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LUTI models, freight transport and freight facility location

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Abstract

In transport geography, the key role of freight traffic has often been unnoticed. On the other hand, studies of freight mobility traditionally focus only on restocking flows and neglect the linkage with shopping activities, ignoring in this way the impact that freight flows have on location of freight facilities (e.g. warehouses, distribution centres) and shops, and on end consumer's shopping choices.

Starting from these considerations, the paper presents a method to simulate and assess spatial scenarios able to optimize city sustainability and meet the interests of end-consumers and freight operators. In particular, the paper provides insights on the interrelations among the distribution of freight facilities, shopping mobility and location of freight facilities by presenting a system of simulation models. The results of an application of this method to a test site are also reported and discussed.

Keywords: urban freight transport, city logistics, end-consumer behavior.

1. Introduction

This research germinates from the view that in transport and urban geography, freight distribution are widely underrepresented and only aspects related to passenger mobility are traditionally pointed out (Hesse and Rodrigue, 2004; Allen et.al, 2012). However, more recent studies stress the importance of spatial issues for urban freight movement, in terms of density and distribution of activities (McKinnon 2009; Cidell, 2010; Brunetta and Morandi, 2010; Allen et al. 2012). These activities can be defined as "urban freight nodes", and include transport nodes, distribution center and warehouses, and other delivery areas. The location of these activities in the urban area affects the design and management of supply chains and the position, intensity of demand for freight movements and the relative generated urban freight transport flows (Miodonski and Kawamura, 2012). In literature, it is widely investigated the relation between spatial features (as urban form or building enviroments) and travel behaviour and many studies agree that integrated land-use and transportation policies (known as Smart Growth, Travel Minimising, Accessibility Planning, Transit Oriented Development - TOD) can encourage non-motorized travel and lead to less demand for travel by cars, in line with principles of sustainable mobility (Boarnet and Crane, 2001; Naess, 2006). The same principles should be further explored for freight mobility (Bronzini, 2008; Browne et al., 2011; Huschebeck and Allen, 2005): can density and distribution of freight facilities (e.g. restocking centres, warehouses and distribution centres) have impacts on both the volume and efficiency of freight movements?

Another key aspect is that freight mobility concerns two segments of mobility: freight distribution and shopping. These two segments should be jointly analysed as components of the same system, while few studies uses this integrated approach (Russo and Comi, 2010; Gonzalez-Feliu et al., 2010; Browne et al., 2012; Nuzzolo and Comi, 2014a). In fact, end-consumer choices in relation to type of shop (e.g. small, medium or large) undoubtedly impact on shopping travel frequency and mode, but also on freight distribution flows. Indeed, the characteristics of the restocking process are strictly related to the size of commercial activities, in terms of delivery size, delivery frequency, freight vehicle type and so on. This separation of freight distribution mobility and shopping mobility has a direct negative consequence in freight transport system planning and implementation. Local administrators seek to reduce the negative impacts of urban freight transport, using mainly tactical and operational city logistics measures (Muñuzuri et al., 2005; Russo and Comi, 2011) with sectorial views. The two segments of freight mobility are independently managed through restocking freight demand management (e.g. time windows, loading/unloading areas, emission constraints) or though measures for shopping travel demand management (e.g. parking fees, access constraints). On the other hand joint interventions on freight distribution and shopping mobility could increase the efficiency of the integrated transport system and the sustainability of urban environment. In fact total transportation costs of freight and shopping mobility can be split into internal costs, including freight restocking and home delivery operator costs and end-consumer shopping mobility costs, and external costs with regard pollution noise, road accidents or impacts on other road users.

Starting from this consideration, this study assumes the hypothesis that freight and shops mobility have to be jointly considered by transport and spatial planner in order to achieve sustainability goals. Starting from such considerations, and within a transport - land use integrated approach for freight mobility, this paper examines the effects of freight facilities and shop location scenarios in term of total equivalent vehicle-km for both shop and freight mobility, with the aim of assessing mobility externalities and achieving goals of urban sustainability.

In particular, the study seeks to answer the following research questions:

- What are the impacts of freight facilities and shop location on end-consumer behaviour (e.g. choice of shop type and transport mode) and freight distribution flows?

- What is the optimal location in an urban area for freight facilities and shops in order to reduce the internal and external costs of freight and shopping mobility, achieving sustainability goals?

The paper is organised into five sections. Section 2 defines the framework of freight facility and shop location in urban areas, describing the system of stakeholders and the location dynamics. Section 3 describes a modelling system to compare integrated scenarios of freight facility and shop location. Finally, section 4 describes the results of the simulation in a medium-sized urban area of different scenarios with a view to define optimal spatial distribution of shops and freight facilities. Conclusions are drawn in section 5.

