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Investigating Impacts of Pickup-Delivery Maneuvers on Traffic Flow Dynamics

Nicolas Chiabaut*

Université de Lyon, ENTPE/IFSTTAR, LICIT
Rue Maurice Audin, 69518 Valulx-en-Velin, France

Abstract

Even if urban logistic has been extensively investigated in the literature, its effects on traffic flow dynamic remain mostly unknown. This paper aims to assess the impact of pickup-delivery trucks on traffic conditions. To this end, we resort to a theoretical but realistic urban arterial where deliveries are completed in double-park. The study first focuses on traffic flowing at capacity and determines the analytical formulation of the effective capacity when neglecting the effects of traffic signals. This formulation only depends on the characteristics of the arterial, the average time headway between truck arrivals and the average stop duration. It turns out that the pickup-delivery maneuvers strongly reduce the capacity. Then, this modeling framework is extended to other traffic conditions. The use of the macroscopic fundamental diagram (MFD) makes it possible to incorporate effects of traffic signals. To this end, an existing MFD estimation method is adapted to the case of double-park deliveries. The comparison of the MFD estimates highlights that logistic activities have a major impact for traffic conditions near the maximal capacity. It confirms that creation of dedicated delivery areas and related logistic policies (pre-booked area, off-pick hours deliveries, etc.) are very promising solutions to improve both the efficiency of the transportation network and the logistic system.

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Keywords: urban logistic; traffic flow; simulation; pickup-delivery manoeuvers; KW model; Macroscopic Fundamental Diagram; Multimodal;

* Corresponding author. Tel.: +33-4-720 477 58
E-mail address: nicolas.chiabaut@entpe.fr

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1. Introduction

In urban environments, there are now many challenging problems concerning freight transport. As cities around the world grow rapidly, there is an increase in pickup-delivery truck traffic in urban areas. It turns out that commercial traffic is now a major source of externalities in metro areas, including congestion, noise, air pollution (small particulates, NOx, greenhouse gas emissions), and traffic incidents (Dablanc, 2013).

To overcome these issues, many interesting and innovative strategies have been developed in Europe and other parts of the world. Especially, some researchers proposed the idea of city logistics to solve these difficult problems (Taniguchi and Thompson, 2002; Dablanc, 2012). The idea of this concept is to rationalize the freight activities in cities by optimizing operations considering the traffic conditions and the congestion issues. Consequently, public authorities strongly need decision support frameworks to evaluate urban logistics planning and management.

It turns out that a key point in predicting the impacts of city logistics is the influence of freight on traffic flow dynamics. Particularly, pickup-delivery maneuvers generate road capacity reduction and lead to delay for individual drivers. Although this is a crucial topic, the literature rarely addresses this issue. This paper aims to fill this lack of understanding by incorporating the effects of urban freight in an aggregated traffic flow model.

To this end, we seek to introduce a general modeling framework to assess the effects of city logistics actions on traffic flow dynamics. This goal can be achieved in two steps. The study focuses on a theoretical but realistic urban arterial. (i) First, we focus on traffic flowing at capacity. Analytical formulations depending on the characteristics of the urban site and the logistic system to anticipate the capacity reduction generated by pickup-delivery maneuvers are determined. (ii) Then, this work is extended to account for the whole range of traffic conditions. To this end, we resort to the Macroscopic Fundamental Diagram (MFD). It furnishes equivalent mean states to understand the dynamics of the system and to quantify its performance. To tackle this issue, it is necessary to refine the existing estimation MFD methods to incorporate the effects of urban freight. Eventually, this permits to analytically compare the efficiency of different city logistics solutions such as the creation of dedicated areas, parking regulations, off-hour deliveries or consolidation programs (Jaller et al., 2013; Holguin-Veras et al., 2011).

Section 1 introduces a theoretical but realistic case study. Section 2 focuses on the general modeling framework to estimate the capacity reduction generated by double-park deliveries. Section 3 extends this method to estimate MFD and/or aggregated models that account for effects of urban freight. Existing estimation method is extended to reproduce the effects of pickup-delivery trucks at this larger scale. Actually, this approach will permit to predict the performance of different city logistics solutions and to determine their optimal domain of application. Section 4 is devoted to a conclusion.

2. The case study

In this paper, we consider here a hypothetic urban arterial (see Figure 1a) composed of n successive links with traffic signal and p lanes. The length of link i is l_i and its signal settings are: green g_i, red r_i, cycle c_i and offset o_i from a common reference. The total length of the arterial is L. In the remaining of the paper, we assumed n=11 links, p=2 lanes and l_i=200 m. Concerning the traffic signal settings, g_i is equal to 50s and c_i to 100s. For the sake of simplicity, we supposed that there is no offset, o_i=0. Moreover, we do not consider turning movements.

