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Urban Freight Vehicle Flows: an Analysis of Freight Delivery Patterns through Floating Car Data

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Abstract

The assessment procedures of city logistics scenarios require the simulation of freight transport demand and hence the estimation of freight vehicle origin-destination (O-D) flows. These O-D flows can be obtained from the simulation of delivery tours. Therefore, the paper recalls a system of models able to simulate delivery tours using an aggregate approach proposed by the authors and presents the propaedeutic analysis for setting up such a tool. The data come from a dataset of commercial vehicles operating in the Veneto Region (Italy) for which floating car data (FCD) of 60 operating-days were available. The analysis allowed us to investigate the current patters of delivering tours and to point out some evidences on which models for delivering simulation can be based.

Keywords: freight distribution tour; trip chain; floating car data; delivery model; aumated vehicle monitoring.

1. Introduction

Region/urban freight transport is crucial to meet people needs, but it affects also negatively on environment, economy and society. As would be expected, local administrators use city logistics measures to reduce the above negative impacts. Indeed, several city logistics measures can be implemented with a view to reducing the negative effects of freight distribution, seeking to reduce the number of commercial vehicles, increase the use of light and environment-friendly vehicles, and optimize loading and unloading operations in order to reduce traffic congestion and interference with the other components of urban mobility (e.g. pedestrians).

Since the characteristics of region/urban areas can differ substantially, city logistics measures have to be specifically designed and assessed in order to implement the most effective. In this context, the choice of a set of city logistics

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measures to be implemented (i.e. city logistics scenarios) has to be based on the simulation of the main effects of exogenously specified scenario (i.e. *what if* approach). In these simulation/design tools, the freight vehicle origin-destination (O-D) matrices, interacting within the assignment model, allow us to obtain the link freight vehicle flows. Then, the link performances and the direct effects of a given city logistics scenario can be estimated and evaluated. In literature, different models for the estimation of freight O-D matrices have been proposed, but few of them focused on issues related to conversion from quantities (or deliveries) to tours (vehicle movements). Thus, the first objective of the paper is to review the literature on freight O-D matrices and to identify the main characteristics requested to models for such an aim.

Besides, the patterns of movements followed by commercial vehicles have to be pointed out in order to investigate the process of conversion from delivery O-D matrices to vehicles one. Tour and trip chain are an important elements of commercial vehicle movements in an urban/metropolitan setting. A tour can be defined as a chain of trips made by a vehicle beginning and ending at base location (e.g. warehouse). Then, the second objective of the paper is to study the main characteristics of commercial vehicles identifying their patterns and their daily activity. The data source consists of a sample of commercial vehicles operating on 60 days within the Veneto Region from January to June 2018.

The paper is organized as follows. Section 2 briefly reviews the literature on delivery tour analysis and simulation, while Section 3 recalls the delivery tour model proposed by authors (Nuzzolo and Comi, 2013) that can be used for estimating O-D matrices. Section 4 describes the data used for analyzing delivery tours and synthesis the first results. Finally, Section 5 draws conclusions and identified the further development of this study

2. Literature review

2.1. Models for freight O-D flow forecasting

Different demand models have been proposed to indicate the two sets of freight restocking flows taking place in a study area (i.e. from wholesalers to retailers or end-consumers): the O-D flows of *commodities* and the O-D flows of commercial/freight *vehicles*. The current literature (Hu *et al.*, 2019) has mainly investigated the former, and models for the estimation of the level and the spatial distribution of commodity exchanges, in terms of quantity and/or origin-destination delivery matrices, have been proposed (de Jong *et al.*, 2012; Comi *et al.*, 2014). Quantity-based models simulate the mechanism underlying the generation of freight transport demand (Gonzalez-Feliu *et al.*, 2010; Russo and Comi, 2010; Comi and Nuzzolo, 2016), while those using delivery units are more specific for studying the logistic process of restocking (Routhier and Toiler, 2007; Muñuzuri *et al.*, 2012). Furthermore, solutions combining quantity and delivery units, and hence their advantages, have been developed (Nuzzolo and Comi, 2013).

