Freight Distribution in Urban Area: Estimating the Impact of Commercial Vehicles on Traffic Congestion

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Abstract. Urban freight transport plays an important role in the sustainability of the cities, as it is the last-leg of the supply chain which connect the production activities, generally located outside, to both commercial activities and final consumers, located inside the city. The problem that arises is related to the estimation of impact that the commercial vehicles determines on traffic congestion, and more generally on the liveability of urban areas. Current methods use the passenger car equivalent coefficients to convert heterogeneous traffic into homogeneous one in which it is assumed that only cars are travelling, according to different criteria based on road and vehicles characteristics, and traffic composition. The paper introduces a criterion of conversion of commercial vehicles based on the freight capacity, according to the potential impact of the vehicle when executing the freight delivery operations inside urban areas. This problem is further amplified in urban areas where there is a lack of material and immaterial infrastructures able to support city logistics operations, as in the case study examined.

Keywords: Sustainable development · city logistics · freight vehicles · car equivalent coefficients · case study

1 Introduction

Cities are moving nowadays towards a low-carbon transport and several measures allowing to increase people walking, cycling, using transit and vehicles powered by alternative fuels have been introduced in order to reach sustainable development goals [1, 2].

Urban freight transport plays an important role in the sustainability of the cities; however, it has negative externalities in terms of environmental, economic and social issues [3, 4]. It is worth noting that freight vehicles travelling inside urban areas have increased considerably in recent years due to changes in retailers' patterns (e.g., reduction/elimination of stocks, just-in-time) and in citizens' habits (e.g., e-commerce) (see [5, 6]).

Several city logistics measures have been promoted and implemented by cities during the last two decades [7, 8]. They are commonly grouped into four categories: *governance*, such as delivery-pick up time windows, road pricing; *equipment*, related to loading units

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(new standards) or transport units (e.g. vehicles); *immaterial infrastructures*, involving research, training and emerging ICT; *material infrastructures*, such as roads and lanes (i.e. reserved to freight vehicles), and dedicated areas (i.e. for loading/unloading operations, urban distribution centres).

City logistics measure should be identified inside a circular process that considers three interconnected elements: city planning theories, city policies and rules and city development, [9]. In order to achieve the convergence among the above elements, city planning theories should be materialized into city policies and rules in order to implement city development, on one side; city development should influence policies and rules that should match city planning theories, on the other side.

In the above circular process, the role of regional administrations is important in accompanying municipalities along the path from planning theories to policies and rules. In the literature a relevant experience comes from Calabria regional administration, which provided financial resources, scientific and technical support inside a public engagement approach with city decision makers and society [10–12].

The ex-ante performance and impacts generated by city logistics measures could be evaluated by means of Transport System Models (TSMs) [13, 14], which are able to reproduce the process of urban distribution of freight to commercial activities and final consumers. TSMs for urban freight distribution have been developed since the end of the 90s, when the first city logistics experiences were carried out in some Northern European cities. The existing literature covers different elements of the urban freight distribution process: the representation of the last-mile distribution chain and the role of the emerging ICT technologies [15], on the supply side; and the simulation of stakeholders' behaviour and interactions, on the demand side. Detailed literature reviews are reported in [16–19].

The problem that arises is related to the impact that city logistics determines in terms of commercial vehicle flows, and more generally on the liveability of urban areas. Current methods use the "passenger car equivalent" coefficients to convert heterogeneous traffic into homogeneous one, according to different criteria related to road and vehicles characteristics, and traffic composition. In the literature many works have studied the load determined by commercial vehicles and various models have been developed in the last 20 years that allow to simulate the movements of vehicles in highly congested urban areas [20, 21]. There is a lack in the literature concerning the study of city logistics impacts in regions where the socio-economic development levels are lower than more developed regions and where material and immaterial infrastructures that support city logistics operations are scarcely present. That is, it is necessary to verify what is the impact on the urban transport system in territories where these two characteristics are present. The answer to this question is particularly important, in order to arrive to theoretical hypotheses on which appropriate city logistics measures depend.