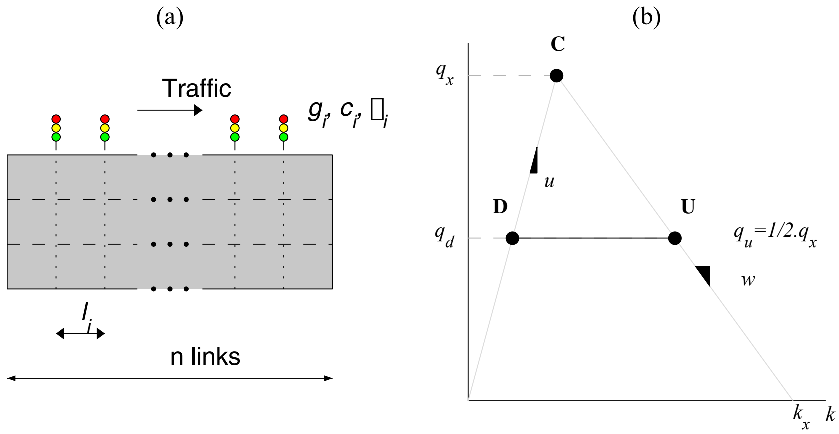

Figure 1: (a) study case (b) fundamental diagram

All lanes of the arterial are modeled as a single pipe and traffic on each link is supposed to obey a triangular fundamental diagram (FD, see Figure 1b) that only depends on three observable parameters (Chiabaut and Leclercq, 2011): free-flow speed u [m/s], wave speed w [m/s] and jam density k_x [veh/m]. Capacity q_x [veh/s] and optimum density k_c [veh/m] can be easily derived: $q_x = \frac{uw\kappa}{u+w}$ and $k_c = \frac{q_x}{u}$. For the numerical examples in this paper we have used u = 15 m/s, w = 5m/s and k_x = 0.185veh/m (q_x= 2.08 veh/s =7500 veh/h).

We assume that the logistic system is only composed of pickup-delivery trucks that stop in double-park along the arterial. Consequently, they temporary reduce the capacity to $q_u=(p-1)/p.q_x$ because the truck completely blocks a lane, see Figure 2. The associated maneuvers occur with time headway h_i and can be located anywhere on the urban arterial x_i. Each maneuver lasts δ_i. We assume that these three variables are distributed according to a uniform distribution. Notice that the distributions may reasonably be considered as independent. For the sake of simplicity, we also assume that trucks have the same maximal free-flow speed u as individual vehicles. This assumption seems reasonable because a major part of delivery trucks are composed of van and we only focus on urban traffic where the authorized speed is very low.
Before focusing on the analytical formulation of the arterial's capacity, the traffic states that turn to be of interest in the remainder of the study have to be identified (see Figure 1b). State ***D*** corresponds to the downstream conditions when a truck is double parked on the arterial. The associated flow is assumed to equal to $q_d = \frac{p-1}{p} q_x$. State ***U*** describes the upstream-congested condition. The flow is also equal to $q_u = \frac{p-1}{p} q_x$. State ***C*** corresponds to the maximal capacity of the arterial.

3. Arterial capacity

This section focuses on the analytical capacity of an arterial traversed by pickup-delivery maneuvers. Two sources of reduction can be identified. First, double-park deliveries generate local and temporary capacity reductions which may lead to congestion and considerably reduce the maximal and effective capacity of the arterial. Second, trucks also constrain the flow upstream during the acceleration phase (Laval, 2009; Leclercq, 2007).Figure 2 highlights these phenomena. In this work, we first do not consider the effect of traffic signals and of the bounded acceleration ability of trucks. Within this modeling framework, the kinematic wave (KW) theory makes it possible to reproduce the effects of urban logistics on traffic dynamics.

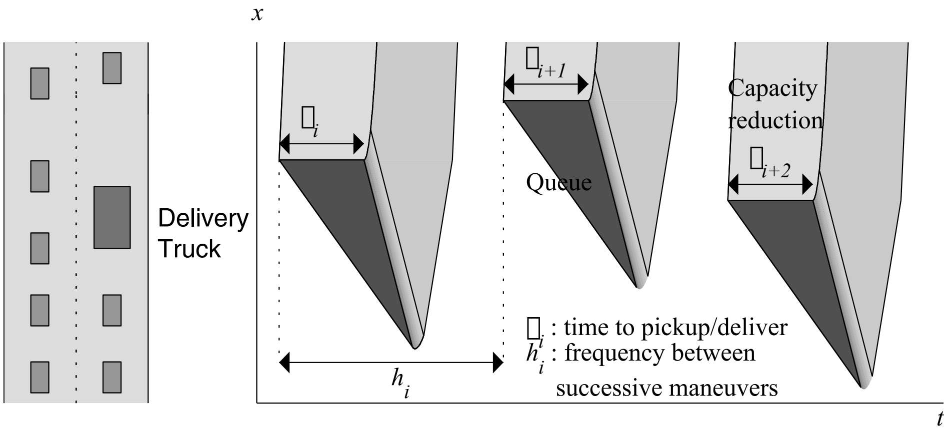

Figure 2: Effects of pickup-delivery maneuvers on traffic flow

Meanwhile, pickup-delivery maneuvers can occur at any position x_i of the arterial. Two cases will be distinguished in the present work: x_i is constant and x_i is uniformly distributed between 0 and L. However, δ_i and h_i remain randomly generated according to uniform and independent distributions for both cases. The goal is now to express the effective capacity of the arterial as a function of the distribution parameters of δ_i, h_i and x_i.