2. Freight facility and shop location in urban areas

2.1 Freight facility and shop location's stakeholders

The location's choice of freight facilities and shops in urban areas involves several stakeholders that have different goals and act with complementary strategies: supply-chain actors, shopping actors and city planners.

The goal of supply chain actors (i.e. wholesalers, carriers, producers and distributors) is to maximise their profit; their strategic objectives are thus to reduce delivery and inventory costs. Accordingly, the relocation of the manufacturing process and warehousing requirements in recent years have forced freight operators to locate storage areas and regional and national distribution centres outside urban areas. This trend has increased the spatial centralisation of stockholding (Browne et al., 2012) and is amplified by the rising of land prices and increasing traffic congestion in central parts of urban areas. These phenomena have forced companies to relocate warehousing outside urban centres, to sites with lower prices.

Shopping actors include both retailers and end-consumers. Retailers also conventionally aim at profit maximisation: their strategic objectives are generally to increase the number of end-consumers, to reduce product prices, and minimise delivery and inventory costs. Retailers can be divided into small shops, medium (i.e. supermarkets) and large shops. In recent years, several studies have shown that medium-size shops are moving from urban centres, which have become less accessible for private vehicles, and are relocating towards peripheral areas, contributing to the progression of the “doughnut syndrome”, according to which the periphery prospers while the centre declines (Brunetta and Caldarice, 2011). Car accessibility and parking availability affect the choice of peripheral locations against central area. Accordingly the number and scale of regional shopping centres along major roads and junctions in suburban areas is increasing (Stratec, 2005). New shopping centres stand as multifunctional structures that include shopping and other activities (e.g. cinemas, sport centres). At the same time, shops in downtown areas are becoming smaller and more fragmentized.

As regards end-consumers, their goals are to reduce shopping costs and increase product quality and choice. Parking supply is also one of the attributes that influence the choice of a shopping destination together with the travel distance from home to shopping destination, the variety, the price and the quality of products (van der Waerden et al., 1998). With regard to this, in recent decades end-consumers have appeared to prefer clusters of shops or commercial centres to combine shopping with other leisure activities. That said, new channels such as those provided by e-commerce (Taniguchi et al. 2003; Durand and Gonzalez-Feliu, 2012) are becoming increasingly popular, with many effects on the transport system as detailed by Mokhtarian (2004). In long-term scenarios, when also socio-economic shifts take place, an increase in freight trips is in part limited by the diffusion of e-commerce. The e-shopping could in fact limit the negative effects of these changes, decreasing shopping trip production, but the pattern of home deliveries have to be investigated. The expectation is that e-shopping growth could cause more deliveries and more freight vehicles in residential areas. Then, new actions have to be investigated in order to promote consolidation for making home deliveries more efficient.

Finally, as regard city planners, their priority is to integrate the dimensions of sustainability: the economical, the social and the ecological components, in line with the sustainable mobility paradigm (Banister, 2008). In other words what they want to achieve is a sustainable transport system, which should be safe, efficient in providing accessibility and mobility, and in enhancing economic productivity, without impacting the natural environment negatively – all in a manner that is equitable to those who use and are affected (either directly or indirectly) by the system. In more details, relating to the freight transport system, economic goals entail supporting the growth of the retail and freight segment in the context of local economies. The environmental dimension is achieved by limiting the losses of natural and agricultural areas; reducing the amount of freight and shopping travel, car dependency for shopping purpose and energy use for transport. The social dimension another goal of the sustainable mobility paradigm and it concern social welfare, equity, human health, community liveability, public involvement; in particular transportation affects directly people's opportunities to access goods, services and activities and could directly impacts social exclusion: the constraint that prevent people from participating adequately in society and city activities. Within the specific focus of freight and shopping mobility system, to achieve social sustainability, retail services should be developed without detriment to those living in any particular region or working in any particular sector.

2.2 Freight facilitiy and shop location dynamics

From the analysis of stakeholders' behaviour some phenomena can be observed: freight distribution and shopping costs depend on the locations in the urban area of freight facilities and of shops, in particular medium-size shops such as supermarkets and large outlets. Internal and external freight restocking costs strictly depend on the locations of logistics centres (such as warehouses and distribution centres), retailers and end-consumers. Given that warehouses and distribution centres are located mainly in the suburbs (Ibeas et al., 2012), increasing the share of shops located in the city centre would lead to an increase in restocking costs (Wygonik et al., 2012). Moving shops out of residential or central zones would reduce transportation costs for restocking but could increase end-consumer costs of purchasing (shopping mobility) and, of course, can reduce the attractiveness of the city centre.