The paper introduces a criterion to convert commercial vehicles into equivalent passenger cars based on the freight capacity, given the high impact of these vehicles on traffic congestion when executing the freight delivery operations inside urban areas. This problem is further amplified in urban areas where there is a lack of material and immaterial infrastructures able to support city logistics operations (e.g. parking, loading and unloading operations), as in the case study examined.

The method used in the paper consists in the decomposition of the problem into two parts. In a first part, the overall traffic that affects a territory that has the two characteristics identified above is studied, highlighting the presence of commercial vehicles inside vehicular traffic flow. In the second part, the classification of commercial vehicles is studied by specifying different classes in terms of freight capacity. On this basis, conversion factors have been estimated, uniquely and schematically determined by the capacity of the commercial vehicles. It is therefore possible to go back to private cars in order to verify the impact to traffic provided by commercial vehicles, which are converted into equivalent cars.

It is important to note that the surveys reported in this paper refer to a pre-Covid time period, as Covid has implied a further increase in commercial vehicles due to a relevant increase of e-commerce [22].

The paper reports a description of a survey carried out in a small-size city related to freight vehicles entering in the central area in order to estimate their impact on the vehicular traffic. To this end, the indicators for estimating the coefficients of equivalence of commercial vehicles are presented in Sect. 2. Section 3 describes a specific survey, on freight vehicles entering in the central area of a small-size city and the estimation of the incidence of equivalent freight vehicles respect to the vehicular traffic flow. The conclusions and the further research are presented in the last section.

The results obtained are particularly significant because they highlight a decisive theme for urban areas. In this sense, the paper is important for technicians and decision-makers of public administrations, because it remarks the need to intervene even in areas that are not particularly rich and densely populated. It is also important for researchers because it requires the development of appropriate intervention models.

2 Vehicular Traffic in Urban Area: Incidence of Freight Vehicles

Vehicular traffic in urban area is composed by different classes of vehicles. Road vehicles for people mobility differ in the dimension and passenger's occupancy rate. Road vehicles for freight mobility differ in the capacity in terms of maximum volume and weight that can be transported. In relation to city logistics, vehicles can be used for distribution and delivery of different categories of freight (food, wastes, medicines, fuel delivery, raw materials for production processes, etc.).

Current methods [23, 24] use the passenger car equivalent coefficients to convert heterogeneous traffic into homogeneous one in which it is assumed that only cars are travelling, according to different criteria related to road and vehicles characteristics, and to traffic composition. They are important in the field of traffic engineering for supporting capacity analysis in road links and saturation flow rates at road intersections, and in general in the network.

Urban freight distribution processes have a relevant role for the cities. The pandemic emergency connected to COVID-19 produced transformations and uncertainties in the transport and logistics sector, especially in the recovery period. Users' purchasing habits have changed and e-commerce has begun to have an increasingly important role. The growing use of logistics services has produced an increase in the number of vehicles that delivery goods in urban areas. These changes have direct effects on urban transport systems.

It is therefore necessary to understand the urban logistics systems by increasing knowledge of the phenomenon in order to identify solutions suitable for the urban context.

In this paper, in order to contribute to the understanding of the urban freight transport phenomenon, the road vehicles flows crossing a generic road section (i) are grouped in the following classes:

- passenger (p) vehicles' class:
  - p0: bike or vehicles for micro-mobility, indicated as $f_{i,p0}$;
  - p1: motorcycle, indicated as $f_{i,p1}$;
  - p2: cars, indicated as $f_{i,p2}$;
  - p3: bus, indicated as $f_{i,p3}$;
- freight (f) vehicles' class:
  - f0: including vehicles with a capacity C > 18000 indicated as $f_{i,f0}$;
  - f1: ultra heavy (UL) vehicles, including vehicles with a capacity (C) comprises in the interval 3600 < C < 18000 indicated as $f_{i,f1}$;
  - f2: heavy (H) vehicles, including vehicles with a capacity (C) comprises in the interval 1600 < C < 3600 kg, indicated as $f_{i,f2}$;
  - f3: light (L) vehicles, including vehicles with a capacity comprises in the interval 1000 < C < 1600 kg, indicated as $f_{i,f3}$;
  - f4: ultra light (UL) vehicles, including vehicles with a capacity (C) comprises in the interval C < 1000 kg, indicated as $f_{i,f4}$.

