that in the trip-based approach, the generation and distribution models are those that traditionally trips allow to be calculated. In the literature we have several models available, such as statistic-descriptive (Ortuzar and Willumsen, 1994) or probabilistic-behavioural (Ben-Akiva and Lerman, 1985). While all are usable, the difficulty of employing them is the complexity of the purchase choice model, defined above, to convert trips into quantities.
Now, we must convert the trips to quantities to obtain the quantities of freight need in each zone *d* and we can use a purchase choice model. The probability $p^f(dim/odk)$ that a trip concludes with a purchase of dimension *dim* (0, dim_1, dim_2, …., dim_n) can be expresses as:

$$p^f(dim/odk) = prob(U_{dim}^f > U_{dim'}^f) = prob(V_{dim}^f + \varepsilon_{dim}^f > V_{dim'}^f + \varepsilon_{dim'}^f) \quad \forall\, dim' \neq dim, dim' \in \{0,...,dim_n\}$$

Acquisition model

The acquisition model informs us where a generic retailer *r* obtains freight in his/her shops for restocking. Using the previous models, we know the quantities of freight, disaggregated in different typology, required in each traffic zone. Now we must know where these goods are purchased by the retailer.

Before, we need to inquire into the acquisition process (large-scale distribution). In general, we have several channels of acquisition. A generic firm that wants to sell (hence send its freight) into an urban area, can use several channels of large-scale distribution:

- channel 1 (c_1): a firm, located in zone *z* (outside of the study area), uses a warehouse near (or inside) the study area and each retailer brings the freight that he sells in his shop from this warehouse;
- channel 2 (c_2): a firm, located in zone *z*, send its freight directly to the shop inside the city.

On these firm choices the retailer can choose like to acquire the freight. Then, the decision maker in the case of channel 1 is the retailer, not for case of channel 2. In fact the retailer deals with agent the purchase and does not perceive from which zone the freight arrives to his shop.
The probability $p^r(c/dk)$ of choosing the channel *c* to acquire freight *k* for a retailer *r* of zone *d*, with C_d^r set of alternatives, can be defined as:

$$p^r(c/dk) = prob(U_c^r > U_{c'}^r) = prob(V_c^r + \varepsilon_c^r > V_{c'}^r + \varepsilon_{c'}^r) \qquad \forall c' \neq c,\ c' \in C_d^r = \{c_1, c_2\}$$

To obtain the different percentages using one or another channel we can use a statistic-descriptive model, too. For surveys, it emerged that the channel 1 is chosen by 48% of cases (CSST, 1998). In the following we report the model developed for channel 1: the residents of zone *o* consume the goods in their resident zone *o* and purchase them in zone *d*, where there are retailers that purchase the freight, sold in their shops, in zone *w*.

Traditionally this model is statistic-descriptive and aggregate. However, we propose a disaggregate approach, and so the model gives the acquisition probability from different zones *w* for the retailer who sells in the generic zone *d*. Formally the model gives the percentage $p^r(w/c_1dk)$ of freight that, having to be sold to end consumers in zone *d*, is supplied from zone *w*. Importantly, for shopping centres the restocking of non-durable goods arrives intermodally or directly by lorry from zone *z*.

The probability $p^r(w/c_1dk)$ of purchasing in zone, with set of $w \in W_d^r$ alternatives, for a generic retailer *r* located in zone *d* that chose channel c_1, can be expressed as (Russo and Comi, 2003b):

$$p^r(w/c_1dk) = prob(U_w^r > U_{w'}^r) = prob(V_w^r + \varepsilon_w^r > V_{w'}^r + \varepsilon_{w'}^r) \qquad \forall w' \neq w, w' \in W_d^r$$

The systematic utility V_w^r can be expressed as a linear combination of parameter vector $\underline{\beta}$ with attribute vector $\underline{\mathbf{X}}$.

The attributes $\underline{\mathbf{X}}$ can be aggregated in three different classes: attributes specific to the generic acquisition zone *w*, attributes specific to the goods and attributes of generalised cost that regard the disutility of making a purchase in zone *w* of goods that are on sale in shops of zone *d*. In many cases, in the expression of systematic utility we can introduce a "size function" to represent the actual number of elementary alternatives depending on other variables of zone *w* and zone *d* (Ben-Akiva et alii, 1984), a "passive" or "active" accessibility to represent the ease of reaching one zone from others or how a zone may have access to businesses in other zones.

Different random utility models can be specified according to the hypothesis on the distribution of random residuals ε_w^r .

3 Conclusions

In this paper a system of models for urban goods movements is been proposed. The model system can be considered the first results to analyse the freight transport at metropolitan level and can be useful if we wish to estimate the number of vehicles that drive in a city, causing many problems to urban traffic. Other analyses are required in order to improve the results obtained.

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