3.1. Fixed location

When x_i is constant, all the maneuvers take place at the same position of the arterial. In that specific case, the solution of the KW model is simple. Figure 3a shows the traffic conditions on the time-space plane for fixed-location maneuvers on an arterial flowing at capacity. The white areas correspond to traffic flowing at capacity (state ***C***), the light gray areas to state ***U*** whereas state ***D*** stands on dark gray areas. Notice that here x_i is equal to 0. Let N_i be the cumulative number of vehicles that have crossed this location by time t_i. At larger time scale, the effective capacity C is the same whatever the location. Thus, C can be simply expressed at $x=0$ with respect to N_i:

$$C = \frac{\sum_{i=1}^{n}(N_{i+1}-N_i)}{\sum_{i=1}^{n} h_i} \text{ with } n \to +\infty \qquad (1)$$

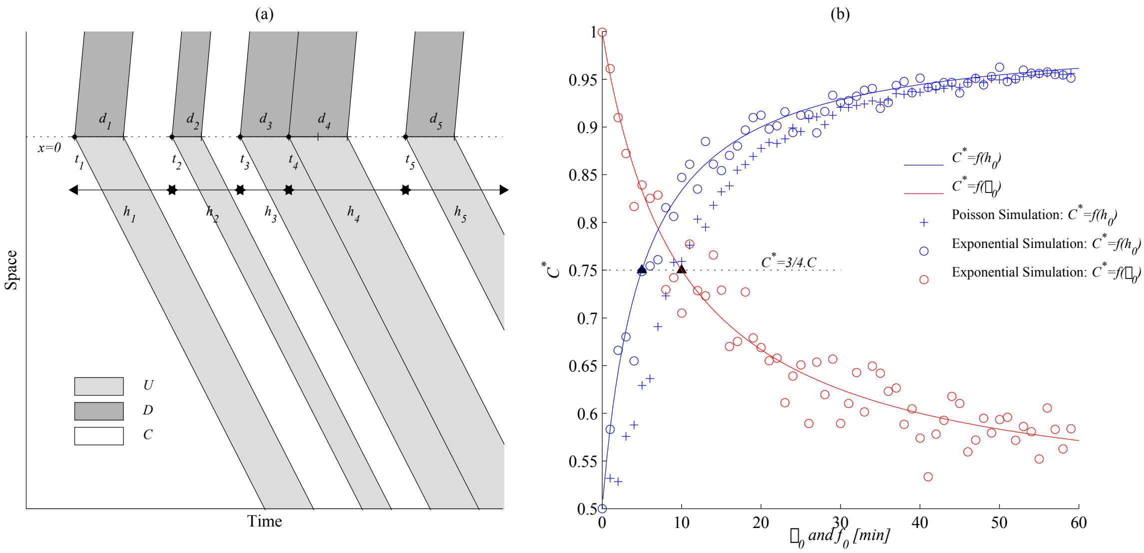

Figure 3: Fixed location (a) solution of KW model in the time-space plane
(b) Evolution of maximal capacity

The increase in N between t_i and t_{i+1} is very simple to calculate. The key observation here is that two cases can be distinguished: (i) the truck arrives within the disturbance time of the previous truck (see for example t_4 in Figure 3a) and (ii) two successive trucks have no interaction (see for example t_2 and t_5 in Figure 3a). It is clear from this observation and Figure 3a that flows at $x=0$ are either q_x or q_u:

$$N_{i+1} - N_i = q_u.h_i \quad \text{if } h_i < \delta_i$$
$$N_{i+1} - N_i = q_u.\delta_i + q_x.(h_i - \delta_i) \quad \text{otherwise}$$

It is thus appealing to segregate the distribution of h_i into two independent sets:

$$H_1 = \{h_i \backslash h_i < \delta_i\}$$
$$H_2 = \{h_i \backslash h_i > \delta_i\}$$

The effective capacity can now be expressed as:

$$C = \frac{\sum_{h_i \in H_1} q_u h_i + \sum_{h_i \in H_2} (q_u \delta_i + q_x (h_i - \delta_i))}{\sum_{i=1}^{n} h_i} \text{ with } n \to +\infty \quad (2)$$

Because distributions of h_i and δ_i are reasonably assumed as independent, the law of large number tells us that:

$$C = \frac{q_u.E[h.\mathbb{I}_{H_1}] + q_x.E[h.\mathbb{I}_{H_2}] + (q_u - q_x).E[\delta.\mathbb{I}_{H_2}]}{E[h]} \quad (3)$$

where $\mathbb{I}$ is the indicator function. It is now very convenient to notice that $E[h.\mathbb{I}_{H_1}] = E[h.P(h < \delta)]$. Moreover, we assume that both distributions of h_i and δ_i follow an exponential law of (respectively) parameters $\lambda_h=1/h_0$ and $\lambda_\delta=1/\delta_0$ (where h_0 and δ_0 are the average time headway and duration). Therefore, the expression of C can be analytically formulated. The reader can verify that:

$$C = \lambda_h.\left(\frac{q_u\lambda_h}{(\lambda_h+\lambda_\delta)^2} + q_x.\left(\frac{1}{\lambda_h} - \frac{\lambda_h}{(\lambda_h+\lambda_\delta)^2}\right) + (q_u - q_x).\frac{\lambda_\delta}{(\lambda_h+\lambda_\delta)^2}\right) \quad (4)$$

Figure 3b shows the dimensionless capacity reduction $C^*=C/q_x$ as a function of the average truck headway (plain line in blue) and average stop duration (plain line in red). It is important to notice that C^* converges toward the maximal capacity q_x when the stop duration tends to zero and/or when the average headway h_0 of pickup-delivery is very long. Moreover, Figure 3b points out that the capacity is less sensitive to the variations of average stop duration and time headway when δ_0 and h_0 are bigger than 10 minutes. The black triangles display the theoretical capacity when δ_0 is equal to ½ h_0. In such a case, the arterial capacity is equal to ¾ of the initial maximal capacity. Figure 3b shows that the general formulation perfectly matches these results.

