A Tour-based Freight Distribution Model

Francesco Russo* Armando Cartenì**

*University of Reggio Calabria "Mediterranea"
Via Graziella, Loc. Feo di Vito, I-89100 Reggio Calabria, Italy
russo@ing.unirc.it

** University of Naples "Federico II"
Via Claudio, 21, 80125 Naples, Italy
acarteni@unina.it

1 Introduction

Today freight covers great importance in the field of the transportation system and in general in the economic system. It represents one of the most important elements in the national economy development process.

Freight transport demand is closely connected to the production and distribution of goods. Demand flows represent movements of quantities of goods; the relevant characteristics are normally associated with goods typology (raw materials, semi-finished products, finished products, etc.), with economic activity sectors, with industrial logistics characteristics (e.g. shipping frequency and size) as well as with modes of transport. The latter are usually defined not only as the physical vehicles (truck, train, ship) but also by their organization (own shipment, by carrier, etc.). The Freight demand is generally influenced by the economics variables of production (value of production by sector, number and size of local units, etc.) and consumption (household consumption, imports, etc.), by the variables of the transport system like the attributes of the different transport modes and services (times, costs, service reliability, etc.).

The complexity of freight mobility is characterized by a large number of journeys connecting several activities in different locations, i.e., journeys consisting of sequences of trips influencing each other. So also the planning activity on the freight transport system is very complex. In this field, project decisions can be made in many different ways. One of these is based on the evaluation of the various effects of the different possible projects on the different parties involved. This approach, which is commonly adopted in the case of "private" decisions, is even more necessary when the decisions are made by a public administration, which must, either directly or indirectly, consider the effects of proposed actions on the collectivity.

To plan actions on a transport system is necessary to have a *Decisions Support System* (*DSS*), like a mathematical model, both to analyze the actual situation (for the identification of its main inadequacies or "critical points") and to verify one or more alternative projects. Precisely, crucial element of the planning process is the simulation of the relevant effects (impacts) of the project realization. Most of these impacts can be quantitatively simulated using the mathematical models.

For the analysis of freight demand are generally used aggregate non-behavioural models. The most investigated topics are the national freight (Harker, 1985; Bayliss, 1988; Cascetta *et alii*, 1995; Nuzzolo and Russo, 1997; Cascetta and Iannò, 2000; Regan. and Garrido, 2000; Cascetta, 2001), the regional freight (Cartenì and Russo, 2004; Russo and Cartenì, 2003) and the movement and management of urban freight and problems concerned with them (Ogden, 1992; Oppenheim, 1995; Russo and Comi, 2002).

This paper presents a system of models for the explicit simulation of freight distribution (see fig. 1) as a whole by analysing the procurement phase (from suppliers to manufacturers) and the distribution phase (from manufacturers to consumers). The models results in all the supplier-manufacturer demand flows and manufacturer-customer ones as well as referred to a fixed period of time, with the explicit simulation of all transfers occurring within the distribution channels considered (logistic centres and/or wholesalers provided in the distribution channel considered).

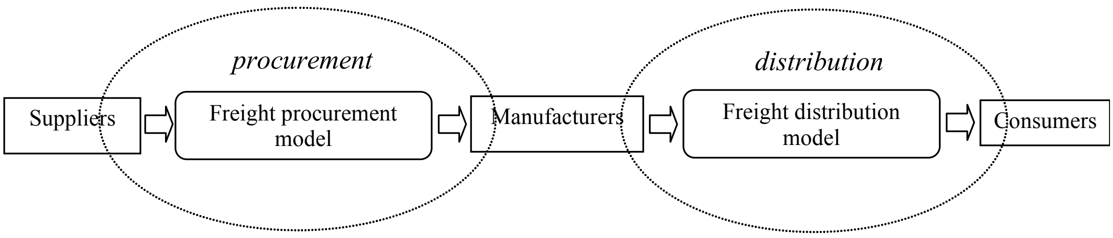

Figure 1 – The hypothesized model

2 Methodology

A *tour-based* model has been used for the simulation of the freight distribution. Tour-based approach, designed to estimate the mobility demand, were developed in the late '80s and the '90s in the Netherlands to face the inefficiencies of the so-called *trip-based* approach. They allow to simulate the dependences existing between successive trips of the same distribution channel. That means that each destination will be chosen considering the preceding and successive destinations by considering the number of transfers as a whole, and so on.

In order to implement such a model it is essential to understand the constraints linking all decision-maker's choices and to identify the type of relations linking one decision-maker to the other.

The hypothesized model assumes as known the level of materials procurement and the quantity of manufacturing, as referred to an *H* fixed reference period of time (for ex. an average business day or a year), grouping together firms acting in a similar way, which means firms for which it is possible to assume a similar commodity group and a similar structure of the supply chain. That allows to take into consideration for any group considered (for ex. company) the same criteria, as representative of the same class of decision-makers. For each class it is therefore possible to use the same set of logistics variables.

