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A modelling system to link end-consumers and distribution logistics

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Abstract

In the last years the interest in urban freight mobility has increased. However, the management and control of urban freight transport requires models which simulate the transport system. In literature some models have been analysed and implemented with tools which allow the verification of the measures adopted in several cities around the world.

In paper a review of measures implemented in some cities to reduce the negative effects of urban freight transport, an updated review of models developed to analyse urban freight mobility and the tools used to verify and check the proposed measures are presented. Finally the modelling system to link end-consumer and distribution logistics is described.

Keywords: Freight; Models; Urban goods movements; Best practices.

Introduction

Freight transport has a major role to play in the transport system, and in the economics system in general, being a key element in the process of economic development.

In Europe, it has emerged from various surveys that the main components of freight urban transport are represented by distribution and purchases, amounting to about 81% of total trips, while construction and building-related trips are about 5% (COST 321). If purchase mobility is not considered in the set, distribution accounts for 68%, while other significant components are construction and building-related trips (8%) and removals (8%).

In recent years, in the industrialized countries, studies of urban freight movements have increased since freight transport is a major source of traffic congestion and nuisance, including air and noise pollution.

The swift increase of freight vehicles in urban and metropolitan areas contributes to congestion, air pollution, noise, and to increases in logistic costs and hence, the price of

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products. In addition, a combination of different types of vehicles on the road increases the risk of accidents. An efficient freight distribution system is required as it plays a significant role in the competitiveness of an urban area and is in itself an important element in the urban economy, both in terms of the income it generates and the employment levels it supports. Many initiatives have been developed in urban areas but few are supported by mathematical models. This emerged, as conclusions, also from a European Project that analysed the implemented measures in many cities around the world (BESTUFS, 2000-2004; Egger and Ruesch, 2003). It is necessary to have models for the design, evaluation and control of urban freight transport systems, thus simulating with the use of models what the state of the system will be once the new scheme/practice is adopted.

In this paper we will focus on the research into urban goods movements and we propose an advanced model system that seeks to link end-consumers and distribution logistics.

In the following section the freight measures at urban scale will be investigated and a classification will be proposed; state-of-the-art urban freight models will be discussed and finally, the tools and software used to simulate urban freight mobility will be described. Section three describes the modelling system developed to analyse freight and passengers together. This is followed by several conclusions.

State of the art

Freight measures at urban scale

An initial list of measures related to urban freight transport was given by COST 321 Action (1998). The identified measures are about 60 and are classified in 8 different classes. COST 321 provided quantitative results on the impact of measures and estimated effects in projects and case studies.

In 2000, the European Commission established a thematic network on Best Urban Freight Solutions (BESTUFS) with a 4-year duration. BESTUFS aims to identify and disseminate best practices with respect to urban freight transport. The BESTUFS project can be seen as a follow-up and continuation of the COST 321 project (Ruesch and Glucker, 2000; Wild, 2003).

Recently two European Projects on urban freight distribution were concluded: City Freight and City Ports.

City Freight was concluded in 2004. It carried out an analysis of selected freight transport systems already functioning in Europe and evaluated their socio-economic and environmental impacts in an urban context, with a common assessment methodology. City Freight focused on innovative and promising logistic schemes in the seven countries represented in the project consortium. The objectives of the City Freight project are the following: to identify and analyze the working of innovative and promising logistic schemes in the seven countries represented in the project consortium as well as the urban policies which could accompany their implementation in order to promote more sustainable development; set up a list of criteria and a common assessment method for evaluating such logistic schemes and the related accompanying policies (legal framework, land use planning, road traffic regulation, pricing); to analyze their internal technical and economical efficiency; to design, for a city or an urban region in each country, one or more implementation scenarios of these schemes and related policies; to assess and optimize the scenarios according to the criteria of a sustainable development of the city; to present guidelines for implementing integrated strategies that could be recommended as "Best Practices"; to disseminate and exploit the Best Practice Guidelines through collaboration with local authorities for the design of concrete implementation plans of integrated strategies in each of the case study cities (City Freight, 2005).

The investigation of tools and policies for urban goods distribution in some European cities was done with an European project called City Ports and concluded in 2005. This project has been devoted to outline a general method to address city logistics problems within a comprehensive framework where policies are defined after local analysis, ranking of critical issues, design and evaluation of specific solutions, and through the involvement of the various stakeholders. The project joined a network of various cities, which followed a coordinated and parallel implementation of pilot actions, in the framework of the common methodology and exchanging experiences and results (City Ports, 2005).