Moreover, it is appealing to compare with other shapes of distribution. To this end, we resort to simulation to determine the effective capacity C and the associated dimensionless capacity C^*. The blue circles depict the evolution of C^* with h_0 for simulated exponential distributions, see Figure 3b. The agreement between the analytical formulation and the simulation results is strikingly good. The blue crosses shows C^* when h_0 increases in the case of Poisson distributions (δ_0=5 min). Once again, the analytical formulation is a very good approximation of the results. Finally, it is important to notice that double-park deliveries have a significant impact on the arterial capacity. As depicted by Figure 3b, the capacity is reduced of 20% for h_0=10 min and δ_0=5 min. Consequently, the creation of dedicated areas for delivery may strongly increase the arterial performance. This urban logistic policy and those related (pre-booked area, temporary dedicated lane, etc.) are thus very promising to increase both performance of the transportation network and logistic system.

3.2. Bounded acceleration

It is worth noting that the bounded acceleration ability of trucks has been neglected in the present work. It is thus appealing to relax this assumption and try to quantify the effect of bounded acceleration on the effective capacity. We now consider that trucks accelerate at a constant rate a until they reach the free-flow speed u, see Figure 4a. For the sake of simplicity, a is assumed identical for all trucks. During the acceleration phase, trucks behave as moving bottlenecks (Newell, 1998; Leclercq et al., 2004). Thus, these moving obstructions constrain the traffic flowing at capacity. In (Leclercq et al., 2011), it was shown that these moving obstructions are responsible for the capacity drop in a case of a freeway merge. Same phenomenon occurs here.

Consequently, the acceleration phase corresponds to a specific pattern in the time-space plane of traffic conditions that stand at each end of pickup-delivery maneuvers (see Figure 2 and Figure 4). The associated capacity reduction has to be added in the formulation of C. To this end, we now focus on the increase of N between **A** and **B** as depicted by Figure 4a, b and c. As Figure 3a, Figure 4a, b and c show the different traffic conditions along the arterial. The darkest gray areas correspond to the acceleration phases. The increase strongly depends on the possible interactions between successive truck arrivals. Three different cases can be identified: (i) there is no interaction between successive trucks (Figure 4a – case *i*); (ii) the truck arrives within the disturbance of the previous truck. This situation can also be segregated into two subcases. First, the truck arrives during the bounded acceleration phase (see Figure 4b – case *ii*). This situation is not trivial and deserves a careful attention. Second, the truck arrives when the previous one is still stopped (see Figure 4c case *iii*). This situation is straightforward and has been studied in the previous section.

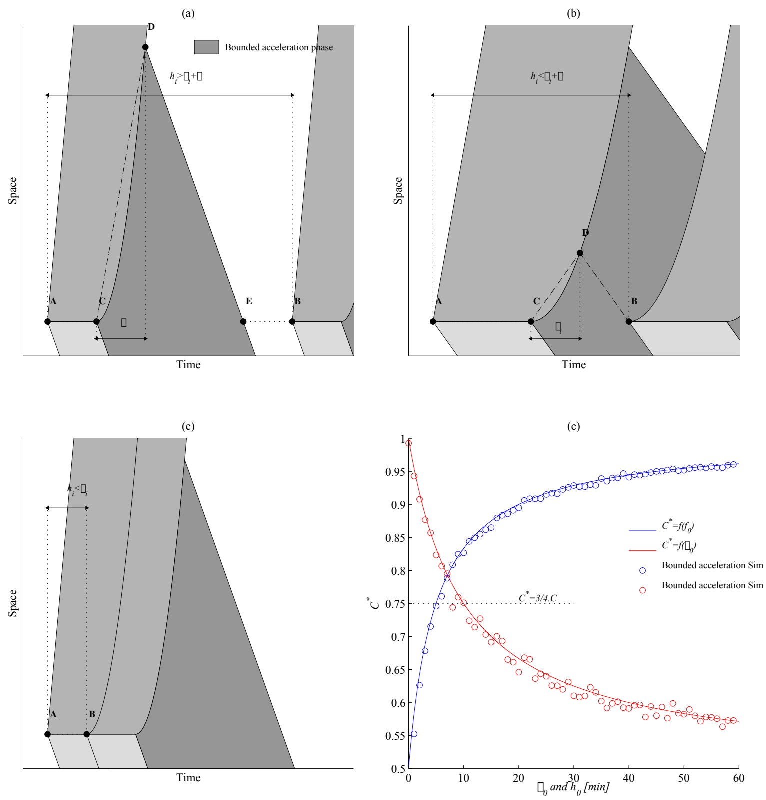

Figure 4: Bounded acceleration (a) (b) and (c) solution of KW model
(c) Evolution of capacity with the mean of fi and delta i

Variational theory (Daganzo, 2005) provides a convenient way to calculate C for all these situations. Indeed, the increase in N between **A** and **B** is the same as on the alternative paths **A-D-B**, see Figure 4a and b. To segregate the different situations, it is now convenient to denote τ the time needed by a truck to reach its free-flow speed u ($\tau = \frac{a}{u}$) and $\tau(h_i)$ the time duration between **A** and **D** that can be expressed as (Leclercq et al., 2004; Leclercq et al., 2011):

$$\tau(h_i) = \min\left[\tau, \frac{1}{a}\sqrt{w^2 + 2awh_i} - \frac{w}{a}\right] \qquad (5)$$

According to Figure 4 and equation (5), it turns out that the acceleration phase of a truck lasts:

$$\tau^* = \frac{1}{2}a\tau(h_i)^2 + \tau(h_i) \qquad (6)$$

This last result makes it possible to analytically characterize the different cases. Consequently, case *i* occurs when $h_i \geq \delta_i + \tau^*$ (Figure 4a), case *ii* occurs when $h_i < \delta_i + \tau^*$ and $h_i \geq \delta_i$, i.e. $\tau(h_i) < \tau$ (Figure 4b) whereas case *iii* occurs when $h_i < \delta_i$. We can now calculate the increase in N for each case.

