Assessing the impacts of goods deliveries' double line parking on the overall traffic under realistic conditions

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Abstract. This paper proposes a framework for quantifying the macroscopic impacts of delivery goods made by double-parked vehicles in urban arterial using microscopic simulation. It is applied to a real urban corridor: the Lafayette Avenue in Lyon (France). The framework combines traffic states with stochastic and microscopic freight demand generation model, i.e. the delivery movements and the delivery duration. Cooperative and competitive scenarios are considered. Impacts of goods delivery have been captured in a traffic evaluation model. The results of these configurations' assessment are discussed. Finally, practical implications for transport planners are highlighted.

Keywords: urban logistics; microscopic freight demand generation; stochastic model; traffic evaluation; scenario assessment, microsimulation.

1 Introduction

Congestion is a one of the major issues in urban area, with increasing individuals travel times and energy consumption, causing noise and air pollution which lead to healthy and environmental consequences. The quantification of impacts of urban goods transport on traffic is one of the main issues of city logistics [1]. Although urban freight is a major factor contributing to economic growth and development, it negatively affects the traffic states. Local authorities have to carefully consider freight organizations on the traffic flow evaluation. Three ways to evaluate a freight restriction can be distinguished. (i) A survey before and after the application of a limitation can be deployed. One of the major problems is that this uncontrolled environment can lead to bias in results. For example, rainy days or specials events during the survey can be a sample non-representative to the reality. A larger survey can smooth this phenomenon but it will take more time and more resources. (ii) By macroscopic level, those flow estimations are traditionally made via the assessment of traveled distances and the subsequent transformation of those distances into road occupancy issues [2]. Nevertheless, this approach is suitable in deterministic and aggregated assessments (mainly at the level of an urban area), but needs to be revised and eventually changed at a local scale. For example, in the identification of impacts of truck flows into traffic dynamics on a street (mainly an arterial) or a smaller zone (a neighborhood) of a city. (iii) Using microscopic simulation, which includes the overall traffic flow phenomenon. By this controlled environment, the evaluation of a new freight restriction can be done through metrics taking into account individual vehicles. In this study, microsimulation has been used to access the impacts of delivery goods made by double-parked vehicles at the micro level: an urban corridor. We considered a one-way corridor of 3 lanes with traffic light.

Bottlenecks are one of the major factors of congestion. More precisely, we are interested in moving bottleneck, i.e. a vehicle parked on the right lane of a road during a specified time, commonly called double-parking which is a common phenomenon in European cities. We can distinguish two major kinds of vehicles who double-park: private vehicles and delivery trucks. More than 50% of freight movements were made with a double-parked vehicle according to a survey in Paris [3]. Trucks constrain the flow upstream during the acceleration phase [4]. Two major reasons can explain this phenomenon: (i) no load zone infrastructure exists near the consumer. Indeed, the economic condition can change and the location of shops too. For example, some non-economic street can change through time, but the management of the infrastructure, like the creation or deletion of load zone do not follow this dynamic. In addition, the notion of distance of the nearest load zone depends on the delivery driver. The driver behavior can also influence the choice of double-parking the vehicles for saving time, either by parked the truck closer to the consumer or to avoid doing maneuvers. (ii) The existing load zone is already occupied by a private vehicle which is parked illegally, which happens in Paris usually where 90% of load zone are used by private vehicles [5]. Moreover, another delivery trucks can occupy the load zone. Some limitations of delivery time try to minimize this phenomenon [6].

This paper aims to quantify effects of the urban freight movements on traffic flow dynamics via an adapted simulation and evaluation framework. More precisely, this study investigates at a theoretical yet realistic urban corridor scale, the impacts of deliveries made by double-parked vehicles on the traffic states. In this sense, a combined approach is used, with a realistic and stochastic freight demand generation model at micro level and a microscopic traffic simulation model. This study seeks to estimate the realistic micro demand of the Lafayette Avenue in Lyon (France). The adaptation is made on the definition of the arterial and the deployment of a realistic scenario in terms of demand. To generate it, we need a model that takes into account the dynamic nature of traffic. However, the existing models are mainly based on deterministic generation either linear or constant [7]. For this reason, we propose a probabilistic generation approach. This approach constitutes the major contribution of this research.