To analyse the effects of policy measures and company initiatives for sustainable urban distribution, in England a project entitled "Modelling policy measures and company initiatives for sustainable urban distribution" was developed (Allen et alii, 2003). The main aim of the project has been to investigate the extent to which policy measures and company initiatives are likely to result in changes in patterns of goods flows and goods vehicle activity in different types of urban distribution operations.

The previous studies that analysed the measures implemented in urban area gave a list and did not consider the possibility to classify them in function of some characteristics, e.g. who takes the decisions (public agencies, etc.) or who has to undergo to them (community, retailers, carriers, etc.). So trying to find a classification that allows to consider it and from the study of world urban contexts, the main measures adopted in the urban areas can be classified into four classes:

- unit of transport, load and handling;
- infrastructure;
- telematics;
- management.

The measures on units of transport are on weights, space and emissions. This has implied the use of zero emission vehicles (tram, electric vehicles, etc.).

The infrastructural measures can be classified into three classes:

- nodal, like a Freight Platform (areas with different transport related companies and where at least two transport modes are connected); according to REFORM (1999) freight platforms can be defined as areas in which different transport related companies such as forwarders, logistic service providers etc. are established. There are different types of Freight Platform:
    - Freight Village (focus on multimodal transport), place where the transhipment is done and service providers are established on site, as well as a large number of forwarders and transport companies,

   - Urban Distribution Centre; according to COST 321 it is a place of transhipment from long distance traffic to short distance (urban) traffic where the consignments can be sorted and bundled. In some cases the Urban Distribution Centre located close to city borders can be within the Freight Village and interfaces long distance transport and city distribution services;
- linear, as heavy vehicle network;
- surface, as areas for loading and unloading operations (Egger et alii, 2001; Egger and Ruesch, 2003).

The main measures on telematics can be aggregated in: traffic information, freight capacity exchange system, route optimisation services, vehicle maintenance management system, other information services through internet access, centralised route planning.

Finally there are the measures on management. We can have measures on: access time, heavy vehicles network, road-pricing, maximum parking time, maximum occupied surface and specific permission.

In Table 1, as an example, we summarise some measures adopted in four European metropolitan cities.

Table 1**:** Example of some freight measures in four European cities.

		Barcelona	***Paris***	***London***	***Rome***
Unit of transport	*Emissions*	X			X
	Weight	X			X
	Space	X			
Infrastructure	*Urban Freight Platform*	X			X
	Loading and unloading surface	X	X		
	Network for commercial vehicles	X			
Telematics	*Access system*	X			
	Centralised Route Planning	X	X	X	X
Management	*Access time*				X
	Road-pricing			X	
	Maximum occupied surface		X		
	Specific permission			X	X

Urban freight models

The first models on urban freight movements were proposed by Hutchinson in 1974. These models refer to the estimation of truck trips for some types of goods. Some daily truck-movement profiles were also reported.

In-depth analysis and a detailed description of urban goods movements were performed by Ogden (1992), who was the first to classify urban freight models, reviewing models which have actually been developed for each freight category. He also reports the first results of case studies in several cities worldwide, especially in the USA and Australia.

The models developed first by Hutchinson and later by Ogden are multi-step models, similar to those used for urban passenger mobility. Ogden proposed some models, both for goods quantity estimation and for direct truck estimation. Some of these models were specified and calibrated for many urban freight categories. The models aiming to analyze the generation of freight or truck trips are descriptive of the index type per category. For distribution he reports some gravitational models. As he focuses mainly on attraction/generation and distribution models, he does not study models for commodity modal split, vehicle loading or for assignment in depth. He only proposes, for example in the case of assignment, some procedures to adapt the traditional models to freight movements.

More recently, similar analyses have been proposed by List and Turnquist (1994), Taylor (1997), Fridstrom (1998), He and Crainic (1998) and Gorys and Hausmanis (1999), while a combined equilibrium model of urban passenger travel and goods movement was proposed by Oppenheim (1994), in which commodity flows are generated by the need to support a given generic urban activity undertaken by individual travellers, which involves consumption of a given commodity. Travellers are assumed to maximize their utilities, through their joint choice of an activity site and travel route to it. Activity suppliers also maximize their utilities through their joint choice of commodity suppliers and freight shipping routes. An input-output model was adapted and applied to the Portsmouth area to predict purchases and sales for different freight categories within and outside the city limits by Harris and Liu (1998). An in-depth analysis of the relationship between trip length distributions (TLDs), in particular between vehicle TLD and tonnage TLD was performed by Holguin-Veras and Thorson (2000). The analysis revealed that: the shape of the TLDs depends upon the type of movements being considered; TLDs defined in terms of tonnage differ significantly from those defined in terms of vehicle-trips; TLDs for different types of vehicles, transporting similar commodities, reflect the range of use of each type of vehicle; albeit different, the relationship between tonnage TLDs and vehicle TLDs seems to follow a systematic pattern that, if successfully identified, would enable transportation planners to estimate a type of TLD, given the other. Major freight generators are likely to impact the shape of the TLDs such that complementary models may be needed to provide meaningful depictions of freight movements. An overall discussion of freight demand modelling is also conducted.