Finally, given that 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, procedures for obtaining such O-D matrices from delivery ones are of interest. The translation is not direct, particularly in region/urban areas where freight vehicles undertake complex routing patterns involving trip chains (tours). In fact, each restocker jointly chooses the tour pattern (e.g. single/multiple direct or single/multiple peddling), the number and the location of deliveries for each tour and hence defines his/her tours, trying to reduce the related costs (e.g. using routing algorithm). As pictured in Figure 1, the freight vehicle O-D matrices can be obtained from the delivery O-D matrices through a *delivery tour model* which uses a two-step procedure:

- computation, from delivery O-D matrices, of the number of delivery tours departing from each zone *o* (*tour generation* sub-model);
- definition of freight vehicle O-D matrices from delivery tours (*delivery location* sub-model).

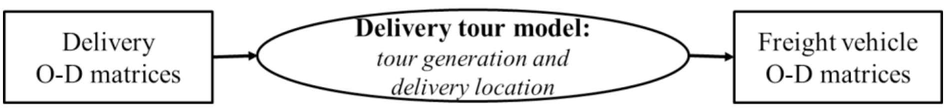


Fig. 1 - Structure of freight vehicle O-D flow modelling

2.2. Delivery tour model literature

Following the classification proposed by Nuzzolo and Comi (2013), the models to define delivery tours from given delivery O-D matrices, can be subdivided into *simulation* and *analytical* models.

The simulation models are based on empirical relationships that allow the single trip to be combined into a tour. These models are usually implemented into an ad hoc decision support system (DSS; Ambrosini *et al.*, 2008), such as Wiver/Viseva (Sonntag, 1985; Lohse, 2004) and Freturb (Routhier and Toilier, 2007).

The analytical models propose mathematical relationships based on economic, statistical or behavioral assumptions within a disaggregate or aggregate approach. The disaggregate approach involves the use of procedures that include estimation of the delivery tours for each decision-maker (e.g. carrier) with different locations of warehouses and shops to restock, different vehicles and time constraints to respect. Several principles are used to accomplish this, leading to models based on vehicle routing (Crainic *et al.*, 2009; Tamagawa *et al.*, 2010; Musolino *et al.*, 2018), behavioural (Ruan *et al.*, 2012) or activity models (Gliebe *et al.*, 2007; Sanchez-Diaz *et al.*, 2015) and on heuristic procedure (Figliozzi, 2006; Wisetjindawat *et al.*, 2007). However, in spite of their significant potential, implementation of these types of models has a fundamental limitation related to the amount of information required (which can only be obtained through specific large surveys) and to the expansion to the universe.

Aggregate models can be used as an alternative way to forecast region/urban delivery tours, given their smaller data requirements, lower computational times, and less reliance on behavioral assumptions. These models consider the average behavior of all restockers (or categories of restockers) leaving from the same warehouse zone. Within these common characteristics, three main groups of models have been proposed, as well as different specifications within each group depending on the variables explicitly simulated.

Models of the first group, known as spatial price equilibrium models (SPE), are based on Samuelson's work (1952) and propose a multiple vehicle routing problem in which profit is maximized subject to competition (Thorson *et al.*, 2005).

The second group of models is based on entropy maximization theory (Wilson, 1969). The resulting entropy formulations are aimed to find the most likely set of tour flows that meet the system's constraints such as the trips generated or attracted by each zone and the travel cost (Wang and Holguin-Veras, 2009).

The third group consists of partial share models. They give the probabilities that a delivery tour has a given number of stops, a given sequence of stops/deliveries and a given type of vehicle used. Within this group, two approaches have been proposed: *incremental growth* and *multi-step*. Incremental growth studies (Hunt and Stefan, 2007; Wang and Holguin-Veras, 2008; Khan and Machemehl, 2017) propose to obtain, for a given type of vehicle, the number of stops per tour by incremental growth for which, at each stop, the option to come back to the base (i.e. warehouse) is considered. If the tour continues, the probability of the next destination zone is calculated (Holguin-Veras and Thorson, 2003). This approach implies major approximations because the actual choice process is not reproduced. Indeed, the choices of the number of stops and delivery zone sequence are generally pre-trip choices. The multi-step approach (Nuzzolo and Comi, 2013) defines tours through joint definition of the trip chain order (that is the number of stops in a tour), the type of vehicle used and the delivery location sequence. Below, a model of this type is recalled and the potential advancement (e.g. definition of tour pattern) on specification and calibration exploiting the opportunities offered by floating car data (FCD), which allow to follow continually in time and space the operating vehicles, will be pointed out.

3. The used delivery tour model

Let ND_{od} be the generic element of a given delivery O-D matrix representing the average number of deliveries departing from warehouse zone *o* and with destination zone *d*. The freight vehicle O-D matrices, satisfying the given delivery O-D matrix, can then be estimated by using an aggregate multi-step delivery tour model that considers the average behavior of all restockers starting from the same warehouse zone.