In order to measure the incidence of road freight vehicles in section (i), the following indicator is introduced:

$$a_{i,f} = \sum_{k=0,\ldots4} f_{i,fk} / \sum_{k=2,3} f_{i,pk} \tag{1}$$

The indicator is expressed in terms of a ratio between all freight vehicles (class f) and the sum of auto and buses dedicated to people mobility (classes p = 2, 3).

The equivalent road vehicle flow, $f_{i,p*}$, in section (i) is expressed as:

$$f_{i,p*} = \sum_{k=2,3} f_{i,pk} + \sum_{k=0,\ldots4} E_{fk} \cdot f_{i,fk} \tag{2}$$

where E_{fk} is the passenger car equivalent coefficient of freight vehicles of class fk.

3 Case Study

The study area is part of the municipality of Reggio Calabria (180 000 inhabitants and an extension of 236.02 km^2) and consists of a central district with mixed residential and retail activities and clustered educational and public services; and of suburban districts with manufacturing activities and scattered residences (Fig. 1).

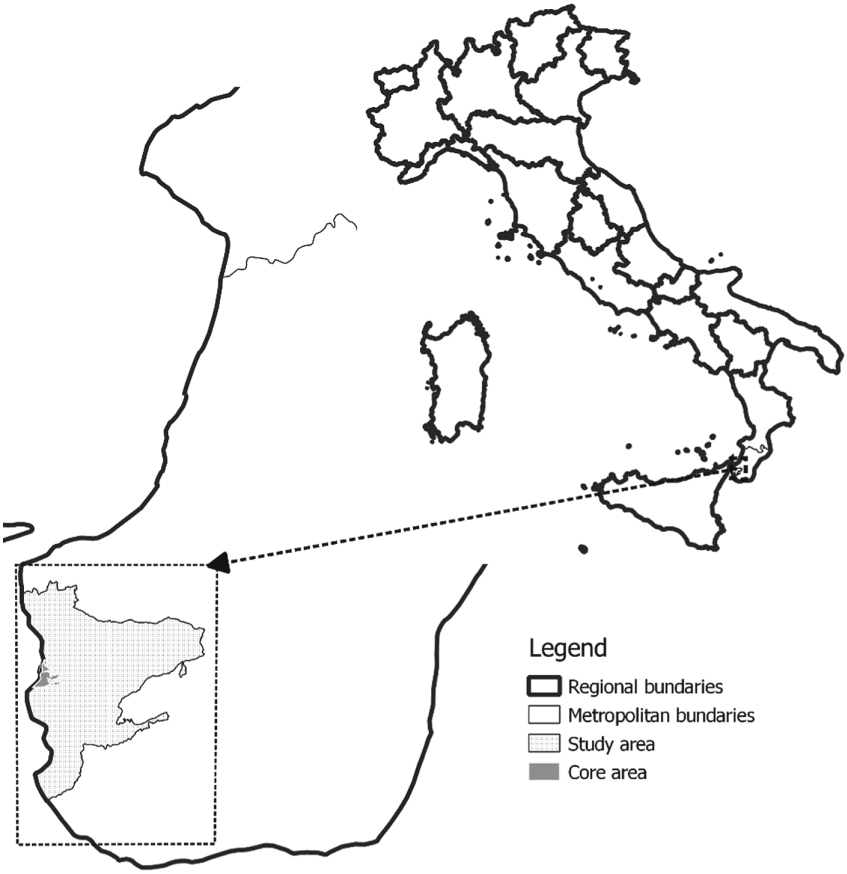

Fig. 1. Study area (a) and portion of the central district with zones (b). (Source: elaborated by authors)