According to the outputs given by the models developed for freight analysis at urban scale a classification, accepted by several authors (Hutchinson, 1974; Ogden, 1992; Holguín-Veras and Thorson, 2000; Taniguchi et alii, 2001), categorizes the existing urban models in:

- *commodity-based*, models based upon the notion that the freight system is essentially concerned with the movement of goods, not of vehicles, and the movements of goods are modelled directly;
- *truck-based models*, that focus on movements of trucks and estimate them directly.

Commodity-based models receive socio-economic data as input and give as output commodity quantity flows that can be converted into truck flows by vehicle loading models. The input of truck-based models is the same as the first but it gives truck freight flows directly as output. Within the first and the second classes different types of models have been developed.

Commodity-based models can be further divided into multi-step models, similar to those used for passenger travel mobility (Ogden, 1992), input-output models by Harris and Liu (1998) and spatial equilibrium of the prices models by Oppenheim (1994).

Truck-based models are mainly multi-step models and use models developed for passenger assignment to obtain network flows. In Seville a process based on entropy maximization to estimate origin-destination matrices in trips for freight transport has been developed by Munuzuri et alii (2003).

In recent years other types of models have been developed to determine the optimal size and location, to analyse the effects and impacts of Urban Distribution Centers (Taniguchi et alii, 1999; Crainic et alii, 2004). This concept of logistics terminals (multi-company distribution centres) has been proposed in Japan to help alleviate traffic congestion, environment, energy and labour costs. These facilities allow more efficient logistic systems to be established and they facilitate the implementation of advanced information systems and cooperative freight systems. A national project on City Logistics developed in Italy aims to promote the development of Intelligent Transportation Systems, new technology vehicles with cleaner fuels and innovative policy measures (Gragnani et alii, 2004). In Taniguchi et alii (1999), Castro et alii (1999) and Segalou et alii (2004), there are models to limit the impacts of commercial vehicle traffic. In Thompson and Taniguchi (1999), the traditional routing and scheduling methods are fitted to urban scale with constraints of time slots. This model, connected to a dynamic flow simulation model, was applied to evaluate the following three measures (Taniguchi and Van Der Euden, 2000): implementation of an advanced system of route programming, co-operative organisation of transport operators and optimal control of vehicle loading. Other papers focus on the effect of e-commerce and its effects on urban freight distribution (Visser et alii, 2001; Thompson et alii, 2001; Taniguchi and Kakimoto, 2003; Taniguchi and Hata, 2004; Stumm and Bollo, 2004).

In 2000 a review and summary of research in the fields of freight demand and shipper behaviour modelling were presented by Regan and Garrido (2000). The authors divide the models according to the nature of data required and geographical scope into aggregate, disaggregate, international, intercity (interregional) and urban.

In Italy some models for different aspects have been developed: *macro-economic models*, which simulate the level (quantity) and spatial distribution of goods traded between various zones and ultimately produce Origin-Destination matrixes; models that simulate *modal split* and *route choice* on representative transport service networks (Cascetta, 2001; see for a set of specific models reference note in Russo, 2005).

In particular two different segments of the chain from producers to end-consumers are investigated: end-consumer – wholesaler (Russo and Comi, 2005) and wholesaler – producer (Russo and Cartenì, 2005). For a general review see Russo and Comi (2003b); some specifications are reported in the next section.

An international comparison of methods developed and results obtained in urban goods movements is made by Ambrosini and Routhier (2001). In the countries analyzed, it may be noted that the recent approaches are very diverse and sometimes experimental regarding the data and methods used. It emerges that issues and methods vary according to the countries concerned.

Urban freight tools

To manage and control urban freight transport, it is of great importance to have tools (DSS) to simulate the system. The main tools developed to support urban freight planning are: Freturb© in France, GoodTrip© in the Netherlands and Wiver© in Germany.