- In case *i*, the most convenient path is **A-C-D-E-B**. Indeed, the passing rate, i.e. increase ratio of N, between **A-C** is equal to q_u and between **E-B** to q_x. The passing rate between **C-D** and **D-B** can also be easily calculated. Because the FD is triangular, a convenient way is to linearize the trajectory of the trucks between **A** and **D**. It turns out that the average speed v is equal to $v = \frac{1}{2}a\tau$ because trucks have a uniform acceleration. Another key observation is that traffic is in equilibrium condition downstream of the truck (state ***D***): the flow is equal to q_d and the density to k_d. According to its definition, the passing rate from **A** to **D** is thus equal to $q_d - \frac{1}{2}k_d a\tau$. Finally, the passing rate from **D** to **B** is always equal to wk_x because the path slope is w and the traffic flows at capacity.

- In case *ii*, the situation is very similar. A convenient path to calculate the increase in N is **A-C-D-B**. The passing rates from **A** to **C** and from **D** to **B** are equal to those of case *i*. However, **D** is different because $\tau(h_i) < \tau$. Fortunately, the trajectory of the truck can still be linearized between **C** and **D**. The average speed v is now equal to $v = \frac{1}{2}a\tau(h_i)$. Because the traffic is still in equilibrium condition downstream of the trucks, the passing rate between **C** and **D** is thus equal to $q_d - \frac{1}{2}k_d a\tau(h_i)$.

- In case *iii*, the situation is straightforward and correspond to the interactions highlighted in the previous section (see Figure 4c). The increase of N between two successive arrivals is equal to $q_u h_i$ vehicles.
Thus, the formulation of C is now given by:

$$C = \frac{\sum_{h_i \in H_1} q_u . h_i + \sum_{h_i \in H_2'} \left(q_u . \delta_i + \left(q_d - \frac{1}{2} k_d a\tau(h_i) \right) \tau(h_i) + wk_x . (f_i - \delta_i - \tau(h_i)) \right) + \sum_{h_i \in H_3'} \left(q_u . \delta_i + \left(q_d - \frac{1}{2} k_d a\tau \right) \tau + q_x . (h_i - \delta_i - \tau) \right)}{\sum_{i=1}^{n} f_i} \tag{7}$$

where

$$H_1 = \{h_i \backslash h_i \leq \delta_i\}$$
$$F_2' = \{h_i \backslash h_i > \delta_i \,\&\, h_i \leq \delta_i + \tau^*\}$$
$$H_3' = \{h_i \backslash\, h_i > \delta_i + \tau^*\}$$

Unfortunately, this expression has a no simple analytical formulation. Consequently, we resort to simulation to calculate the expected value of C. Values of h_i and δ_i are still exponentially distributed. Figure 4c shows the evolution of $C^* = C/q_x$ with the average time headway h_0 and stop duration δ_0. Several runs have been performed. It clearly turns out that the acceleration phase has no impact in our specific case. This is not surprising because the time headway and the duration of the pickup-delivery maneuvers are much longer than the acceleration phase (τ is equal to 12s). This observation is confirmed by Figure 4c where C^* is more sensitive to the bounded acceleration for the left part of the curves (short h_0 and δ_0). Therefore, we can easily continue to neglect the bounded acceleration of trucks in the remainder of the paper. This will be very useful to simplify the study and ensure general results.

3.3. Distributed positions

Now we consider the case of distributed location for pickup-delivery maneuvers, i.e. x_i are now randomly generated along the arterial according to a uniform distribution (see Figure 5a). We still aim to analytically calculate the effective capacity as a function of the distribution parameters of δ_i, h_i and x_i. In the vein of Leclercq et al. (2011), let t'_i be the time when the wave coming from (t_i, x_i) reaches $x=0$ and $t'_{(i)}$ the ordered series built from the realizations of t'_i. Figure 5a shows the solution on the time-space plane of the problem. As previously mentioned, the white areas correspond to traffic flow at capacity (state ***C***) whereas the gray areas correspond to state ***U***. For the sake of simplicity, interactions of upstream propagating waves with downstream propagating traffic condition (state ***D***) have been neglected. This assumption will be relaxed in the next section dedicated to MFD estimation. Consequently, the effective capacity C can still be calculated at $x=0$ by focusing on the increase in N between $t'_{(i)}$ and $t'_{(i+1)}$.Thus, the problem appears to be equivalent to the previous one with $x_i=0$ by substituting h_i by h'_i where h'_i is equal to $t'_{(i+1)}$ - $t'_{(i)}$.

$$C = \frac{q_u.E[h.\mathbb{I}_{\{h<\delta\}}]+q_x.E[h.\mathbb{I}_{\{h>\delta\}}]+(q_u-q_x).E[\delta.\mathbb{I}_{\{h>\delta\}}]}{E[h]} \qquad (8)$$

Again, we resort to simulation to compute the distribution of h'_i. It is a very convenient way because t'_i is equal to t_i+x_i/w. Then, distribution of t'_i can be easily re-ordered to obtain $t'_{(i)}$. Figure 5b shows the results. It turns out that distributing positions along the arterial does not impact the effective capacity compared to fixed positions. Indeed, the agreement between the analytical formula obtained in the case of fixed position and the simulation for distributed position is still very good.