3.1 Indicators for Road Vehicles

The examined city has road infrastructures of primary and secondary relevance. The primary connection is the A2 motorway, also known as "Mediterranean or Salerno-Reggio Calabria". This road connects Campania, Basilicata and Calabria regions, representing one of the main national axes. Others relevant roads are: the SS 106 Jonica that connects Calabria, Basilicata and part of the Puglia regions; the road SS18 Tirrena Inferiore that is one of the most important and longest arterial roads in Southern Italy.

Part of the recalled roads cross the study area of Reggio Calabria (see Fig. 2).

Different vehicular road traffic surveys were realized in the city to analyze the mobility of people and goods. The results supported the urban transport planning process, and in particular the Sustainable Urban Mobility Plan (SUMP) referred to the municipal area, adopted in 2017 [25]. With this aim, some surveys are conducted for updating the traffic database with road vehicular flows relative to the municipal area. A survey was conducted on vehicular flows crossing a subset of road sections. The sections are located

within the urban center (core sections) and at their boundary (cordon sections). The data presented in Table 1 concern the cordon sections.

The traffic counts in the road sections are collected in three time periods of a typical working day (07:00 – 09:00; 12:30 – 14:30; 17:00 – 19:00).

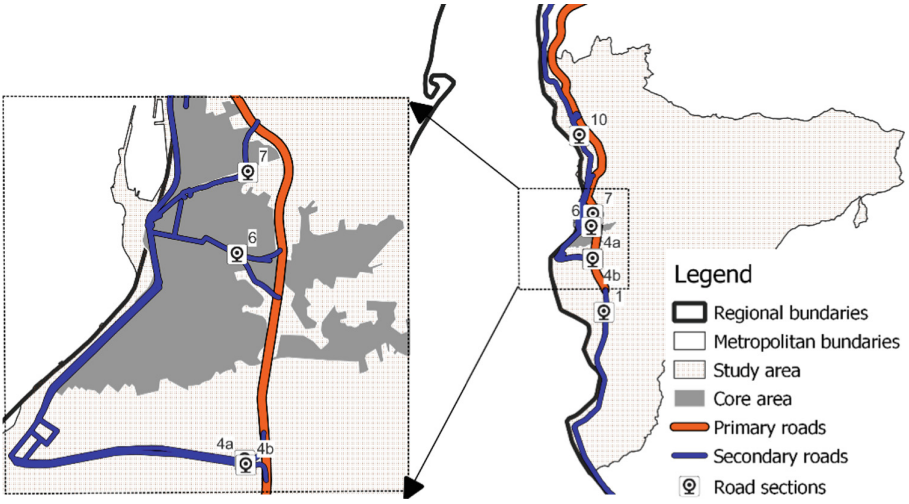

Fig. 2. Location of the selected road core sections. (Source: elaborated by authors)

Table 1. Traffic counts in the road sections in the periods 7:00–09:00, 12:30–14:30, 17:00–19:00.

		People vehicles		Freight vehicles			Indicator	
		Car	bus	UL+L	H	UH		
	Name	$f_{i,p2}$	$f_{i,p3}$	$f_{i,f}+f_{i,f3}$	$f_{i,f2}$	$f_{i,f1}+f_{i,f0}$	$\alpha_{i,f}$	
North(N)	10-SS18 Archi	7208	59	290	174	22	6.7%	4.6%
	7-Via Lia	7788	29	201	107	1	4.0%	
	6-Via Cardinale P.	7759	39	241	60	1	3.9%	
	4b-Cedir	10458	44	323	111	10	4.2%	
South(S)	4a-Cedir	10075	58	393	133	7	5.3%	6.4%
	1-Saracinello	5224	70	346	95	7	8.5%	
Total		48512	299	1794	680	48	4.5%	5.5%