The total number of tours T_o departing from zone *o* can be determined as follows (*tour generation* sub-model):

$$T_{o.}\left[vnt\right]=T_{o.}\cdot p\left[t/o\right]\cdot p\left[n/to\right]\cdot p\left[v/nto\right] \qquad T_{o.}=\frac{ND_{o.}}{\bar{n}_o}=\frac{ND_{o.}}{\sum_n n\cdot p\left[n/to\right]} \tag{1}$$

where

- $T_{o.}$ *[vntr]* is the number of tours departing (generated) from zone *o* at time *t* by vehicle type *v* with *n* stops/deliveries;
- $T_{o.}$ is the number of tours departing (generated) from zone *o*;
- $ND_{o.}$ is the average number of deliveries performed departing from origin zone *o*;
- *p[t/o]* is the share or probability to undertake tour at time *t*;
- *p[n/to]* is the share or probability to undertake tour with *n* stops/deliveries;
- *p[v/nto]* is the share or probability to undertake tour by vehicle type *v*;
- $\bar{n}_o$ is the average number of deliveries performed by tours departing from zone *o* at time *t*.

Once the tours departing from a zone *o* are estimated, the following step is the estimation of the sequence of stops/deliveries (*delivery location* sub-model). Let $p\left[d_j^{k+1}/d_i^k\, vno\right]$ be the probability of delivering in zone d_j the delivery *(k+1)*, conditional upon having previously delivered in zone d_i the delivery *k*, within a tour with *n* stops/deliveries departing from a given zone *o* and using a vehicle type *v*, obtained by a delivery location choice model.

Finally, the number of vehicles $VC_{d_id_j}$ on (d_i-d_j) pair can be estimated as follows:

$$VC_{d_id_j}\left[vno\right]=\sum_k VC_{d_i^{k+1}d_j^k}\left[vno\right]=T_{o.}\left[vn\right]\cdot\sum_k p\left[d_j^{k+1}/d_i^k vno\right] \tag{2}$$

The probabilities *p[t/o]*, *p[n/to]*, *p[v/nto]*, $p\left[d_j^{k+1}/d_i^k\, vno\right]$ can be obtained by statistic-descriptive or probabilistic-behavioral models. Below, the investigation obtained analyzing a large dataset of light goods vehicles (less than 3.5 tons) operating in the Veneto Region is presented. Such results are the basis for the identification of the tour patterns and are propaedeutic for delivery tour model specification as well as for its calibration and validation.

4. Data analysis

In recent years, the massive collection of traffic data (e.g. tracking data, mobile phone data and automated traffic counts) can be a source for simulating, modelling and planning transportation systems. Below, the first results of a delivery tour analysis procedure is synthesized. It aims to investigate freight vehicle tours in order to point out their patterns (i.e. structure of the tours in relation to various attributes, as number of stops, travel time and so on).

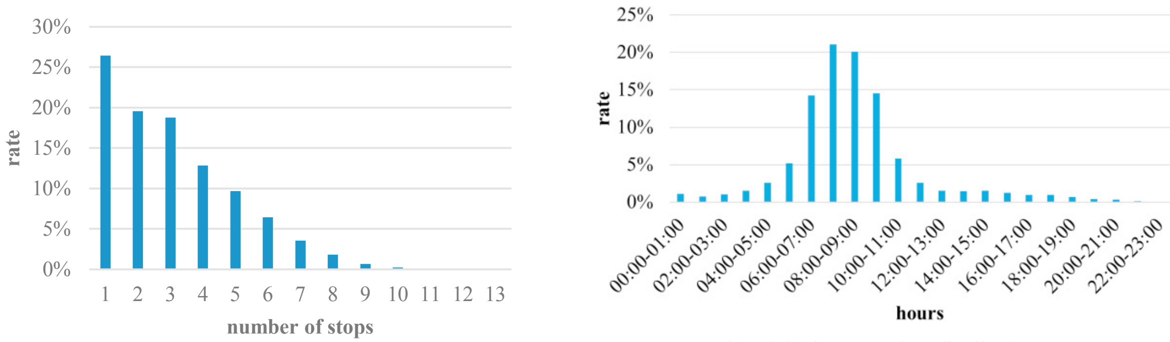
The procedure was developed and tested using some data on the movements of light freight vehicles (i.e. laden weight less than 3.5 tons) operating in the Veneto region in order to identify the tour patterns obtaining indications on the performed travels. The available database consists of 60 working-day observations within the first semester of 2018 (from January to June). For each sampled vehicle, the information form contains the basic vehicle data such as vehicle class, make, model, year, type, fuel type, gross weight. The daily vehicle operation log records, indeed, contain all trips made by the surveyed vehicle in chronological order: vehicle identifier, date (date the record is logged), timestamp (time the record is logged), coordinates (geographical location: latitude and longitude), instantaneous speed, type of road (urban, extra urban, freeway), direction angle. After cleaning and eliminating observations with missing data, the remaining data were processed in order to investigate *delivery tour patterns* and the *tour/trip performances*. A set of 1579 vehicles was analyzed, corresponding at more than 33,000 tours undertaken in the 60 days.