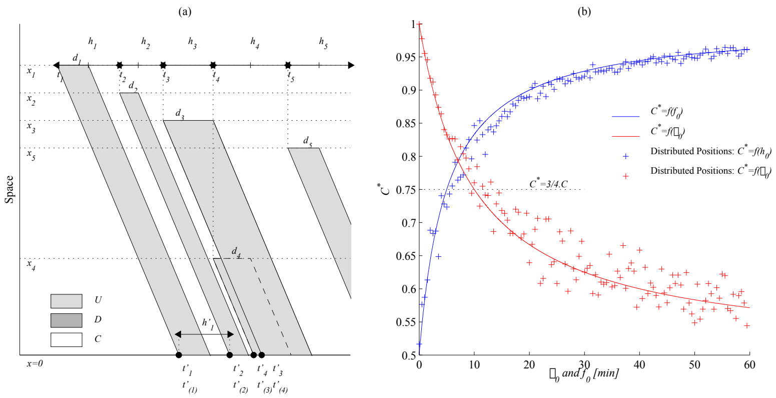

Figure 5: Distributed position (a) Solution of KW model
(b) Evolution of capacity with the mean of h_i and δ_i

Finally, we can conclude that adding bounded acceleration abilities or distributed positions changes the capacity curve only marginally. Moreover, it is now very clear that double-park pickup-delivery maneuvers have a strong impact on the maximal capacity of an urban arterial. Consequently, the creation of dedicated areas and associated policies (pre-booked area, temporary lane closure, etc.) can strongly improve the performance of the transportation network. However, the effects of traffic signals have not been accounted for. Next we extend the method to account for these effects. Moreover, we also focus on other traffic conditions than traffic flowing at capacity.

4. Macroscopic fundamental diagram

In this section we extend the previous modeling framework to account for traffic signals and various traffic conditions. Towards this end, we resort to an aggregated and parsimonious model. Such a model often provides a better understanding and valuable insights on arterial traffic dynamics. The macroscopic fundamental diagram (MFD) can play this role. Indeed, several studies have shown that the MFD is a reliable tool for traffic agencies to evaluate the transportation network performance. Moreover, recent works (Boyaci and Geroliminis, 2010; Boyaci and Geroliminis, 2011) propose accurate method to analytically estimate the MFD for multimodal arterial based on its characteristics (number of lanes, traffic signal parameters, etc.). Therefore, we propose to refine the existing estimation method of (Leclercq and Geroliminis, 2013; Xie et al., 2013) to the case of double-park deliveries. It turns out that the effects of urban freight can be easily added in the MFD estimation method.

4.1. Method description

4.1.1. General methodology

The foundation of the variational method comes from (Daganzo and Geroliminis, 2008). This paper shows that a MFD can be defined by the following equation:

$$q = Q(k) = min_V(R(V) + kV \backslash V \in [-w, u]) \quad (9)$$

where q is the mean flow [veh/h] and k the mean density [veh/km] on the studied arterial. $R(V)$ can be determined with variational theory (VT). It denotes the maximum average at which the traffic can overtake a moving observer that moves into the considered arterial with a constant average speed V. Equation $R(V)+kV$ defines a so-called cut on the (k,q) plane. Consequently, the MFD is the lower bound of any possible cuts. The key point is the computation of $R(V)$ for a relevant set of different average speeds V.

Leclercq and Geroliminis (2013) provides a simple solution to determine $R(V)$ for different value of V. The time-space plane is discretized to obtain a variational graph on which moving observers travel. It turns out that only three local speeds are of interest: u, 0 and $-w$. Note that an observer begins its trip at the end of a red phase. It cannot change its speed on a link. If it reaches a green signal, it can continue its trip at the same speed or stop. If the signal is red, the observer must stop until the end of the red phase. A graph composed of all these possible paths has been proved sufficient and minimal to properly estimate $R(V)$ for a large range of V even in heterogeneous cases. Consequently, equation (9) can be solved and it makes it possible to accurately estimate the MFD of the considered arterial. In this graph, costs are assimilated to edges according to VT. This cost $r(v)$ corresponds to the passing rate of an observer travelling at speed v. The sufficient variational graph is composed of four kinds of edges linked to different pairs of speed v and cost $r(v)$, see **Erreur ! Source du renvoi introuvable.**a:

a. the red phases of all traffic signals: $v=0$ and $r(v)=0$;

b. the green phases of all traffic signals: $v=0$ and $r(v)=q_x$;

c. the paths with speed u that start from the ends of all red times of each signal and propagate until another edge (a): $v=u$ and $r(v)=0$. Vertices should be added anytime such a path crosses edges (b) and (a).

d. the reverse paths of edges (c) with speed –w: $v=-w$ and $r(v)=wk_x$.

The proof of sufficiency can be found in Leclercq and Geroliminis (2013). All the paths into the variational graph that have the same initial and final points, i.e. the same speed V, define the same cut of speed V. The associated $R(V)$ corresponds to the least-cost between these initial and final points.

$$R(V) = \min_P \left[\frac{1}{T_P} \int_{s \in P} r(v_s) ds\right] \quad (10)$$

where P is the set of all the possible paths of average speed V, T_P is the travel time of the observer crossing the arterial with average speed V, i.e. $T_P = L/V$, v_s is the observer's speed at any point **S** of the path P.