UL: Ultra Light; L: Light; H:Heavy; UH: Ultra Heavy
(Source: Elaborations from [25])

3.2 Indicators for freight vehicles

The commercial vehicle fleet has been subdivided into classes according to the load capacity. Five classes of freight vehicles have been identified. Table 2 shows a range

of load capacity associated with each class of commercial vehicles and the average conversion equivalence coefficient calculated assuming the Fiat Panda Van as equivalent vehicle with a load capacity of 550 kg. For each of the five classes considered, an average equivalence coefficient was assumed equal to the coefficient calculated respect to the freight vehicles in the market belonging to each class.

Table 2. Freight vehicles: classes of capacity and equivalent conversion coefficients

Class	Capacity, C [kg]	Equivalence coefficient
0	C>18000	54.5
1	3600 < C < 18000	24.5
2	1600 < C < 3600	4.0
3	1000 < C < 1600	2.4
4	C < 1000	1.4

Freight vehicles entering inside the study area in the peak period (7:00 am – 9:00 am) of a working day have been counted and classified according to the five classes defined. The observation includes freight vehicles delivering perishable food, building materials, materials for maintenance and services and other durable goods.

The road sections that are the gate for entering inside the city are grouped according to two geographic areas:

- *Southern gates*, vehicles entering in the city from the following road sections: 106 Jonica (SS 106): 1-Saracinello, 2-Arangea, 3a-Modena Sud, 3b-Modena Nord, 4-Cedir, 5a-Spirito Santo Sud;
- *Northern gates*, vehicles entering in the city from the following road sections: 18 Tirrena Inferiore, 5b-Spirito Santo Nord, 6a-Via Petrara, 6b-Via Cardinale Portanova, 7-Via Lia, 8-Via Esperia, 9-Via Genoese Zerbi, 10-SS18 Archi.

Table 3 shows the flows of freight vehicles subdivided into the five classes according to their load capacity. It should be noted that it was not possible to identify the freight transported of the vehicles crossing the road sections considered, therefore the data reported may not be exhaustive. It emerged from the survey that, in the period considered, 400 commercial vehicles entered inside the city from the Southern gates, and 229 commercial vehicles entered inside the city from the Northern gates. The total number of entering vehicles was 629.

Figure 3 reports the frequencies of flow percentages of freight vehicles per each class entering inside the city trough the Northern gates, the Southern gates and the total vehicles entering inside the city. It is worth noting that class 4 of freight vehicles has the highest percentages (ranging from 42.0% to 33.0%), while class 1, 2 and 3 of freight vehicles have similar percentages (ranging from 25.0% to 14.0%), the lowest percentage belong to freight vehicles of class 0.

Table 3. Flow of freight vehicles per class in each road section

Road section	0 [veih/2h]	1 [veih/2h]	2 [veih/2h]	3 [veih/2h]	4 [veih/2h]	Total [veih/2h]
1-Saracinello	5	17	9	9	21	**61**
2-Arangea	0	7	5	12	19	**43**
3a-Modena Sud	0	12	9	6	34	**61**
3b-Modena Nord	6	4	3	12	9	**34**
4-Cedir	1	26	30	21	52	**130**
5a-Spirito Santo Sud	0	15	9	11	36	**71**
Southern road sections	**12**	**81**	**65**	**71**	**171**	**400**
5b-Spirito Santo Nord	0	8	10	6	6	**30**
6a-Via Petrara	0	1	9	20	11	**41**
6b-Via Cardinale Portanova	0	5	8	2	29	**44**
7-Via Lia	0	10	6	4	16	**36**
8-Via Esperia	1	3	12	5	0	**21**
9-Via Genoese Zerbi	0	2	8	6	8	**24**
10-SS18 Archi	0	16	4	6	7	**33**
Northern road sections	**1**	**45**	**57**	**49**	**77**	**229**
Total	**13**	**126**	**122**	**120**	**248**	**629**

Figure 4 reports the frequencies of standard deviation (s.d.) of flow freight vehicles per each class entering inside the city among the Northern gates, the Southern gates and the total gates. It is worth noting that the classes 1, 2, 3 and 4 of freight vehicles have similar values of s.d. (ranging from 5,0% to 15,0%), the s.d. among the Northern gates presents the highest values.