This research is organized as follow: Section 2 provides the realistic and stochastic urban freight demand to calibrate the simulation. Section 3 presents the experimental results and analysis. And finally, Section 4 deals with discussion and future works.

2 Methodology

Our methodological framework aims to quantify the impacts of truck movements made by double-parked vehicles on global traffic dynamic. We consider period of 5 hours, which can represents a time window from 7 AM to noon. This framework uses two models: a microscopic demand generation model (Sect. 2.1) and a traffic simulation model (Sect. 2.2). The application of the demand model on micro-simulation is described in Sect. 2.3.

2.1 Freight demand generation at micro level

Customer is the person who received the delivery or the pick-up products. Either of them is defined by a movement and the sum of movements represent the demand in this paper. The demand has been estimated at a micro level: scale of individual customer and time scale of a week. In this case of study, it represents the Lafayette Avenue in Lyon (France). It is an economic avenue where each customer is considered as a shop and characterized by a categorical class. We consider that each categorical cluster is characterized by a logistic demand pattern. And, theses cluster's patterns will be the same for every town of the country [8]. This problem can be easily approached by a machine learning problem where, the quantitative target variable is the number of delivery per week, using the so called dataset learning and dataset training, i.e. the three towns' survey and the Lafayette Avenue respectively. However, we cannot predict the target variable using data mining techniques, because we only have one quantitative variable and there is no correlation with the target variable.

The data collection for our freight demand study is composed by three French cities: Marseille, Dijon and Bordeaux. This learning dataset provides information about the average freight movement of a shop's category for each town. This one can be divided into four levels of aggregation, defined in the French Surveys of Urban Goods Transport [9] and analyzed and discussed by [10]. We used the third level of aggregation on this study, namely *ST29*, which makes it possible to approach more closely the micro demand estimation to reality. Thus, *ST29* presents 13 modalities for the Lafayette Street customers. This level of aggregation is not too coarse to access micro demand and is enough too fine to present a sample's size surrounding sufficient based on qualitative results. Note that this survey has only been used to generate the microscopic demand and no freight data parameters like delivery times are provided.

Based on this average freight movement per week and per category, and based on the assumption previously stated, we are able to estimate the deterministic goods movements of each Lafayette's shop. To include stochasticity, we consider the Rayleigh probability distribution (eq. 1) [7]. The scale parameter of this distribution σ is determined using equation (2). Thus, for each Lafayette shop, its stochastic demand is computed using the Rayleigh probability distribution, which belongs to its shop's category.

$$f(x;\sigma) = \frac{x}{\sigma^2} \exp\left(\frac{-x^2}{2\sigma^2}\right) \quad (1)$$

$$\hat{\sigma} = \sqrt{\frac{1}{2N}\sum_{i=1}^{N} {X_i}^2} \quad (2)$$

The French National Program on Urban Goods Transport [12] stated that working days for goods transport are Monday to Saturday, but the freight activity in this last day is about 30% of the average activity when compared to the other days. For that reason, to estimate the daily demand we divide the good movement by 5.3. Then, we estimated the morning deliveries. As discussed by different authors [12-13], morning deliveries (meaning from 8a.m. to noon) represent, on average, about the two thirds of the overall deliveries in a day. Consequently, we have multiplied the total daily deliveries by 2/3 in order to get the number of morning deliveries.

2.2 Microsimulation model

We consider a hypothetic yet realistic network (Fig. 1), composed by n (n=6) successive links separated by traffic lights. Each link consists of 3 lanes. The length of a link i is denoted by l_i and its Traffic lights settings are given by: green time g_i, red time r_i and cycle c_i. For simplicity, we consider that all traffic lights have the same parameters but are synchronized with an offset of 13s. Note that this assumption can be easily relaxed. The total length of the arterial is $L=1350$ meters, which ensures that we cover all of the Lafayette's existing shops in our dataset training. Other parameters, like traffic lights are kept the same as in the previous study [14].