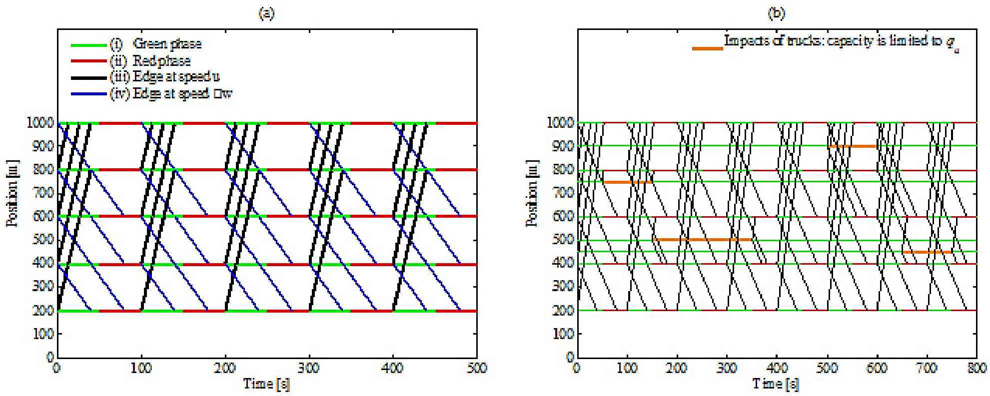

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Figure 6: sufficient variational graphs: (a) without trucks (b) with trucks

4.1.2. Extension to pickup-delivery trucks

The above variational method can be easily extended to account for pickup-delivery maneuvers. As previously explained, this phenomenon corresponds to a temporary capacity reduction of the arterial. The flow is constraint to q_u. This defines into the variational graph new edges (see orange lines in **Erreur ! Source du renvoi introuvable.**b). The costs of such edges are thus equal to q_u. Note that introducing trucks makes the studied case irregular (trucks are introduced according to a given headway). Thus, several initial points have to be considered. To be sure that the mean value of *r(v)* is properly estimated, i.e. that we consider enough initial points, we check that the standard deviation of *r(v)* is lower than 10% of its mean value.

4.2. MFD estimation for double-park deliveries

Figure 7a presents the resulting free-flow and congested cuts calculated for an arterial and a pickup-delivery maneuvers that occur every h_0=10 min and last δ_0=5 min. Red lines in Figure 7a show the only relevant cuts that fully define the MFD. In this first case, we consider long green time, *g/c* are close to 95%. It is important to notice the very good agreement between the maximal capacity given by the MFD and the maximal capacity calculating within the analytical framework where impacts of traffic signals have been neglected (C_{MFD} = 3218 veh/h vs C=3967 veh/h). Then, Figure 7b depicts the estimated MFDs (in red) for a more realistic situation (*g/c* = 50%). It clearly shows that the presence of urban logistics activities on the arterials reduces the maximal capacity. Figure 7b also highlights the sensitivity of the MFD to the average time headway h_0 and the average stop duration δ_0. Moreover, it is not surprising that the maximal capacity decreases with the increase of h_0. Figure 7b also reveals that trucks have a major effect on the MFD shape in the vicinity of the top of the MFD. Hence, trucks are active bottlenecks in this domain of traffic conditions. The flow of individual vehicles is constrained by double-park deliveries. Consequently, the performance of the arterial can be increased by preventing the double-park deliveries by creating dedicated areas or/and banishing trucks during peak-hours.

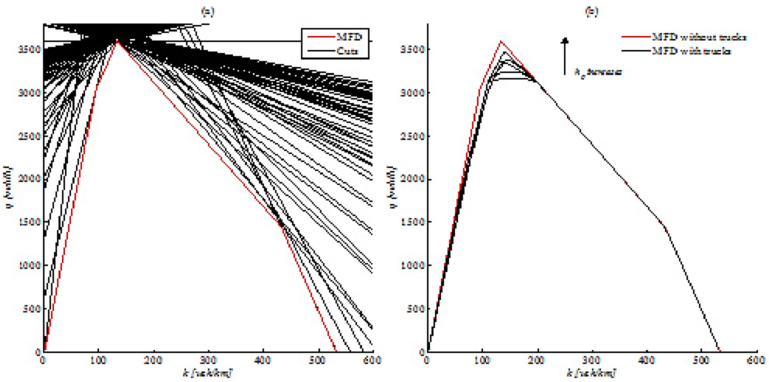

Figure 7: (a) whole sets of cuts of a MFD without trucks) (b) estimated MFDs (h0 between 5 min and 20 min)

5. Conclusion

In this paper, we further study the effects of urban logistic on traffic flow dynamics. The final goal of such an approach is to make it possible to compare *ex ante* different logistics and traffic management policies. Rather than using a microscopic traffic simulator, we resort here to an analytical modeling framework. To this end, we have considered a hypothetical but realistic urban arterial where pickup-delivery maneuvers occur. The trucks stop in double-park to pickup or deliver. Consequently, such phenomena yield to local and temporary capacity reduction that may impact the performance of the arterial.

To assess the effects of such operations on traffic dynamics, we first focus on traffic flowing at capacity without accounting for traffic signals. Consequently, we derive formulas for the effective capacity of arterials in presence of pickup-delivery maneuvers, when the distribution of time-headway and duration of stops are known and when stops occur at the same position. It turns out that this simplistic approach is sufficient to reproduce properly the impacts of trucks. Indeed, the effects of bounded acceleration ability and distribution delivery positions are negligible. The agreement of the analytical formulation with simulated results is strikingly good.