Table 4 reports the flow of equivalent freight vehicles for each class and for each road section considered. These values are obtained by multiplying the values of flow in Table 3 for the values of equivalent conversion coefficients per class of Table 2.

Table 5 reports the value of incidence of freight vehicles respect to passenger vehicles calculated from eq.1 considering equivalent freight vehicles for each class. It is worth noting that the value of the indicator increases to 30.40% respect to the value calculated with the freight vehicle counted (5.5%) reported in Table 2.

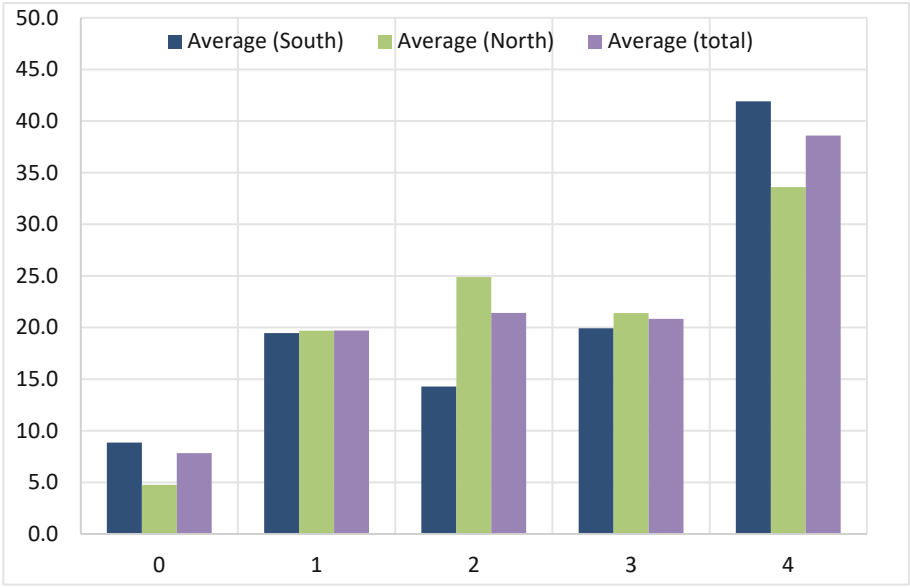

Fig. 3. Observed percentages of freight vehicle class: average values

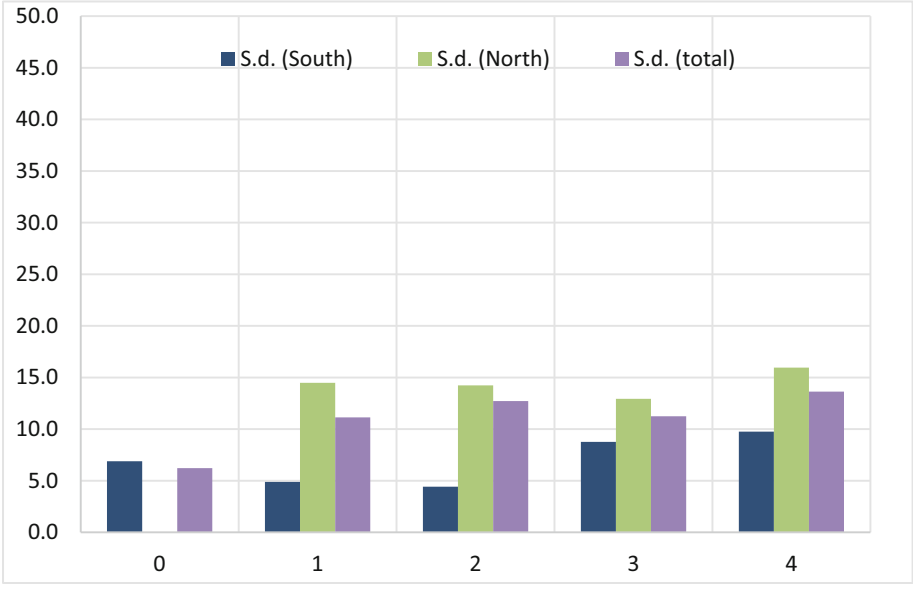

Fig. 4. Observed percentages of freight vehicle class: standard deviation (s.d.) values.

Table 4. Flow of equivalent freight vehicles per class in each road section

	0	1	2	3	4	Total
Road section	[veih/2h]	[veih/2h]	[veih/2h]	[veih/2h]	[veih/2h]	[veih/2h]
1-Saracinello	273	418	36	22	30	**779**
2-Arangea	0	172	20	29	27	**248**
3a-Modena Sud	0	295	36	15	48	**394**
3b-Modena Nord	327	98	12	29	13	**480**
4-Cedir	55	640	122	51	73	**940**
5a-Spirito Santo Sud	0	369	36	27	51	**483**
Total road sections (South)	**655**	**1993**	**263**	**173**	**241**	**3324**
5b-Spirito Santo Nord	0	197	41	15	8	**260**
6a-Via Petrara	0	25	36	49	16	**125**
6b-Via Cardinale Portanova	0	123	32	5	41	**201**
7-Via Lia	0	246	24	10	23	**303**
8-Via Esperia	55	74	49	12	0	**189**
9-Via Genoese Zerbi	0	49	32	15	11	**107**
10-SS18 Archi	0	394	16	15	10	**434**
Total road sections (North)	**55**	**1107**	**231**	**119**	**109**	**1620**
Total	**709**	**3100**	**494**	**292**	**350**	**4944**

Table 5. Incidence of equivalent freight vehicles respect to passenger vehicles. Period 7:00-9:00 a.m.

	Passenger vehicles	Equivalent freight vehicles					Indicator
	$fp1+f_{p2}$	f_{f0}	f_{f1}	f_{f2}	f_{f3}	f_{f4}	(eq.1)
Total	16270	710	3100	494	292	350	30,40%

4 Conclusions