Some researches carried out in France have shown that transport costs for shopping mobility are higher than their freight restocking counterpart (Schoemaker et al., 2006; Gonzalez-Feliu et al., 2010). Thus, for land-use and city logistics planners, it is important to investigate the influence of the location of shops on end-consumer choices, such as where to shop and how to get there, and vice versa.

In synthesis, the location of shops, warehouses and distribution centres has impacts on freight distribution and shopping mobility, according to their travel distance from urban centres. Location outside residential or central zones of warehouses and distribution centres increases restocking costs by increasing the travel distance between retailers and distribution activity. The location of large retail businesses outside residential or central zones reduces restocking costs by reducing the travel distance between retailers and distribution activity and increasing the average transported quantity and vehicle size. As regards the impact of shopping mobility, the location of large retail businesses outside residential or central zones reduces the number of shopping trips (trip frequency), but increases shopping trip lengths and car use, whilst reducing the attractiveness of city centres.

Starting from the above considerations, the location in urban areas of freight facilities and shops can be planned in order to minimise transport costs both for freight distribution and shopping mobility. Most urban areas, that are characterized by a mono-centric structure, can be divided into three types of zones, according to the travel distance from the centre: the central area (CA), where the density of end-consumers and small retailers is usually higher; the first ring (FR), with medium end-consumer density and the presence of warehouses, and the second ring (SR), where end-consumer density is low and large shopping malls and freight facilities are located.

With regard to this common clustering, some location strategies for freight facilities can be applied and then verified through assessment methods:

- relocation of medium and large shops from CA to SR, in order to have distribution centres closer to shopping malls and hence to reduce freight distribution travel distances, and to increase the average transported quantity and vehicle size; on the other hand, this strategy increases shopping travel distances;
- clustering of warehousing and distribution centres in FR in order to reduce freight distribution travel distances and to keep shopping travel times constant;
- clustering of warehousing, distribution centres and medium and big size shops in FR in order to reduce both freight distribution travel distances and shopping travel distances.

3. Urban freight modelling framework

In order to evaluate freight facility and shop location scenarios, we used a system of models that simulates the two demand segments (i.e. restocking and shopping flows). Traditionally, these two demand segments have been independently managed. Studies of urban freight mobility (Taniguchi et al., 2001; Comi et al., 2014) generally focused only on restocking flows, i.e. vehicle flows from warehouse and distribution centres to trade or service locations (e.g. shops, food-and-drink outlets, service activities). They neglect the linkage with shopping activities, even if end-consumer choices in relation to type of shops (e.g. small, medium or large) undoubtedly impact freight distribution flows. Indeed, the characteristics of the restocking process are strictly related to the type of shops to be restocked in terms of delivery size, delivery frequency, freight vehicle type and so on.

The modelling framework used, derived from the current literature where few authors propose joint modelling frameworks (Comi et al., 2014), is based on that proposed by Nuzzolo and Comi (2014b and c), and consists of two main components:

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

The shopping model sub-system allows pointing out the effects arising from implementation of long-term actions on the location of shops 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 (warehouses, distribution centres).

By applying jointly the above modelling sub-systems, it is possible to forecast how different locations of shops and freight facilities and shopping attitudes influence the flows of restocking vehicle and shopping trips and hence the effects, with and impact on city sustainability.

3.1 Shopping model sub-system

Following that proposed by Russo and Comi (2010, 2012) and assuming that the decision-maker (i.e. family) 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) and destination (*d*), 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:

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

where:

- $D^i_{od}[skm]$ is the weekly average number of trips with origin in zone *o* undertaken by the end-consumer (i.e. family) belonging to category *i* (e.g. families with one or more components) for purchasing freight of type *s* (e.g. foodstuffs) in the type of shop *k* (e.g. small, medium and large shops) located in zone *d* by using transport mode *m*;
- $D^i_{o.}[s]$ is the weekly average number of relevant trips undertaken by end-consumers (i.e. family) 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 shopping in shop type *k*, use transport mode *m*, obtained by a *modal choice or split* model.

Finally, the quantities required by each zone to satisfy end consumer needs can be obtained by introducing a quantity purchase model. This model provides the probability that the end consumer, arriving in a given zone, purchases something of a certain size. Therefore, the total quantity of freight type *s* attracted by shop *k* in zone *d*, $QT_d[sk]$, can be calculated as:

$$QT_{.d}\left[sk\right] = \sum_i Q^i_{.d}\left[sk\right] + QE^i_d\left[sk\right] = \sum_i \sum_{o,m,dim} D^i_{od}\left[skm\right]\cdot p^i\left[dim / mks\right]\cdot dim + QE^i_d\left[sk\right] \quad (2)$$

where:

- $Q^i_d[sk]$ is the goods quantity bought/sold in shop *k* in zone *d* given by the demand of end-consumers belonging to category *i* living/working in a zone *within* the study area;
- $QE^i_d[sk]$ is the goods quantity bought/sold in shops *k* in *d* given by the demand of end-consumers belonging to category *i* living/working in a zone *external* to the study area;
- *dim* is the dimension of purchases, e.g. expressed in kg;
- $p^i[dim/mks]$ is the probability that a trip concludes with a purchase of dimension *dim* conditional upon undertaking a trip from zone *o* to shop *k* in zone *d* for a purchase of goods type *s* using the transport mode *m*.

