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A system of models to forecast the effects of demographic changes on urban shop restocking

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ABSTRACT

End-consumer choices in relation to type of retail outlet impact upon shopping travel frequency and mode, and hence on freight distribution flows for restocking shops. The characteristics of the restocking process, in terms of delivery size, delivery frequency, freight vehicle type and so on, are strictly related to the size of commercial activities to be restocked. Since end-consumer choices depend on end-consumer characteristics, such as age, gender and occupation, which change over time in an urban area, changes in such characteristics impact upon the nature of freight restocking. In city logistics analysis, in order to forecast the future characteristics of freight distribution in an urban area, a system of models is required that allows shopping mobility and freight restocking distribution to be considered in an integrated approach, with shopping demand models that take end-consumer characteristics into account. This paper discusses a number of issues related to the transportation impacts of shopping attitudes on urban freight distribution. It focuses on the factors that mainly influence freight distribution: quantity and choices of retail type (including e-shopping). After an analysis of state-of-the-art shopping mobility demand modelling, a new system of models for simulating shopping choices is presented. The models were obtained by using surveys carried out in Rome where more than 300 families were interviewed. Jointly with urban restocking models, they were used to assess the effects on freight restocking under a future scenario when demographic changes occur in a medium-size urban area. The results indicate that effects of demographic changes on shop restocking flows can be significant. For example, the shifting of middle aged adults into later age could result in an increase in shopping trips to nearby shops, mainly to small and medium-size retail outlets. This could lead to a consequent increase in car-kms. Further, expectation of an increase in e-shopping could reduce consumer trips. However, new measures able to promote consolidation for making home deliveries more efficient should be investigated.

1. Introduction

Several measures have been implemented by city administrators to make urban mobility more sustainable and reduce the environmental impacts of freight transport due to restocking flows. According to the effects produced, the city logistics measures can be classified into: short-term measures, if their effects appear in a few days or weeks, (e.g. freight traffic management, telematics and urban freight distribution organisation) or as medium/long-term measures, if the effects appear after several months or years, (e.g. two-tier systems, improvement of cooperation among actors and urban land-use governance). When focusing on medium/long-term measures, the forecasting of effects due to demographic changes should be stressed.

End-consumer choices in relation to retail outlet type (e.g. small, medium or large) and location impact upon freight distribution flows: the characteristics of the restocking process are strictly related to the type of retail business to be restocked in terms of delivery size, delivery frequency, freight vehicle type and so on. For example, delivery size and freight vehicle size tend to increase with the size of retail activities, while delivery frequency tends to decrease, with considerable effect on the total distance travelled by freight vehicles. Therefore, end-consumer choices among small, medium and large retail outlets affect restocking characteristics and the total freight vehicle distance travelled. In this context, as end-consumer choices depend on characteristics such as age, gender and occupation, and as the distribution of these characteristics changes over time in an urban area, freight restocking characteristics will also change in place and time. Therefore, City Logistics Analysis should not consider only shopping and restocking jointly. Since freight transport is mainly generated by the requirement of end consumers to satisfy their needs for goods and services, we also require suitable methods that allow us to simulate shopping demand whilst taking into consideration the attitudes of end consumers (Nuzzolo & Comi, 2014a).

Although several models have been proposed in the field of shopping mobility and restocking mobility (De Jong, Vierth, Tavasszy, & Ben-Akiva, 2012; Ambrosini, Gonzalez-Feliu, & Toilier, 2013; Nuzzolo, Coppola, &

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Comi, 2013), traditionally these two demand segments have been independently handled. Shopping mobility has been studied as a component of passenger demand through the relationships between travel behaviour, the built environment (e.g. land use allocated for different business activities, density) and socio-economic characteristics (Ewing & Cervero, 2010). Further, the growth of internet shopping has led to changes in shopping behaviour. Few studies have examined the geographic distribution of online buyers and its implications on retail development and transport. Cao, Chen, and Choo (2013) found that the influence of shopping accessibility on e-shopping is not uniform, but depends on locations in metropolitan areas. Specifically, internet users living in urban and/or high shopping accessibility areas tend to purchase online more often than their counterparts in other areas because the former use the internet more than the latter. However, low shopping accessibility in non-urban areas promotes the use of e-shopping, compared to non-urban areas with relatively high shopping accessibility.

As regards *restocking*, various freight demand models have been proposed, many of which are multi-stage models (Taniguchi, Thompson, Yamada, & van Duin, 2001; Anand, Quak, van Duin, & Tavasszy, 2012; Nuzzolo et al., 2013) that can be classified in relation to the reference units used: quantity, delivery, tour and vehicle. Quantity allows us to highlight the mechanism underlying the generation of freight transport demand: freight transport is generated by the requirement of end consumers to satisfy their needs for goods and services (Gonzalez-Feliu, Toilier, & Routhier, 2010; Russo & Comi, 2012; Comi & Nuzzolo, 2014). Quantity-based models are more specific for assessing strategic action on transportation flows, such as those impacting on the location of warehouses and retail activity. Delivery is the unit used by transport and logistics operators, allowing us to investigate in greater depth the logistic process of restocking (Muñuzuri, Cortés, Onieva, & Guadix, 2012). Using delivery-based models, assessment may be made of the impacts on the transport service type used for restocking (e.g. on own account or by third party), and on shipment size. Tours can be used to investigate delivery in relation to departure time, vehicle type, number and sequence of stops. Finally, vehicle flows, interacting within the assignment model, allow us to obtain link flows and to estimate and evaluate the transport performance and impacts of a given city logistics scenario.