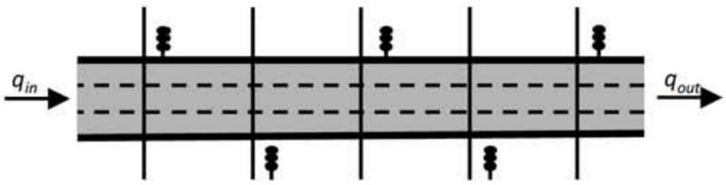

Fig. 1. Scheme of the urban corridor

We use the traffic simulation model proposed by [14]. The microscopic simulator *SymuVia* developed by LICIT was used to reproduce the traffic flow. More precisely, the model reproduces individual private vehicles trajectories based on LWR (Lighthill-Whitham-Richards) model, proposed independently by [15] and [16]. Depending on the period, day and time, traffic conditions change on the corridor. To provide general results, all the possible traffic conditions are considered. Thus, the simulation is not based on a dynamic private vehicles demand. Every demand and capacity are considered to present a systematic analysis of the traffic states, i.e. different demand in entry and supply at exit are considered. For this reason, let q be the flow on the corridor. Two regimes can be segregated: (a) free-flow where the whole demand at entry can travel the corridor without creating queues at traffic lights; (b) congestion where a restricted outflow engenders queues from downstream to upstream.

The urban freight system is completely defined by the distributions of the time-headway between two successive deliveries h_j, the duration d_j and the location x_j of the deliveries. Trucks can double park randomly location on the corridor, not taking into account the light position. Indeed, some multi-lane managements allow double-park deliveries where they must park 100 meters after or before a traffic light. In our case, double-park represents an illegal park. That is why we do not consider this constraint.

Local impacts of the urban freight movement on the traffic flow are quantified at an aggregated scale. Thus, we used the MFD and its related metrics [14]. Various theories have been proposed to reproduce traffic stream on an aggregate level. Many of these papers are based on the key idea that it exists a Macroscopic Fundamental Diagram (MFD) able to reproduce both free-flow and congested traffic conditions. Earlier studies were devoted to look for such relationship in data of real-world network or arterials. However, evidences of the existence of the MFD have been found only very recently [17]. On their seminal works, the authors pointed out a major insight: the MFD is an intrinsic property of the network itself and its traffic composition (proportion of buses and trucks). Consequently, the average spatial flow of a network can be easily related to the average spatial density through the MFD. A very convenient property is that the MFD remain invariant when demand changes for homogeneous networks such as an urban arterial. At this scale, the MFD is thus a reliable tool for traffic agency to manage and evaluate solutions for improving mobility. [18] provided a very good example of how MFD can be used to dynamically control signals and prevent congestion. Many papers have been recently directed toward highlighting links between shapes of the MFD and different simulated or measured parameters [19-20] or exploring impact of distributions of vehicles and space on the MFD. A crucial question is how to accurately estimate the MFD. Fully analytical techniques have been recently proposed [19-20] and enable to estimate MFD directly from the network characteristics. However, they do not account for urban freight activities. The remaining solution is to resort to traffic flow dynamic simulations that provide vehicles trajectories and account for impacts of deliveries. It turns out that the MFD can be easily determined if individual trajectories of vehicles are available.

2.3 Application of the demand model on microscopic simulation

Logistic organizations are characterized by numerous factors. At the scale of an urban corridor and in the context of using of double-parked vehicles, four parameters are considered: (i) the delivery duration, (ii) the delivery location, (iii) the level of massification of the handling of goods, i.e. mass grouping of volumes and (iv) the distribution of trucks departure. The following variables described have been incorporated into a micro simulation framework.