The main element distinguishing the French approach is the aim to take into account all city management aspects and not only environmental problems. Since 1994, heavy goods vehicles traffic has been measured with driver surveys in towns and a national shippers survey has been conducted to describe the organisation of logistic chains but without reaching the final urban link. Three surveys (in the cities of Bordeaux, Dijon and Marseilles) enabled quantitative and qualitative information to be collected, which provided the basis for developing the systemic and analogical Freturb© model (Gerardin et alii, 2000, Patier and Routhier, 2003).

The French tool (Freturb©) allows us to obtain the number of vehicles used in each urban traffic zone for restocking shops and warehouses. The tool uses some statistic-descriptive models, it uses as inputs the socio-economic data on the urban area (number of establishments in the traffic zone and number of relative employees, disaggregated in 45 different freight types belonging to 8 main classes). The surveys to specify and calibrate the Freturb© models were carried out in many cities of France and for each type the number of movements effected per establishment and per week was estimated.

The tool is articulated in four steps and each permits specific indicators to be obtained (Routhier and Aubert, 1998): movement generations, estimation of parking time for loading and unloading, estimation of freight flows on the road, estimation of freight vehicle density and flows among traffic zones.

In the early 1990s in the Netherlands, the Ministry of Transport and Civil Engineering launched a national programme to fight pollution and traffic congestion in the urban centres and particularly supported research regarding the urban distribution centres. The main idea of the Dutch project is to reduce, at the same time, the number of commercial vehicles running and the number of kilometres travelled, while rationalising and optimising the rounds. In this context, the Goodtrip© DSS was conceived (Boerkamps and Van Binsbergen, 1999). It is a tool to evaluate different steps of urban freight distribution using geographical, economic and logistical data. It estimates goods flows, urban traffic and its impacts. Goodtrip© calculates the volume per goods type in m^3 in every zone. It consists of four physical components of urban freight transportation: spatial organisation (it describes where people live and work, where facilities are located and where goods are produced and consumed), goods flows, traffic flows and (multi-modal) infrastructure. It starts by generating freight flows for different commodities from end-consumer demand and these freight flows are probabilistically linked to different distribution channels. It was applied in the city of Groningen to evaluate the impacts on the city of different freight distribution alternatives (Boerkamps and Van Binsbergen, 1999). It is not clear which models are used in the DSS.

Finally, the DSS Wiver© was developed in Germany. In the city of Berlin, Munich and Hamburg, with regard to urban freight transport, a large quantity of statistical data was collected and analysed to develop an oriented DSS for commercial traffic on roads for the purposes of city planning. It provides the basis for different scenarios and measures. The outputs can be differentiated by business sector, vehicle type and time of day (Sonntag and Tullius, 1998).

Wiver© is a simulation model that acknowledges the complexity of trip chains for commercial freight traffic. Wiver© differentiates between 10 business sectors and four vehicle types: passenger cars/station wagons, trucks up to 2.8 tons, trucks between 2.8 and 7.5 tons, trucks weighing more than 7.5 tons.

The input data result from land use data (zone-based data concerning jobs, work places and population) as well as surveyed data. The calculations permit zone-precise information to be obtained about origin and destination. The freight traffic matrices refer to the number of vehicles or the weight of freight. Results can be differentiated by business sector, vehicle type and time of day. To construct the Wiver© models many companies were surveyed. They represent different branches and for each investigation zone, the number of companies and employees per branch was identified.

As GoodTrip©, in the knowledge of authors, it is not evident which models are used. Indeed, only the steps to calculate commercial traffic and the method to combine the elementary trip into tours are described. This tool has been applied for many city traffic planning processes both in Germany and other European countries such as Italy (Rome and the Region of Lazio in 1997), and Spain (Meimbresse and Sonntag, 2000).

In 2003 the Wiver© approach was transferred by Lohse (Lohse, 2001; Boyce et alii, 2002) to a general framework backed up by a system theory and included in the software program Viseva© at the Technical University of Dresden (Friedrich et alii, 2003).