First, data were processed in order to identify the freight type moved. Based on the requirement for transporting freight and on the subsequent characteristics required to vehicles (e.g. insulated vehicles), the following freight types were able to be identified: alive animals, building materials, foodstuffs at controlled temperature (both fresh and frozen), transport of vehicles, other. Then, the attention was paid to the tour patterns (Ruan *et al*., 2012): single direct, multiple direct, single loading/unloading and multiple loading/unloading (peddling). In a single direct tour pattern, a commercial vehicle makes only one intermediate stop per vehicle loading, while multiple direct tour involves multiple single direct trips from the base location. Peddling shipping serves more than one intermediate stop per vehicle load. In a single peddling tour, a commercial vehicle performs more than one intermediate stop before returning to the base location. A multiple peddling tour involves more than one single tour with more than one stop from the base location.

In the investigated dataset, about the 26% of tours are single direct tours (i.e. only one intermediate stop), the remaining ones are single peddling tours (i.e. one origin and more than one stop), more than 19% have two stops per tours and the remaining 54% have three or more trips/stops (Fig. 2a). Therefore, according to the *eq. (1)*, the distribution of number of stops per tour (i.e. *p[n]*) can be obtained. The average number of stops per tour is 3.1.

The analysis of tour patterns also allows to identify the main origin of delivery tours (i.e. warehouses) and to characterize the production of vehicle trips according to time of the day (i.e. *p[t]*). It can be noted that more than 75% of tours start from 05:00 to 10:00 a.m., while about 21% depart between 07:00 and 08:00 a.m. (Fig. 2b).

As plotted in Fig. 3, the processing of daily activities performed by each vehicle allowed to identify some of the main locations from where tours depart as well as to identify the systematicity of such an activity. Fig. 3a shows the tours undertaken by one of the investigated vehicles which performed 8 daily tours in the given time period, from the same origin. The daily tour pattern plotted in Fig. 3a is a single peddling tour (i.e. some origins – warehouse and many stops before returning finally at warehouse). Besides, four main activity patterns can be identified. Vehicle is used for serving a large area with different towns. In particular, tours 5 and 6 refer to deliveries along the lake Garda; the tours 1 and 3 serve the same urban area on Monday and Friday with departure time from the warehouse at (about) 7:50 a.m. and 8:00 a.m. respectively. Tours 2 and 7 mainly deliver into two different and close towns, i.e. San Giovanni Lupatoto and the west periphery of Verona, with an initial overlapped path.



a) number of stops per tour

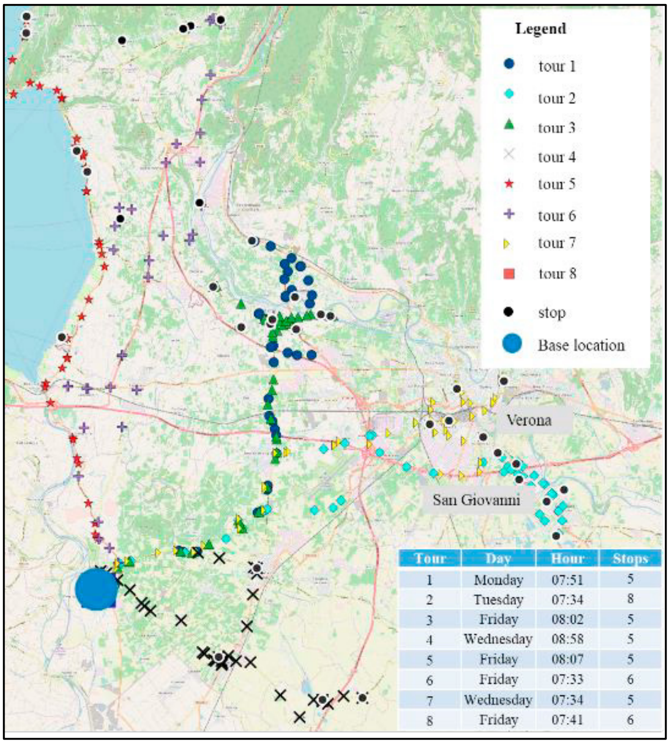
b) origin departure time distribution

Fig. 2 – Tours: number of stops per tour and tour departure time from origins/warehouses