In the following, the study area is defined as a closed system and then assumes that the goods quantity is bought by end-consumers living/working in a zone external to the study area can be neglected ($QE^i_d[sk] = 0$).

The above shopping model sub-system have been developed using the results of specific surveys carried out in the city of Rome where more than 300 households have been interviewed. The survey questions covered shopping behaviour during the previous week and the interviews have been structured into three sections in order to reveal the characteristics of: households (e.g. number of household members, location, vehicle availability, socio-economic data of each member), both purchase trips undertaken by each household member (e.g. freight types, trip origin and destination, day, type of shop where the purchases have been made, value of purchased goods) and e-shopping.

With regard to the recalled modelling framework and aim of this study, the used shopping models are able to express the end-consumers' choices as a function of their characteristics, i.e. age, gender and employment status, and to limit the application complexity. A complete description of the models is reported in Nuzzolo and Comi (2014a).

3.2 Restocking sub-model

Once the quantity of goods bought/sold in shop *k* in zone d, $QT_d[sk]$, has been estimated by the above model sub-system, the restocking quantity flows characterised for vehicle type *v*, QV_{od}, departing from zone *o* can be obtained as follows:

$$QV_{od}\left[skv\right] = QT_d\left[sk\right] \cdot p\left[o / dks\right] \cdot p\left[v / dk\right] \quad (3)$$

where:

- $QV_{od}[skv]$ is the freight quantity of type *s* bought/sold in shop *k* in zone *d* transported on pair *od* by vehicle type *v*;
- $p[o/dks]$ is the probability that the freight attracted by outlet type (shop) *k* located in zone *d* comes from warehouse zone *o*, obtained by an *acquisition model*;
- $p[v/dk]$ is the probability that the freight attracted by outlet type *k* located in zone *d* and coming from zone *o* is *transported* by vehicle type *v*, obtained by a *vehicle choice model*.

Finally, assuming that each vehicle only delivers to shops located in the same traffic zone, the number of vehicles of type v required for restocking the shops of the study area can be estimated as follows:

$$VC_{od}\left[v\right] = \sum_{sk} QV_{od}\left[skv\right] / Q\left[skvd\right] \quad (4)$$

where:

- $VC_{od}[v]$ is the total average number of freight vehicles of type *v* moving on pair *od*;
- $Q[skvd]$ is the total average freight quantity of type *s* delivered to shop *k* in zone *d* by vehicle type *v.*

The contribution due to freight vehicles used for home deliveries (e.g. e-commerce) is not considered. In fact, the quantity attracted for satisfying end-consumers' needs can also arrive directly to their consumption zone (e.g. home) using different type of purchasing (e.g. e-commerce). Therefore, in order to characterise this freight flows, a further model could be included in the *eq. (3)* in order to disaggregate the O-D flows for vis-à-vis shopping and e-commerce. Furthermore, the focus is on on predominant shopping modes and leaves these new patterns out of consideration. These problems will be addressed in future research.

The above modelling system has been calibrated by using surveys carried out in the inner area of Rome, in 2008. The surveys consisted of: traffic counts of commercial and other vehicles at the boundary of the study area, with about 600 interviews of truck drivers, in order to investigate the supply chain of freight distribution within the study area, and about 500 interviews of retailers, in order to investigate the retail trade in the study area for each freight type. For more details on data and model estimation and validation, refer to Nuzzolo and Comi (2014c). It has been applied to shop restocking in the city centre of Rome in order to verify the model's capability to reproduce the revealed freight vehicle O-D and link flows. Referring to the aggregate results of the validation phase, the modelling system allowed us to reproduce the actual situation of freight transport in the inner city area of Rome, in terms of commodity flows (variation between revealed and modelled flows less than 1.4%) and vehicle flows (variation between revealed and modelled flows less than 0.3 %).

4. Application to a medium-size urban area

This section describes the results of the application of the recalled modelling system to study the effects of different locations of freight facilities and shops upon transport cost. The test area consists in the medium-size urban area of Padua in northern Italy. The application takes into account the demographic and socio-economic changes expected for the year 2025. This test-site area has been chosen because it is an example of medium-size Italian urban area, characterized by an already well balanced distribution of freight activity location (as pictured in Figure 2 on the right). Furthermore, its well-defined shops offer make possible to suppose it as a closed system so it's worth the assumptions made in the *equation (2)*.