Urban freight transport plays an important role in the sustainability of the cities, as it is the last-leg of the supply chain which connect the production activities, generally located outside, to both commercial activities and final consumers, located inside the city. The estimation of impact that the commercial vehicles determine on traffic congestion, and more generally on the liveability of urban areas, is underestimated and not adequately

studied in the literature. Current methods use the passenger car equivalent coefficients to convert heterogeneous traffic into homogeneous one in which it is assumed that only cars are travelling, based on road and vehicles characteristics, and traffic composition. The idea proposed in the paper is to introduce a criterion of conversion of commercial vehicles into a "reference" commercial vehicle based on freight capacity, given that the impact of commercial vehicles when executing the freight delivery operations inside urban areas increase with their load capacity.

This problem is further amplified in urban areas where there is a lack of material and immaterial infrastructures able to support city logistics operations, as in the case study examined. The case study refers to a small city, located in the South of Italy, where no material and immaterial infrastructures able to support city logistics operations have been implemented. The results show that value of incidence of freight vehicles respect to passenger vehicles calculated considering equivalent freight vehicles for each class is double respect to the value calculated with the counted freight vehicles.

Further developments concern the calibration of the proposed conversion coefficients of freight vehicles according to experimental data, regarding the amount and type of freight transported by commercial vehicles entering inside the city, the number and type of destinations to be served (commercial activities vs. final consumers), the presence and the level of city logistics measures implemented, and other potential attributes.

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