- (i) It is important to stress out that we do not resort to a delivery time model or to delivery time data coming from a survey. Thus, the delivery duration is computed with deterministic values of 10, 20 and 30 minutes to access a sensibility study.
- (ii) We consider that every movement is made by double-parked vehicles on the customer location. Thus, the goal is to match each customer location on the Lafayette Avenue with the theoretical corridor used for the simulation. Based on the house number of customers, we used the corresponding proportion of the theoretical arterial.
- (iii) At the urban corridor scale, delivery routes are not considered. For simplicity, we assumed that each delivery is made by one truck. Note that the micro level demand of a morning is a decimal value. Based on the previous assumption, two cases can be distinguished allowing us to reach a natural number of movement: case 1 the ceiling of the demand, case 2 the floor of the demand. As many vehicles as movement represents the extreme case of competitive. It can also represent own account delivery.
- (iv) The temporal scale used is a morning period of 5 hours. It allows us to access the dynamics of delivery freight departures. In this study, two departures time distribution are considered. The first one is a normal distribution, representing the realistic dynamic demand of freight. Delivery window is strongly constrained by customers. As an example of the latter, one can state the opening hours of individual shop in the Lafayette Avenue. The second one is a uniform distribution. In this case, cooperative strategy can be represented by a uniform departure of delivery, i.e. freight companies share information and accord themseft to spread theirs departures during the whole time windows.

3 Experimental results and analysis

This section quantifies the impacts of deliveries made by double-parked vehicles on a theoretical yet realistic urban arterial (2.1 kilometers long). A microscopic simulation software is used to quantify the global performance of the system affected by freight in peak hour. Based on 55 customers on the Lafayette Avenue in Lyon, two level of micro demand estimation are considered: case 1 and 2 present 123 and 68 movements respectively. Notice that the results can be parallelized for private vehicles as we do not consider the specificities of delivery trucks such as their weights, length, possible hatch, etc.

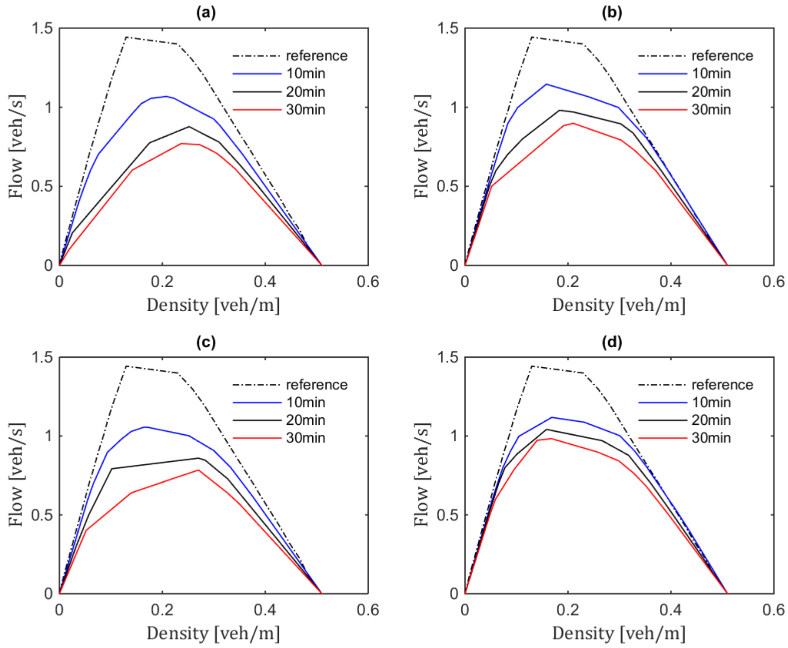

Fig. 2. Estimated MFD, (a-b) normal distribution of trucks departure times with case 1 and 2 respectively, (c-d), uniform distribution of trucks departure times with case 1 and 2 respectively.

Fig. 2 represents results of MFDs. The left figures are from case 1 observations and right figures from case 2. Both the figures on the top are obtained when truck headways follow a normal distribution while those below correspond to a uniform distribution. On each graph, a given curve corresponds to the MFD for a delivery time scenario. The reference MFD represents the traffic states without the logistic system. It makes it possible to evaluate the global impact of the arterial performance. The following analysis uses one of the measurement metrics based on MFD : the capacity C, i.e. the maximal flow of vehicles observed that can cross the corridor.