About 93% of tours analyzed are performed by diesel vehicles, the remaining 7% are fueled by gasoline (0.25%) and by GPL or CNG. In relation to the pollutant emissions, the class of the surveyed vehicles range from EURO 0 to EURO 6. About the 7% of vehicles are in the EURO classes less than or equal to 3; in the class EURO 4 falls about the 15% of vehicles, most of vehicles (about 47%) belong to the class EURO 5, while EURO 6 represent about the 31% (Fig. 4a). In current analysis, about the 6.25% of the tours is made by vehicles classes less than or equal to EURO 3, about the 15% by EURO 4 vehicles, about 41% EURO 5 vehicles, the remaining (about 38%) by EURO 6 vehicles (Fig. 4a). Therefore, a similar usage of vehicle independently by vehicle emission class emerges.

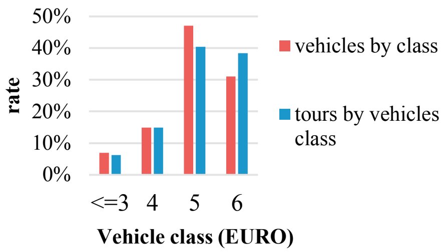
Referring to the characteristics of tour/trips, it emerges that the average travel distance covered by a whole tour is about 186 kilometers (with, as said, an average number of stops equal to 3.1) with an average travel time of 274 minutes. Stop time distribution is reported in Fig. 4b. It emerges that about the 11% of trips have a stop from 25 to 30 minutes.

Fig. 5 plots the distribution of tour per total length (a) and total travel time (b). More than 40% have a length less than 100 km with a peak share around 70-80 km. As expected, due to light vehicles are mainly used for freight distribution, the share of tour with higher length decreases with the distance. Considering the total travel time of a tour, three man sets of tours can be identified (Fig. 5b): one with a travel time less 300 minutes (about 59%), one between 300 and 450 minutes (about 27%), and the other one.

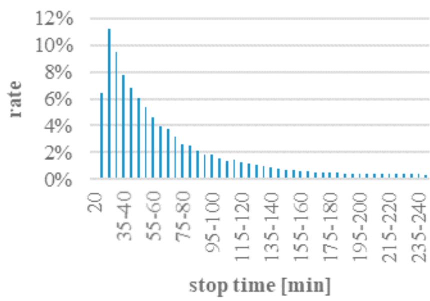


Tour	Day	Hour	Stops
1	Monday	07:51	5
2	Tuesday	07:34	8
3	Friday	08:02	5
4	Wednesday	08:58	5
5	Friday	08:07	5
6	Friday	07:33	6
7	Wednesday	07:34	5
8	Friday	07:41	6

Fig.3 – Example of tours performed by a vehicle on different investigated days.