Padua municipality is also very active since many years to the problems of urban freight transport as shown by the successful Cityporto logistics scheme. It consists of an urban freight consolidation and distribution centre (UDC) operating since 2004 and located in the freight village “Interporto Padova”.

The study area (Figure 1 on the left) comprises the Padua Municipality and 13 small neighbouring municipalities. The total population in 2011 was about 370,000, mainly concentrated in the centre of Padua where residential density is over 18 inh./ha. In the study area, the total number of shops is 6,761 with 23,144 retail employees that are largely located in the historical city centre and in the small town of Abano Terme, a tourist attraction in the south of the study area. 4,750 warehouses, with 17,016 warehouse employees, are mainly located in west of the city centre, near the boundary with Noventa Padovana, where a large warehouse centre is located (Padua City Porto). The study area has been split into 25 traffic zones, as shown in Figure 1.

All data, required for the implementation of modelling system and for characterizing the spatial scenarios, are from the Italian Institute of Statistics (ISTAT, 2013); also the identification of freight types germinates from it. With regard to the classification used by the Italian Institute of Statistics (ISTAT, 2011), three main classes of freights have been identified: foodstuffs, hygiene and household products, and other. Besides, according to characteristics of vehicle fleet (Gonzalez and Morana, 2010), three vehicle types have been studied: light goods vehicles (with a laden weight less than 1.5 t), medium goods vehicles (with a laden weight between 1.5 t and 3.5 t) and heave goods vehicles (with a laden weight more than 3.5 t). With regard to the three identified types of urban zones (CA, FR and SR) and the previous vehicle types, multiple restocking patterns have been considered.

The assessment method proposed in this application is able to evaluate ameliorative scenarios in terms of transportation costs, as a function of vehicle-km. In this first research phase, the spatial scenarios are compared using aggregate transport indicators: total distance travelled (vehicle-km), number of shopping trips (trip-km) and number of freight vehicle-km. In the future steps of this research, the assessment will also take into account environmental, congestion indicators and a specific focus on environmental and social equity issue (Littman, 2014).

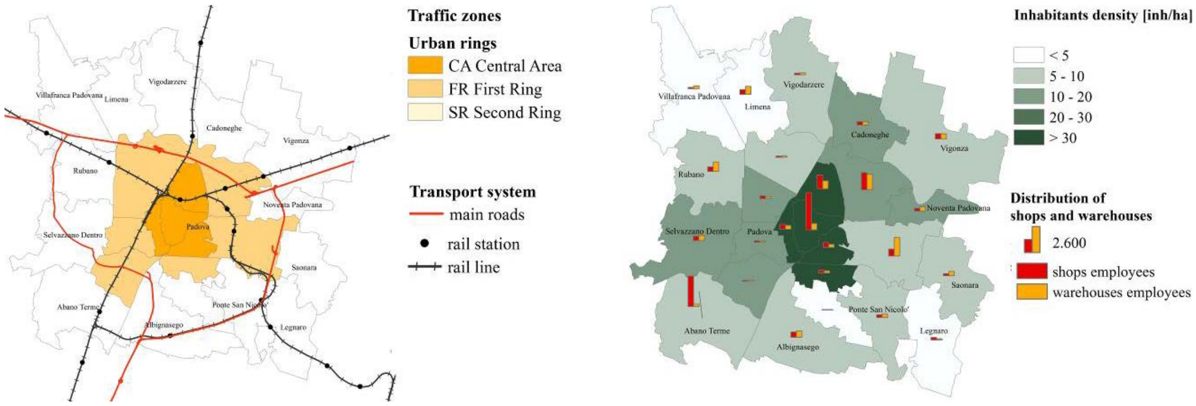

Figure 1: The study area and the distribution of shops, freight facilities and inhabitant density in the 25 traffic zones

4.1 Land use scenarios

In the application, the current scenario (CS) and future scenarios for the year 2025 are simulated and compared: the trend scenario (TS), and three design scenarios (DS), as described in the following sections.

<u>Trend Scenario (TS)</u>

In the Trend Scenario, the effects of socio-economic changes on end-consumer choices, such as where to shop and how to get there, are analysed. In particular, it has been supposed to keep the main socio-economic trends revealed in the last 10 years. In order to emphasise the above effects, no modifications occurring on total population and residence locations has been supposed.

In the last 10 years, there is a different trend according to age: the class of inhabitants between 20 and 44 years has decreased, while the percentage in the upper two age groups (over 45) has increased. As regards socio-economic status, the class of employees has increased, while the percentages of independent workers and other types of employment have decreased. Age, employment status and number of cars per household distributions change according to the estimated trends.