Other simulation tools, within the COST 321 project, have been developed and applied in a series of countries (COST 321). In Denmark the software GAMS (General Algebraic Modelling System) was developed. It calculates total energy consumption, emissions, transport costs and traffic accidents as a function of truck and van traffic at various road categories of the town. To simulate the effects of individual measures, the space-and-time-related desegregate traffic model VENUS was adopted. The latter determines the traffic volumes in a given area on the basis of structures present in each zone. In Italy the work was based on the use of HAPPYTRAILS, which is a suite of programmes dealing with traffic management. It also includes the search for minimum length paths and minimum cost paths. In Switzerland a model to simulate potential for a vehicle fleet transformation was selected, which deals with statistical data and specific surveys. It is called a simple effectiveness analysis model (EWN) and is divided into two parts: firstly the intrinsic characteristics of the city truck are researched; secondly, various determinant factors relating to the feasibility of the proposal are incorporated in the model.

Proposed modelling system

It emerges that the developed urban freight models are not integrated with other components of urban mobility and, in particular, they have no connection with measures implemented at urban scale and are not integrated with urban passenger models, which have been considerably developed (Cascetta, 2001). Indeed, urban freight models are useful to develop tools that allow the potential measures for implementation in urban areas to be assessed. Urban freight demand models appear to have been developed to simulate the restocking process (from warehouse to shop-retailer) and so they do not start from the end-consumer. Hence it is difficult to consider the connection between these urban models (developed for logistics movements) and end-consumer models (that are those developed for traditional passenger mobility) and to analyse the complexity of urban transport systems with all components that make up urban mobility.

A study was developed to link passenger mobility for purchases to retailer demand in urban areas. The study allows to estimate the freight sold in each urban shop (or in general urban business) starting from consumption demand (Russo and Comi, 2003a). Subsequently, the connection for restocking urban businesses was analysed and a specific model was proposed for connection between wholesalers and retailers (Russo and Comi, 2003b).

The urban transport system is a complex system in which freight is moved in the same transport system in which passengers travel.

Two main classes of freight movements can be identified schematically, called here in:

- *end-consumer*: end-consumer movements are those in which the freight is moved by the customer (private or business end-consumer) who purchases and consumes the freight (for example in this class of movement there is the freight movement effected by a generic purchaser who buys the freight in a shop and then transports it to a place where he will consume the goods);
- *logistics*: logistics movements are those movements in which the freight reaches the facilities where it is delivered to markets for producing other products (goods) or services (for example there is the movement of freight from the warehouse to the retail outlet). These movements allow shops and warehouses to be restocked.

Much has been written both on one side and the other, but there are no studies that consider the possibility of linking the two segments of freight mobility. In the same way for each of these two classes of movements a quantity can be defined. To analyse freight mobility in a general planning process that allows the two mobility segments to be connected could be useful as passenger and freight flows take place on a common, congestible network, which is also used for general travel. It is therefore important to remember that several decision-makers are involved in freight: as there are different actors, at each level there are different decision-makers that choose how the freight must be moved.

To overcome these limitations and to create a point of interaction between end-consumer quantities (ring or chain) and logistics quantities (supply-chain or tour-based), a modelling system is developed. Different functional relations can be identified in the chain that takes the freight from producers to end-consumers (Figure 1):

- the freight is moved from the zone of production or from the zone where the international commerce facilities are located (regional port, freight village, etc.) to the zone where it will be consumed by the end-consumer; in Figure 1 this movement is identified by the link from the white square to the black square;
- one contact point between producer and end-consumer exists in which the freight is transferred from the producer or international/national seller (white square) to the end-consumer (black square); this point is shown as a black circle in Figure 1; this last seller is usually called the retailer;
- there are one or more points in which to consolidate/deconsolidate loading between the firm or the international commerce facilities location and end-consumer; this point is shown as a white circle in Figure 1;
- under several trading patterns the black circle can coincide with

- the black square (this happens in the case of sale by correspondence, over the Internet, etc.);
- the white circle (this happens in the case of sale in a cash and carry, metro, etc.);
- the white square (this happens in the case of purchase in a factory, at a general market, etc.).