Furthermore, the article resorts to the MFD to account for the effects of traffic signals and to extend the study to other conditions than traffic flowing at capacity. The MFD is a reliable tool to manage and assess solutions for improving mobility (Xie et al., 2013; Chiabaut et al., 2013). The estimation method proposed by Leclercq and Geroliminis (2013) is extended to the case of pickup-delivery trucks. MFD estimates are then compared to unveil the connections between the performance of the considered arterial and the parameters of the logistic system. It turns out that double-park deliveries strongly constraint the flow for traffic conditions near maximal capacity. It confirms that creation of dedicated areas and related logistics policies (pre-booked area, temporary lane closure, etc.) are very promising solutions to both improve efficiency of the transportation network and of the logistic system.

Double-park deliveries also generate uncertainty in individual vehicles travel times. It may be possible to extend the work of Hans et al., (2014) to our specific case. It will lead to analytical distributions of travel times and allow assessing the uncertainty generated by trucks. The authors currently investigate this. Pending this further research, the results of this article can be generalized for any design of the arterial. Moreover, one of the next challenges will be to extend this work to the network scale. The crucial issue is to properly connect aggregated models with the local scale to account for the impacts of the distributions of pickup-delivery maneuvers. Variational theory or other formal mathematical formulations, e.g. homogenization techniques, may be promising solutions. It will make it possible to compare various city logistics solutions such as consolidation programs.

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References

Boyaci, B., Geroliminis, N. (2010). Estimation of the network capacity for multimodal urban systems, *in Proceedings of the 6th International Symposium on Highway Capacity*.

Boyaci, B., Geroliminis, N. (2011). Exploring the Effect of Variability of Urban Systems Characteristics in the Network Capacity, *in Proceedings of the 90th TRB annual meeting.*

Chiabaut, N., Leclercq, L. (2011). Wave Velocity Estimation Through Automatic Analysis of Cumulative Vehicle Count Curves. *Transportation Research Record: Journal of the Transportation Research Board*, 2249, 1-6.

Chiabaut, N., Xie, X., and Leclercq, L. (2014). Performance analysis for different designs of a multimodal urban arterial. *Transportmetrica B : Transport Dynamics*, 2(3), 229-245.

Dablanc, L. (2012) City Logistics, In: Rodrigue, J-P., Notteboom, T. and Shaw, J. (Eds.). *The Sage Handbook of Transport Studies*, London: Sage.

Dablanc, L. (2013) Best Practices in Urban Freight Management: Lessons from an International Survey. *Transportation Research Record - Journal of the Transportation Research Board*, to be published.

Daganzo, C. F. (2005). A variational formulation of kinematic waves: basic theory and complex boundary conditions, *Transportation Research Part B: Methodological* 39(2), 187-196.

Daganzo, C. F., Geroliminis, N. (2008). An analytical approximation for the macroscopic fundamental diagram of urban traffic, *Transportation Research Part B: Methodological* 42(9), 771-781.

Hans, E., Chiabaut, N., and Leclercq, L. (2014) A Clustering Approach to Assess the Travel Time Reliability of Arterials. *Transportation Research Record - Journal of the Transportation Research Board*, 2422, 42-49.

Holguin-Veras, J., Ozbay, K., Kornhauser, A., Brom, M.A, Iyer, S., Yushimito, W.F., Ukkusuri, S., Allen, B., and Silas, M.A. (2011) Overall Impacts of Off-Hour Delivery Programs in the New-York City Metropolitan Area. *Transportation Research Record - Journal of the Transportation Research Board*, 2238: p. 68-76.

Jaller, M., Holguin-Veras, J. and Darville Hodge, S. (2013) Parking in City: Challenges for Freight Traffic. *Transportation Research Record - Journal of the Transportation Research Board*, to be published.

Laval, J.A (2006) Stochastic Processes of Moving Bottlenecks: Approximate Formulas for Highway Capacity. *Transportation Research Record - Journal of the Transportation Research Board*, 1988: p. 86-91.

Laval, J.A (2009) Effects of geometric design on freeway capacity: Impacts of truck lane restrictions. *Transportation Research B,* 43: p. 720-728.

Leclercq, L., Chanut, S., and Lesort, J.B. (2004) Moving bottlenecks in the LWR model: a unified theory. *Transportation Research Record*, vol 1883, p. 3-13.

Leclercq, L. (2007). Bounded acceleration close to fixed and moving bottlenecks. *Transportation Research part B*, 41(3), 309-319.

Leclercq, L., Laval, J.A., and Chiabaut, N. (2011) Capacity drops at merges: An endogenous model, *Transportation Research Part B,* 45: p. 1302-1313.

Leclercq, L., Geroliminis, N., (2013). Estimating MFDs in Simple Networks with Route Choice, *Transportation Research Part B: Methodological* 57, 468-484.

Newell, G. F. (1998) A moving bottleneck, *Transportation Research Part B,* 8: p. 531-537.

Taniguchi, E., and Thompson, R.G. (2002) Modeling City Logistics, *Transportation Research Record - Journal of the Transportation Research Board*, 1790: p. 45-51.

Xie, X., Chiabaut, N., Leclercq, L. (2013). Macroscopic Fundamental Diagram for Urban Streets and Mixed Traffic: Cross-comparison of Estimation Methods. *Transportation Research Record: Journal of the Transportation Research Board,* 2390, 1-10.