Further, in the trend scenario, the study takes also into account the effects due to changes in e-shopping. In fact, the growth in the home deliveries and the increase of services offered by shops (such as click & collect) all lead to changes in the pattern of urban freight flows and vehicle movements in cities. The changes can be influenced by wider factors such as demographic change and the adoption of new consumer technologies. In some surveys carried out in 2013 (Nuzzolo and Comi, 2014a), the shares of e-purchases made by interviewees according to the three identified age classes: youngers purchase more than elders, especially other products. In order to take into account the growth of e-shopping, based on the revealed shares and the current trends revealed in some word-wide countries (Visser et al., 2014), the possibility to make this type of purchase has been considered, pointing out the inclination to make e-shopping changes with age and freight type.

<u>Design Scenarios (DS25, DS30, DS35)</u>

The Design Scenarios can be considered a medium and long-term result of land use measures in order to improve the sustainability of the city, reducing internal and external transportation costs. The design scenarios are based on the statements that the costs of freight distribution and shopping trips depend on the locations in the urban area of end-consumers, of freight facilities and shops.

Land use scenarios have been defined hypothesizing to move shops and freight facilities among three identified urban rings (i.e. centre, the first and the second ring). Scenarios definition has been made in terms of percentages of shop and freight facilities employees with respect to the total number. Land use scenarios have been defined relocating retail employees from the second ring to the first ring and the warehouse employees from centre and the second ring to the first ring (Table 3) with different variation percentage (25%, 30% and 35%). Retail employees of the central area have not been moved in order to not modify the attraction of city centre, while the medium and large shops, and the freight facilities are located in high accessible areas, along major roads and junctions. Therefore, based on the above assumptions three scenarios have been simulated (Table 1 and 2).

Table 1 – Synopsis of land-use scenarios definition

Scenarios	Socio-economic changes	E-shopping increase	shop and freight facility relocation
Trend scenario (TS)	X	X	
Design scenario (DS25)	X	X	X (25%)
Design scenario (DS30)	X	X	X (30%)
Design scenario (DS35)	X	X	X (35%)

Table 2: Design Scenarios definition: shares of retail and warehouse employees with respect to the total number.

	Current scenario		**DS 25**		**DS 30**		**DS 35**	
	RE	**FFE**	**RE**	**FFE**	**RE**	**FFE**	**RE**	**FFE**
Δ % Central area (CA)	37%	18%	37%	13%	37%	12%	37%	11%
Δ % First ring (FR)	20%	35%	31%	51%	33%	54%	35%	58%
Δ % Second ring (SR)	43%	48%	32%	36%	30%	33%	28%	31%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Design scenarios DS: increase in freight facilities in the first ring and increase in medium-size retails in the first ring; RE: retail employees; FFE: freight facilities employees.

4.2 Simulation results and discussion

The results of simulations are reported as variations of a set of indicators measured for the scenarios compared with the value in the trend scenario (TS). Results are expressed in terms of total travel distance covered by car and commercial vehicles. In particular, the equivalent vehicle kilometres are computed, with specific weights for cars and light, medium and heavy goods vehicles.

Furthermore in the following figures are reported the graphs of the total travel distance covered by car (Figure 3), by commercial vehicles (Figure 4) and the total equivalent kilometres (Figure 5), correlated to the variation of employees in the three analysed scenarios, with different variation percentage (25%, 30% and 35%). As observed in the previous paragraph, these variations refer to employees increase in the first ring and in particular: retail employee's relocation from the second ring to the first ring and freight facilities employees relocation from the centre and the second ring to the first ring.

Figure 2 shows that upon and increased percentage of variation of retail employees towards the first ring, there is an increase of the car traffic.

Figure 3 demonstrates that retail employee's variations determine higher reductions of goods vehicle-km than those obtainable from the relocation of freight facilities employees.

Figure 4 shows that the relocation of employees determines freight facilities reductions equivalent traffic, whereas the relocation of retail employees leads to an increase in traffic. This is presumably due to the fact that the population remains constant, and then this leads to an overall increase of vehicle km.

Table 3 – Scenario comparison: variations of vehicle-km with respect to scenario TS.

