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On-street parking near intersections: effects on traffic

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Conference paper STRC 2013

STRC | **13th Swiss Transport Research Conference**
Monte Verità / Ascona, April 24-26,2013

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April 2013

Abstract

An on-street parking maneuver can often start a temporary bottleneck, leading to additional delay endured by following vehicles. In most cases, the number of vehicles delayed due to a parking maneuver is limited. However, if the maneuver occurs close to a signalized intersection, it may result in a capacity loss at the intersection and the delay could linger over multiple cycles. In this paper, we try to define a minimum distance from the parking area to the intersection to avoid loss of capacity and enhance traffic performance. Using dimensional analysis, the effect of duration of parking maneuver, traffic flow condition, and the distance from parking area to intersection on the capacity loss at intersections is illustrated. The final results will hold for a broad range of cases, and can be used as a basis for developing on-street parking area design guidelines.

Keywords

On-street parking - parking maneuvers - distance to intersection - traffic delay - kinematic wave theory - dimensional analysis

1. Introduction

Although traffic delays caused by on-street parking maneuvers have been studied, most of the existing literature focuses on aspects other than the distance between an on-street parking area and the neighbouring intersection. For example, both Chick (1996) and Valleley (1997) calculated the road capacity reduction caused by on-street parking based on the number of parked vehicles; Yousif (1999) analyzed difference in delays caused by parallel and angel on-street parking maneuvers. Ye (2011), analyzed delays as a function of, among other things, the distance between the parking area and the intersection. However, that study only considered effects of parking on downstream intersections, and focused on improving the signal control scheme. More recently, Guo (2012) proposed a model to estimate travel time including on-street parking using variables such as effective lane width and number of parking maneuvers.

In short, no conclusions regarding the optimal distance between an on-street parking area and the neighboring intersection have been drawn yet. In this study, we will fill this gap in the literature by providing generalized guidelines for this distance. We particularly focus on this distance since it can easily be adjusted in real situations to minimize additional delay imposed by parking maneuvers. Modification of other factors to reduce this delay would require major change in road space or traffic conditions.

On-street parking maneuvers can affect the discharge rate of intersections in two different scenarios: by blocking the upstream intersection, or starving the downstream intersection of flow. In this paper, we will only analyse the first scenario. To do so, the distance between on-street parking and the intersection will be denoted as L_u when the intersection of interest is upstream of the parking area.

In this scenario, it is possible that a parking maneuver to cause a lingering delay (i.e., a delay that persists over multiple signal cycles) or a local delay (i.e., a delay concentrated into a single signal cycle), or no delay at all. Typically, when a capacity loss accurs, there is a high possibility that a lingering delays will also exist. The goal of our study is to find the minimum distance between the parking area and the intersection (i.e., minimum L_u) needed to avoid capacity loss at the intersection, as a function of the traffic condition, signal control scheme and parking duration, etc.

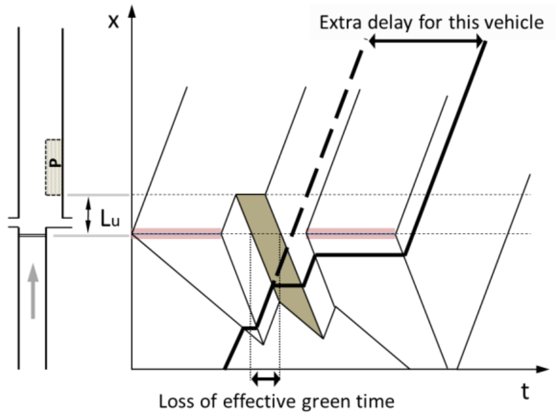
2. Research Questions

In this paper, we try to answer two questions:

- Under what condition (e.g., duration of parking maneuver, traffic signal, traffic demand), does Lu influence the capacity of the intersection?
- What is the minimum Lu required to guarantee no capacity loss at the intersections?