Although restocking flows are generated to satisfy end-consumer demand and restocking models consequently have to take account of end-consumer choices, few have proposed joint modelling frameworks (Russo & Comi, 2010; Gonzalez-Feliu, Ambrosini, Pluvinet, Toilier, & Routhier, 2012; Comi, Donnelly, & Russo, 2014). Few studies have hence analysed shopping mobility as a component of freight mobility and considered that changes in shopping attitudes or actions impacting on purchasing behaviour of end consumers (e.g. location of shopping zone, transport mode to use for shopping) can also affect restocking mobility (Miodonski & Kawamura, 2012; Sanchez-Diaz, Holguin-Veras, & Wang, 2013). This shows that further work needs to be done in this field, especially when long-term scenarios have to be assessed. Given the desirability of a joint modelling framework, this paper presents a modelling system which takes into account some factors of end-consumer behaviour, such as the choice of retail outlet type, and links shopping and shop restocking mobility.

In section 2, we report a joint modelling framework developed in the course of multi-year research, which considers both shopping and restocking flows. A number of issues related to the transportation impacts of shopping attitudes on urban freight distribution are discussed. In particular, the paper focuses on the factors that mainly influence freight distribution: quantity and choices of type of retail (including e-shopping). Some new models calibrated for simulating shopping mobility are hence presented. The models were obtained using some surveys carried out in Rome, where more than 300 families were interviewed.

Such models, in combination with urban restocking models, were used to assess the effects on freight distribution due to demographic changes in a medium-size urban area. The results obtained are reported and discussed in section 3. These results indicate that demographic changes can cause major effects on shopping and restocking flows. Some general conclusions and further research developments are considered in section 4.

2. The integrated modelling framework

The integrated modelling framework (Comi & Nuzzolo, 2014) consists of various steps (Fig. 1):

- *shopping* model sub-system; it allows us to simulate end-consumer shopping behaviour and estimate quantities bought by end consumers in order to satisfy their needs, and hence to identify the freight flows attracted by each traffic zone;
- *restocking* model sub-system; given the quantity attracted by each traffic zone, it allows us to estimate the restocking quantity origin–destination (O-D) matrices by freight type and type of vehicle used.

The shopping model sub-system allows us to point out the effects arising from implementation of long-term actions on the location of retail outlets and places of residence, and due to changes in the characteristics of the population (e.g. age distribution).

The restocking sub-system includes models for the simulation of the freight distribution process from the freight centres to the retail zone, and can be used to determine the long-term effects arising from implementation of actions on the location of logistic establishments (e.g. warehouses, distribution centres). By applying the above model sub-systems jointly, it is possible to forecast how changes in the characteristics of end consumers will influence the flows of restocking vehicles and shopping trips and hence the effects in terms of sustainable development.

Below we describe the two model sub-systems and the shopping models calibrated using some data collected from a survey carried out in the city of Rome.

2.1. Shopping model sub-system

Following the model proposed by Russo and Comi (2010, 2012) and assuming that the decision-maker (i.e. end consumer) is in zone *o*, the choice dimensions involved are: the number of trips (x) for shopping, the type of shop (k; e.g. small, medium, large retail outlets) and destination (d), and the transport mode (or sequence of modes; m). The global demand function can be decomposed into the product of sub-models, each of which relates to one or more choice dimensions. The sequence used is the following:

$$D^{i}_{od}[skm] = D^{i}_{o.}[s] \cdot p^{i}[dk/so] \cdot p^{i}[m/dkso] \quad (1)$$

where:

- $D^{i}_{od}[skm]$ is the weekly average number of trips with origin in zone o undertaken by the end consumer belonging to category i (e.g. families with one or more members) for purchasing goods of type s (e.g. foodstuffs) in the type of retail outlet k (e.g. small, medium and large retail outlets) located in zone d by using transport mode m;
- $D^{i}_{o.}[s]$ is the weekly average number of trips undertaken by end consumers belonging to category i for purchasing goods of type s with origin in zone o, obtained by a *trip generation model*;
- $p^{i}[dk/so]$ is the probability that users, undertaking a trip from o, travel to destination zone d for purchasing at shop type k, obtained by a *shop type and location* model;
- $p^{i}[m/dkso]$ is the probability that users, travelling between o and d for buying in shop type k, use transport mode m, obtained by a *modal choice* model.

Finally, the quantities required by each zone to satisfy end consumer needs can be obtained by introducing a *quantity* purchase model. This