The hypothesized model system basically consists of two submodels: the *procurement model* and the *distribution model*. The former assumes as known the location of suppliers and manufacturing plants; the latter assumes as known the manufacturing plants and possible markets (shops, stores, cities, towns,…). On simulating real conditions it is obviously necessary to know (for both models) the location of freight transport centres (i.e. dry ports, logistic centres, wholesalers…) provided between the suppliers (manufacturers) and the manufacturers (consumers).

2.1 The general freight distribution model

The general freight distribution model consists of three submodels:

- *the simulation model of the distribution strategy*, simulating all choices relative to the procurement/sale market and to the distribution strategies;
- *the simulation model of the first trip*, simulating all choices relative to trips from manufacturers (suppliers) to first level logistic centres, possibly provided in the distribution strategy, (such as dry ports, regional logistic centres…);
- *the simulation model of the subsequent trips*, simulating all the choices relative to trips from first level logistic centres to second level logistic centres, possibly existing in the distribution channel (provincial logistic centres, wholesalers, local warehouses …) up to the end destination (the market);

In figure 2 the structure of the hypothesized model is shown which is conditioned by two types of factors: 1) first level decisions condition the second level ones; 2) second level decisions condition first level ones in some way. An example of how a first level decision can condition a second level one is the choice of the departure lapse of time, according to which if an in-between trip has not been carried out (first level), it is not possible to give start to the subsequent one (second level). An example of how a second level choice can influence a first level one might be the choice concerning the loading unit (first level) which undoubtedly has to take into account the freight modes available (second level).

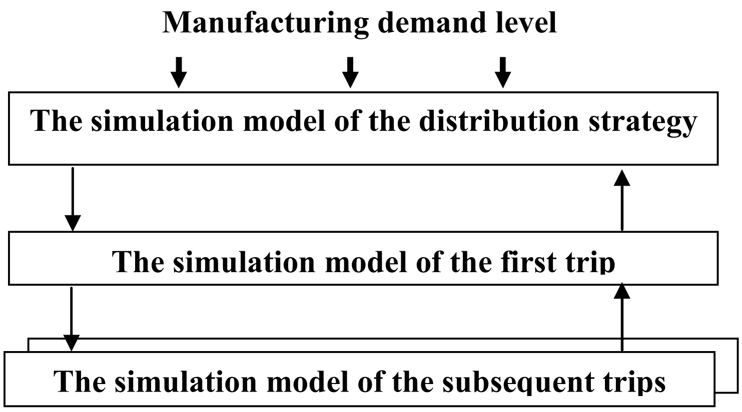

Figure 2 - The structure of the hypothesized distribution model

For the specification of this system of models a Nested Logit model can reproduce the choice hierarchical structure. In particular, as there is no single decision-maker in freight strategies but, quite often, more subjects are involved along the transfers from the manufacturing plants to the retailers, the adoption of such a model allows to explicitly simulate single individual choices (which however affect one another).

Formally the demand pattern to be simulated concerning a particular s commodity sector can be indicated as $d^{s}_{od}(\boldsymbol{L},\boldsymbol{T},\boldsymbol{E},\boldsymbol{\beta})$, where the mean demand flow between o and d zones can be expressed as function of a $\boldsymbol{L}$ vector of logistic variables (for ex. total or partial logistic cost), relative to the logistic system considered, of an $\boldsymbol{T}$ vector of level of service variables (for ex. travel time), of an $\boldsymbol{E}$ vector of economic variables (for ex. number of shops or number of operators in a determined economic sector, number of logistic centres…) and of $\boldsymbol{\beta}$, vector of coefficients existing in mathematical models used.

<u>The simulation model of the distribution strategy</u> allows to simulate:

- choice of the procurement market (manufacturer market), $F^{s}[od/H](\boldsymbol{L},\boldsymbol{T},\boldsymbol{E})$;
- choice of the lapse of time h within the reference period H of time by which delivery of the consignment has to be effected, $p^{s}[h/o,H,d](\boldsymbol{L},\boldsymbol{T},\boldsymbol{E})$;

- choice of the distribution channel K^s, $p^s\left[K^s / o, H, d, h\right]\left(\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E}\right)$:

The simulation model of the first trip allows to simulate the first trip choices conditioned by all the elements that define distribution strategy, H , s , o , d , h :

- choice of the first d' transit destination (dry port, logistic centre,…), $p^s[d' / o, H, d, h, K^s](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$;
- choice of the u' loading unit (container, semitrailer…) for the first trip, $p^s[u' / o, H, d, h, K^s, d'](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$;
- choice of the h' leaving lapse of time between the o departing point (supplier/manufacturer) and first d' intermediate destination, $p^s[h' / o, H, d, h, K^s, d', u'](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$;
- choice of the m' freight service, or of the freight modes available, conditioned with the u' loading unit, and linking the o d' pair starting from h' lapse of time, $p^s[m' / o, H, d, h, K^s, d', u', h'](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$.