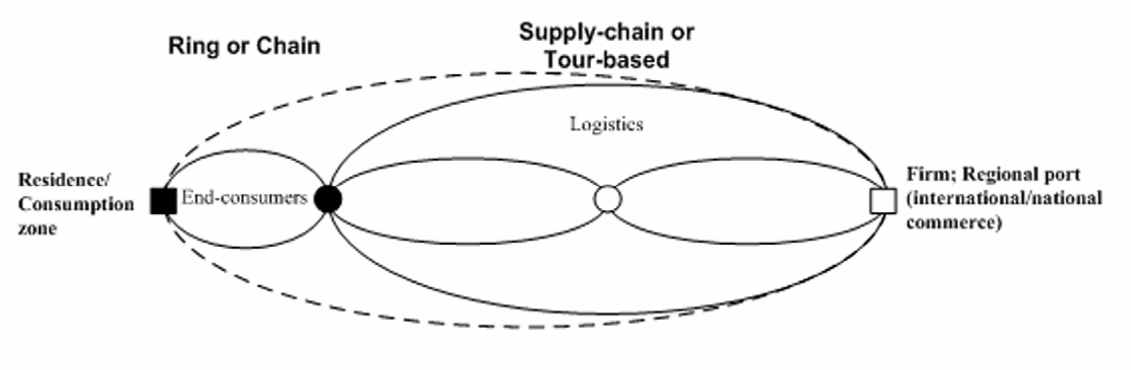

Figure 1: Functional relation between the end-consumer and logistics movements

Starting from this analysis a specific study was developed to define the main structure of a modelling system to analyze urban freight transport and logistics (Russo and Comi, 2003a, b).

In general, urban scale models may be developed, breaking them down into two levels:

- models that concern calculation of the demand by freight type, by *o-d* consumption pair and *d-w/z* restocking pair starting from socio-economic data;
- models that concern 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

Attraction model. This model refers to end-consumer quantities and has as input general socio-economic data (residents, number of employees, etc.) and gives as output the freight quantity required by them (demand in freight quantity for each *od* pair).

The attraction macro-model consists of a set of elementary models that allows to calculate, as final output, the freight quantities (disaggregated by freight type) that are consumed in zone *o*, purchased and thus required in *d*. In this approach, defined as trip-based, the models allow the *o-d* matrices in trips to be calculated, whether ring trip and chaining (Russo and Comi, 2003a).

Acquisition model (or large-scale distribution). This model concerns logistics trips. In the literature several types of models have been developed and different decision-makers can be considered for each choice level. This model receives as input the freight quantity needed in each traffic zone *d* by the retailer and analyses the restocking process (demand in freight quantity for each *d-w*). The freight can arrive in zone *d* in several ways: from a warehouse inside the urban area (zone *w*, which may generally also coincide with *d*), from a warehouse outside the urban area, from the zone where the producer is located (zone *z*, which may generally be inside or outside the urban area).

In general, the acquisition model informs us from where the freight for restocking arrives. Using the previous models the quantities of freight required in each traffic zone, disaggregated in different types, are estimated.

The acquisition macro-model is thus composed by two different models:

- channel choice model, in which the probability of choosing a distribution channel to take freight of each type for each restocking zone is estimated. From the previous model (attraction model) the quantity is obtained. So with this model the freight quantity of each type that arrives in a zone using a defined channel of distribution can be estimated.
- stock model, in which the probability that a retailer takes the freight sold in his/her shop using a certain distribution channel and arriving from a zone inside or outside the study area can be calculated.

Second level

Models for the choice of service, quantity and/or vehicle type, time and path. These models are specific to the restocking process. The type of service performed (one-to-one, one-to-many, many-to-many, many-to-one) can be obtained by means of a logistics model (Daganzo, 1991) The models receive as input the demand in quantity for origin/destination (demand in freight quantity for each *d-w*) and give as output the vehicles and path used, and can be both static and dynamic (demand in vehicles, service and time in each *w*). The choice of vehicle can be analysed using models that treat the choice of vehicle jointly with shipment size or otherwise (McFadden et alii, 1986; Abdelwahab, 1998; Holguin-Veras, 2002). A model that allows simulation of freight distribution when the journeys connect several businesses in different locations using a tour–based approach is given by Russo and Cartenì (2004). Several models can be used to evaluate the probability of choosing each path, considering within them the existence of a supply chain.

Some of the model outputs recalled are the flows of passengers travelling for purchases and the flows of suppliers who restock shops inside the urban area. These flows are divided by freight and vehicle type and allow us to estimate with the above models the environmental impacts on each link of the urban network.

Conclusions

To manage and control urban freight transport it is very important to have models and tools to simulate the system. Indeed, urban freight models are useful to develop tools that allow us to assess the potential measures to be implemented in an urban area.

To analyse freight mobility in a planning process a general model that allows joint treatment of passenger and freight mobility is desirable as passenger and freight flows take place on a common, congestible network, which is also used for general travel.

In this paper the different models, measures and tools developed at urban scale to simulate urban freight demand are reviewed. The paper proposes a modelling system that allows us to link freight and passenger mobility and some of the outputs can be useful to estimate the impacts of urban goods movements.

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