Scenario	Private cars	LGV-km	MGV-km	HGV-km	GV-km	Veh eq-km
Trend Scenario (TS)	0.17%	2.51%	-0,98%	-7,58%	-2.29	0.26%
Design Scenario (DS25)	0.07%	0.04%	-2.89%	-8.33%	-3.97	0.01%
Design Scenario (DS30)	0.17%	0.08%	-3.35%	-9.85%	-4.64	0.10%
Design Scenario (DS35)	0.29%	0.11%	-3.87%	-11.36%	-5.36	0.20%

LGV: Light Goods Vehicles, MGV: Medium Goods Vehicles; HGV: Heavy Goods Vehicle

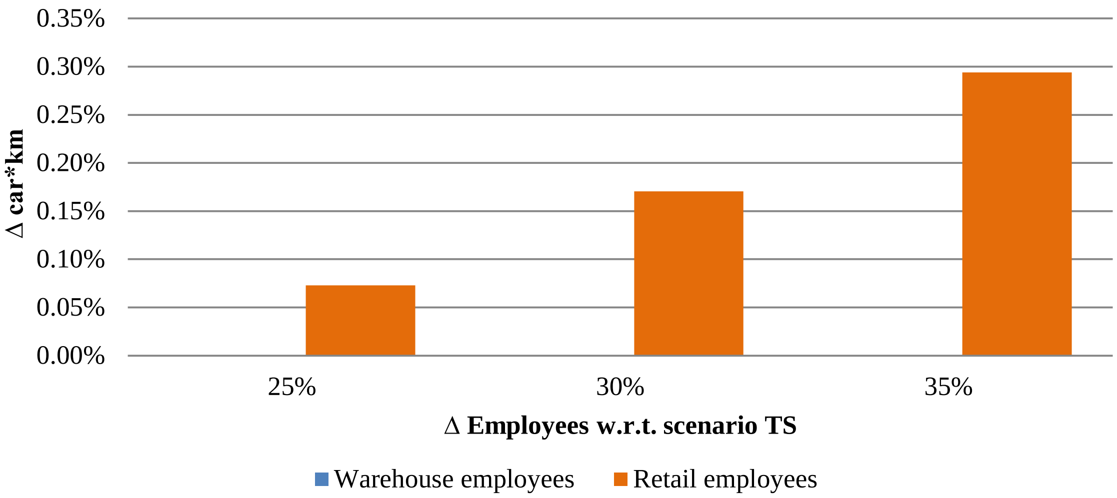

Figure 2: Variation of car-km

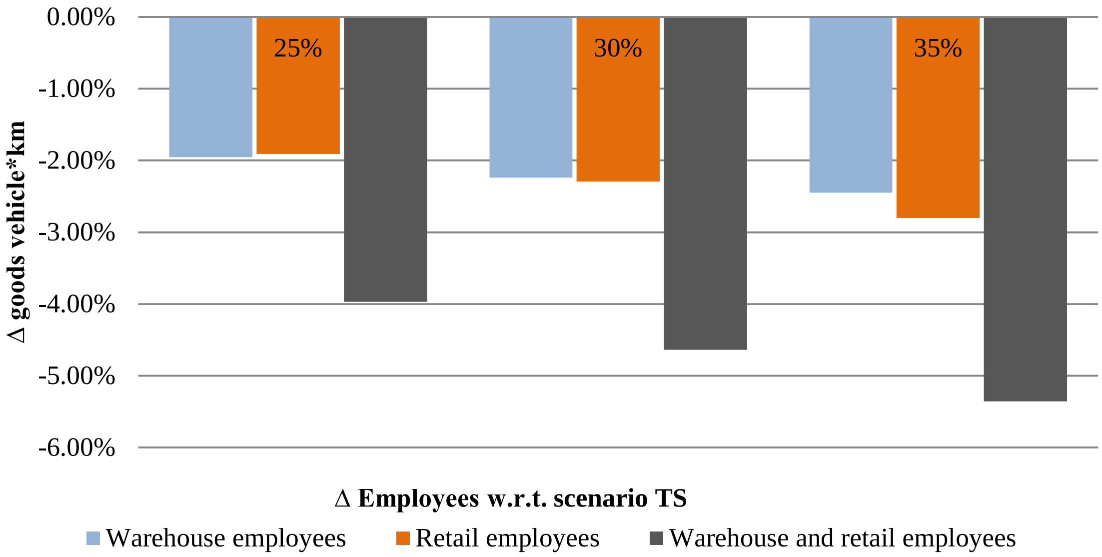

Figure 3: Variation of goods vehicle-km

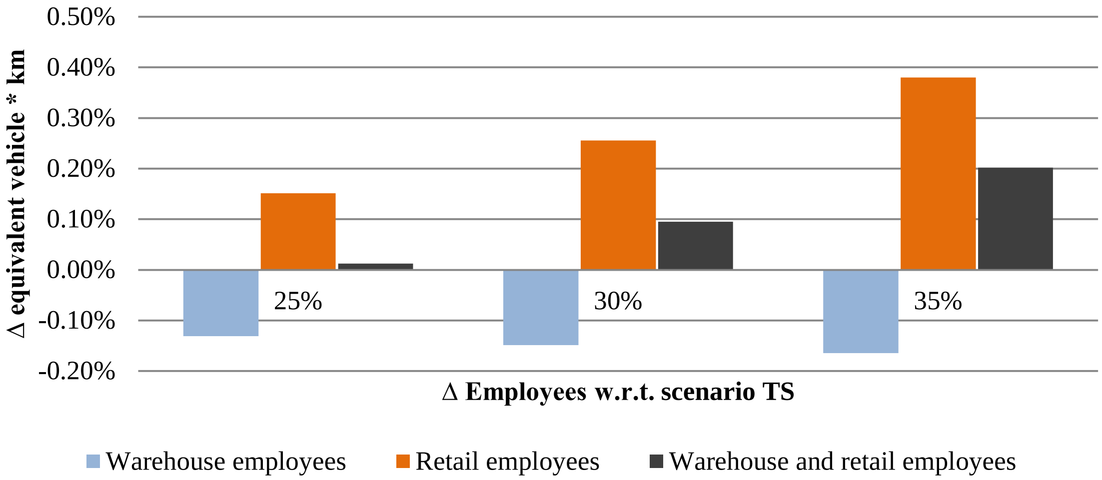

Figure 4: Variation of equivalent vehicle-km

The results indicate that effects of demographic changes (TS scenario) on shop restocking flows can be significant. For example, the shifting of middle aged adults into later age (according to the revealed demographic trends) could result in an increase in shopping trips to nearby shops, mainly to small and medium-size shops. This could lead to a consequent increase in car-km. 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. In fact, home deliveries can cause more truck trips because of repeated deliveries that nowadays represent about 12% of home deliveries (Visser et al., 2014).

The results of simulations also show that the relocation of commercial and logistics centres, with a distribution in the urban area far from the residential distribution, could drive a different restocking pattern with a consequent reduction of freight vehicle mobility. Anyway, this reduction is not very relevant and therefore further city logistics measures have to be implemented because this new pattern pushed to an increasing of private flows. Moving commercial activities far from residential pushes to have more trips by car. The variation in vehicle–km of the two segment components and in equivalent vehicle-km demonstrates that shopping mobility transport costs are higher than their freight restocking counterpart and joint modelling framework has to be used for ex-ante assessment. The integrated approach has the advantage of stressing the interrelations between the two elements and jointly measuring their impacts.

5. Conclusions

The paper proposes an overview of the effects of location of shops and freight facilities upon end-consumer behaviour and urban freight mobility and presented a scenario analysis using a simulation approach. In the application of the proposed system of models, four scenarios, each related to a different distribution of shops and freight facilities, have been simulated. The proposed modelling framework is a useful tool to assess the impact of freight facility and shop location on end-consumer behaviour (e.g. choice of shop type and transport mode) and freight distribution flows; it can be also used as a tool to forecast urban freight transport flows in medium-long term scenarios.