The simulation model of the subsequent trips allows to simulate all the choices relative to trips from “first level” logistic centres to “second level” logistic centres (provincial logistic centres, wholesalers, local warehouses …), possibly existing in the distribution channel up to the end destination (the market). For example, assuming one in-between stop in the distribution channel at the most, the model allows to simulate:

- choice of the u'' loading unit for the second trip, by the loading unit choice patter, $p^s[u'' / o, H, d, h, K^s, d', u', h', m'](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$;
- choice of the h'' departing lapse of time from the d' departing point (for ex. logistic centre) to the d final destination (as conditioned with h'), by the departing lapse of time choice pattern, $p^s[h'' / o, H, d, h, K^s, d', u', h', m, u''](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$;
- choice of the m'' freight service, or of the freight modes available, conditioned with the u'' loading unit, linking the d' d pair starting from h'' lapse of time, by the freight service choice pattern, $p^s[m'' / o, H, d, h, K^s, d', u', h', m, u'', h''](\boldsymbol{L}, \boldsymbol{T}, \boldsymbol{E})$.

The freight demand from origin o to the destination d of the commodity sector s , in the reference period H , with h lapse of time by which delivery of the consignment has to be effected, distribution channel K^s , d' transit destination, u' and u'' loading unit, h' and h'' leaving lapse of time, m' and m'' freight service is:

$$d^s_{od}\left(H, K^s, d', u', h', m', u'', h'', m''\right) = F^s\left[od / H\right] \cdot p^s\left[h / o, H, d\right] \cdot p^s\left[K^s / o, H, d, h\right] \cdot p^s\left[d' / o, H, d, h, K^s\right] \cdot p^s\left[u' / o, H, d, h, K^s, d'\right] \cdot p^s\left[h' / o, H, d, h, K^s, d', u'\right] \cdot p^s\left[m' / o, H, d, h, K^s, d', u', h'\right] \cdot p^s\left[u'' / o, H, d, h, K^s, d', u', h', m'\right] \cdot p^s\left[h'' / o, H, d, h, K^s, d', u', h', m, u''\right] \cdot p^s\left[m'' / o, H, d, h, K^s, d', u', h', m, u'', h''\right].$$

While the freight demand from origin o to the destination d referred to all the commodity sectors s, with characteristics $o, d, H, d', u', h', m', u'', h'', m''$ is:

$$d_{od}\left(H, d', u', h', m', u'', h'', m''\right) = \sum_{s} d_{od}^{s}\left(h, K^{s}, d', u', h', m', u'', h'', m''\right)$$

Altogether the freight demand from origin o to the destination d in the reference period H is:

$$d_{od}(H) = \sum_{s}\sum_{d'}\sum_{u'}\sum_{h'}\sum_{m'}\sum_{u''}\sum_{h''}\sum_{m''} d_{od}^{s}\left(h, K^{s}, d', u', h', m', u'', h'', m''\right)$$

This system of models was applied to estimate the Campania freight distribution. In this application some aggregate data available on the demand and some traffic counts can be used to estimate the parameters of the models.

3 Conclusion

This study has allowed to: (a) understand some aspects of freight mobility problem, highlighting how a thorough knowledge of the matter is essential to choose the best model approach; (b) point out some limits of current scientific literature about freight distribution; (c) design the architecture of an advanced model for the analysis of freight distribution; (d) apply the hypothesized model to the simulation of freight distribution in Campania region.

References

B. Bayliss, *The Measurement of Supply and Demand in Freight Transport*. Hants, England, Avebury Grower Publishing Company Ltd (1988).

A. Cartenì and F. Russo, “A distribution regional freight demand model”, presented at the Tenth International Conference on Urban Transport and the Environment in the 21st Century, Dresden, Germany, May 2004.

E. Cascetta, A. Nuzzolo, L. Biggiero and F. Russo, “Passenger and freight demand models for the Italian transportation system”. *Proceeding of 7 World Conference on Transport Research*, Sydney (1995).

E. Cascetta and D. Iannò, “Calibrazione aggregata di un sistema di modelli di domanda merci a scala nazionale". *Metodi e Tecnologie dell'Ingegneria dei Trasporti* edit by Cantarella G. E. and Russo F., Franco Angeli, 156-178 (2000).

E. Cascetta, *Transportation systems engineering: theory and methods*, Kluwer Academic Publishers (2001).

P.T. Harker, *Spatial price equilibrium: advances in theory, computation and application*, Springer Verlag, Heidelberg (1985).

A. Nuzzolo and F. Russo, "Modal Split at international level: a system of models for Italia based freight". *Proceeding of 25th PTRC*, Europe Transport Forum, London (1997).

K.W. Ogden, *Urban goods movement, a guide to policy and planning*, Ashgate (1992).

N. Oppenheim, *Urban travel demand modelling*, Wiley-International Publication (1995).
A.C. Regan and R. A. Garrido, "Modeling freight demand and shipper behaviour: state of the art, future directions", *Proceeding of IATBR* (2000).

F. Russo and A. Comi, "A general multi-step model for urban freight movements", *Proceeding of PTRC,* Europe Transport Forum, London (2002).

F. Russo and A. Cartenì, "Regional freight transport distribution models", presented at ODYSSEUS, II Inter. Workshop on Freight Transportation and Logistics, Palermo, May 2003.