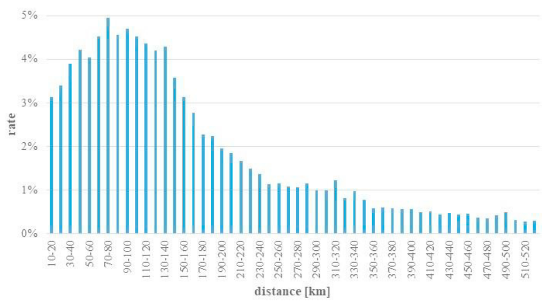


a) Vehicle and tours by EURO class

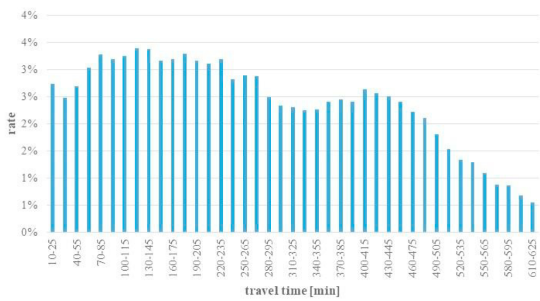


b) stop time distribution

Fig. 4 – Vehicles, tours and stop time



a) classes of tour distance

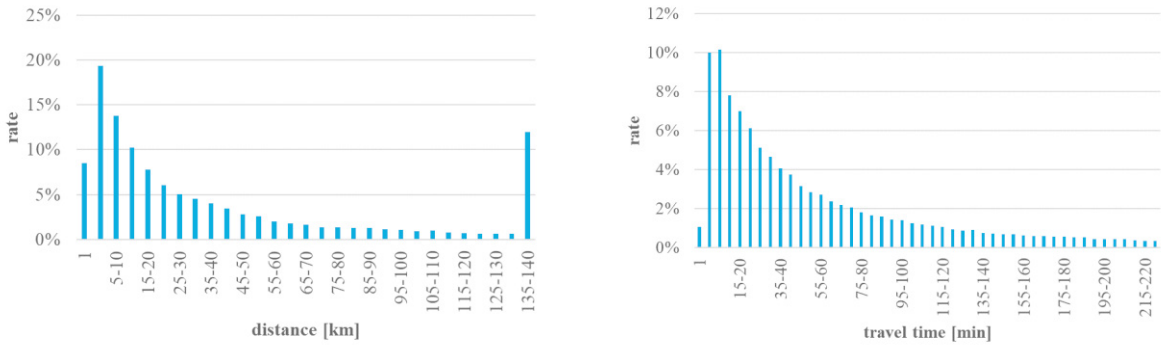


b) classes of tour travel time

Fig. 5 – Tours by classes of distance and travel time

The length of a trip within a tour is, on average, 52 kilometers, although (Fig 6), about the 9% are less than one kilometer (i.e. close deliveries) and about 30% do not overcome 5 kilometers. As expected, increasing the length of trips, the share of tours decreases given that deliveries are expected to be mainly close ($p\left[d_j^{k+1} / d_i^k \ vno\right]$). Such an analysis confirms the results obtained in other region/urban contexts (Nuzzolo *et al.*, 2016), where stops far away from the current stop location are those which have a lower probability of being chosen. Similar considerations can be made for the travel time between two consecutive stops (i.e. trip travel time). Most of trips are less than 10 minutes (about the 40%), the others are distributed in the remaining intervals with a decreasing trend (Fig. 6).

Besides, the relation between the number of stops (deliveries) carried out during a tour and the average length of consecutive stops with short stop time could allow courier movements to be pointed out. For example, in the dataset about 0.31% of tours have a number of stops more than 10 with an average tour length of 161 km and a short average stop time.



a) Classes of trip distance b) Classes of trip travel time

Fig. 6 – Trip by classes of distance, travel time and stop time.

5. Conclusions

The paper presented recent developments in delivery tour analysis that could allow freight vehicle O-D matrices to be obtained, hence link flows and road network performance. In particular, we:

- reviewed the main modelling approaches to be implemented in order to simulate delivery tours;
- presented some analyses developed exploiting the opportunities offered by floating car data capable of identifying and assessing delivery patterns.

The paper was organized into two main parts. The first part gave an overview of the delivery tour modelling and recalled a modelling system to simulate delivery tours using an aggregate approach. The latter presented some evidences on delivery tours performed by light goods vehicles belonging to a large dataset, which operate in the Veneto Region. The modelling system is structured into two levels: tour generation and delivery location. The former focuses on modelling the flow of actual tours leaving from a given zone (e.g. a warehouse) characterized by vehicle type. This allowed the mechanisms driving tour generation to be captured more accurately. Tour definition is modelled by trip chain order and vehicle type. The former identifies the number of stops of each tour, and the latter concerns the definition of the vehicle used. The sequence of stops allows us to model the delivery locations along the tour.

A sequence of statistic evidences was presented based on data coming from a large dataset collecting the operations of light goods vehicles travelling in the Veneto Region (Italy). The performance and ability to reproduce the revealed flows is under development including the development of statistic-descriptive and probabilistic models. Therefore, although the obtained statistics confirm the goodness of the approach used, further analysis is required in order to:

- specify and calibrate models able to consolidate these evidences,
- investigate the influence of socio-economic attributes (e.g. retail size) on tour definition,
- model the choice set generation within the delivery location model,
- include departure time choice in order to investigate the relationship with time windows access restrictions.

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