The main results confirm the modelling validity and at the same time demonstrate that freight and shopping activities location could reduce the externalities of freight distribution and shopping mobility or cause relevant effects, in particular increasing car use in shopping mobility. On the other hand, in areas where freight activities distribution is balanced, the ameliorative margin of land-use planning strategies are not significant, as demonstrated by means of the application in Padua Municipality, where location of retail activities are already well planned and a freight distribution center (the City Port) is located in a strategic position in the first ring of the city.

In any case the research demonstrates that spatial distribution and density of freight facilities can minimise, with more or less influences, freight and shopping transport costs. In particular the relocation of commercial and logistics centres, with a distribution in the urban area more close to the residential distribution, could drive to a restocking pattern with a consequent reduction of freight vehicle mobility.

From the analysis it is also clear that shops and freight facilities relocation can also afford to contain the effects of the increase in goods trips, by reducing the travel distances between retailers and retailers of suppliers, without remove the retailers from the most central areas. In order to achieve sustainable development goals, medium and big retail activities should be placed in high accessible areas, close to multimodal transport nodes, in barycentric position with respect to the metropolitan areas residential distribution and in already dense and mixed used areas.

Finally, the research demonstrates that it is appropriate to jointly simulate the urban mobility of passenger and freights because the share of private vehicles is more important than the goods mobility share. The variation of vehicle – km of the two segments shares and the variation of equivalent vehicle - km demonstrate in fact that the shopping mobility transport costs are higher than their freight restocking counterpart and that it is fundamental to investigate the two components at the same time. The integrated approach provides to consider the linkage between the two mobility segments and to assess jointly their impacts.

Further analyses are also in progress to improve these first results by, (1) developing other models, such as shopping mode choice models, and including zonal and level-of-service attributes (e.g. accessibility) in shopping trip generation, distribution and restocking models; (2) to estimate more disaggregate indicators in order the geo-localize the impacts into different urban areas; (3) to define for each study area specific planning strategies according to their logistic profile.

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