Let us focus on the figure 2.a, representing 123 movements during 5 hours of simulation, where the freight departure distribution follows a normal distribution. The global capacity of the corridor loses 26%, where 10 minutes duration of double-parked deliveries are considered. It represents the most probable case as 70% of delivery durations are less than 10 minutes [21]. For a delivery time of 20 and 30 minutes, the performance loss is 39% and 46% respectively, based on the reference MFD. Basically, we observed that the delivery duration affects the traffic flow.

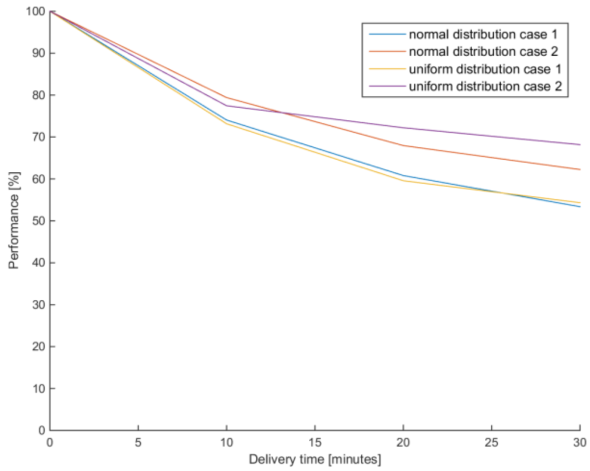

Fig. 3. Capacity *C* through normal and uniform distribution of trucks departure times with case 1 and 2

We compared the freight departure distribution through two levels of demand, i.e. both cases of movements. Despite that the global forms of MFDs are different, the macroscopic performance of the arterial are approximately similar for freight departure distribution - normal and uniform distribution. Both curve for the case 1 are similar, its disparity is slightly higher for the case 2. It can be explained by its lower level of demand. Thus, the choice of the freight departure distribution has no significant impact on the macroscopic traffic flow. A collaborative approach spreading deliveries into a given time window is not relevant in this case study. The movements influence the global performance of the arterial. Sharing vehicle capacity would be a natural solution for the last kilometer cost. The capacity of a delivery truck is equivalent to 8 small vehicles [21]. Naturally, concentration of goods includes less delivery trucks on the road but increases the individual delivery duration. In particular, we can compare two scenarios to capture the influence of trucks density through delivery duration. Using a normal distribution of departure trucks, 123 movements made by double-parked duration of 10 minutes decreases the global performance by 26% instead of 38% for 68 movements made by double-parked vehicles of 30 minutes. Thus, macroscopic traffic flow is more affected by delivery duration than trucks density.

4 Conclusions and future works

This paper presents a framework to evaluate the impact of freight movements made by double-parked vehicles on the global performance of an urban arterial. A microscopic simulation software were used to properly reproduce traffic dynamics. Adapting the freight generation demand at micro level is the major contribution of this paper. Two freight departure distributions are considered: the normal and the uniform distribution.

We observe that the macroscopic performance of the corridor loses 26% with a realistic demand estimation of Lafayette Avenue in Lyon, where every movement made by double-parked vehicle has 10 minutes duration. Freight departure distribution is sparsely influential. Strategy to incite trucks to spread their deliveries into a whole time window is irrelevant. Moreover, the time during which a vehicle is double-parked strongly impacts the global traffic flow, more than the trucks density. Thus, traffic flow regulations have to focus on the reduction of this delivery time; particularly during traffic peak hours. For extension, we can conclude that the trend to reduce the size of last mile delivery trucks is positive on the traffic flow.

The framework is interesting to evaluate traffic limitation/regulation policies, especially the relevance of load zone creation and collaborative approach on the traffic flow. Further works investigate the impact of double-parked delivery trucks on large-network. At this scale, routes are considered, making it possible to evaluate numerous logistical organizations. Moreover, concerning the micro level demand estimation, the creation of our own shop category instead of using the *ST29* can be investigated using machine-learning methods.

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