As mentioned above, our analysis is based on the scenario when the intersection is upstream of the parking area, see Figure 1. The layout and position of the intersection with respect to the parking area is shown on the left side; on the right side, a time-space diagram is given to depict the traffic states when a parking maneuver takes place. Note that the diagram is only a single example, many different situations could arise in reality.

Figure 1 The time-space diagram when a parking maneuver happens



In Figure 1, the light lines show all the traffic waves. The shaded area shows the resulting queue from the parking maneuver. The thick dashed line shows the theoretical trajectory of a given vehicle in the absence of the parking maneuver, and the thick solid line shows the real trajectory for that same vehicle.

Notice that in Figure 1, the parking maneuver causes a lingering delay. It is also possible for a parking maneuver to cause a local delay, or no delay at all. To determine the conditions under which each of these cases arise, and the corresponding minimum distance required between the parking area and the intersection to mitigate delays, the relationship among key variables needs to be theoretically determined based on certain assumptions. These assumptions are stated in the following section.

3. Assumptions

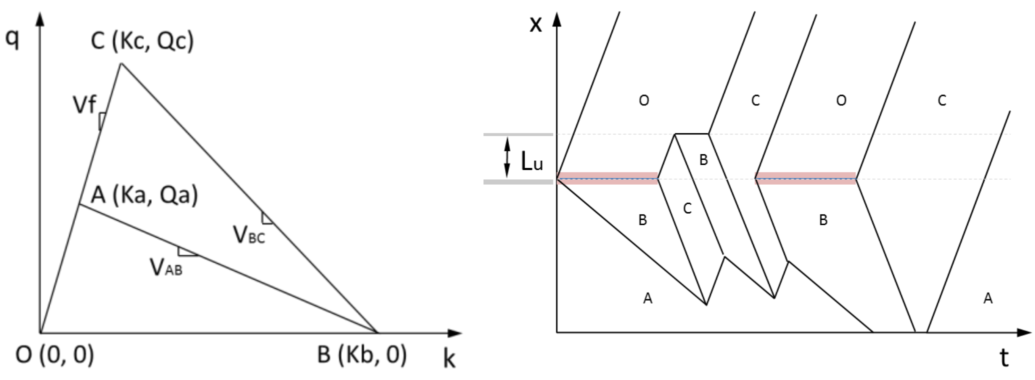
To develop a theoretical model of addition delay caused by parking maneuvers, assumptions such as flow conditions are needed. Those can be found in following subsections.

3.1 Traffic states

A triangular fundamental diagram (i.e., FD) is used to define traffic states on the roadway. In Figure 2(a), an illustrative FD with all necessary variables is depicted.

A constant free-flowing demand of traffic from upstream is assumed and denoted as state A. The jammed state of stopped cars are denoted as state B (note that traffic stops when a parking maneuver happens). Use C to denote the maximum flow on the roadway and O to denote the state of an empty road. Ka, Kb and Kc stand for the density of State A, B and C; similarly, Qa, Qb and Qc stand for the respective flows; Vf stands for free flow speed; VAB and VBC stand for speed of shock waves between states A, B and B, C respectively. An example showing the traffic states in time-space diagram is given in figure 2(b).

Figure 2 (a) Assumed triangular fundamental diagram of the link. (b) An example of traffic states on a time-space diagram



(a) (b)

3.2 Signal control

We assume a signal with green time, G; red time, R and cycle length, C (i.e., C=G+R). The analysis starts at the beginning of a red signal, the signal turns green at time R, and the next red light starts at time C. Use α to denote the ratio between length of green signal, G and the cycle, C:

$$\alpha = \frac{G}{C} \qquad \text{Eq. 1}$$

3.3 Parking maneuver

The parking vehicle is assumed to be the first vehicle which crossed the intersection during the green signal, since this is the worst case scenario. The starting time of the parking maneuver is R+Lu/Vf (see Figure 3). Assume the duration of this maneuver to be P where P<G.

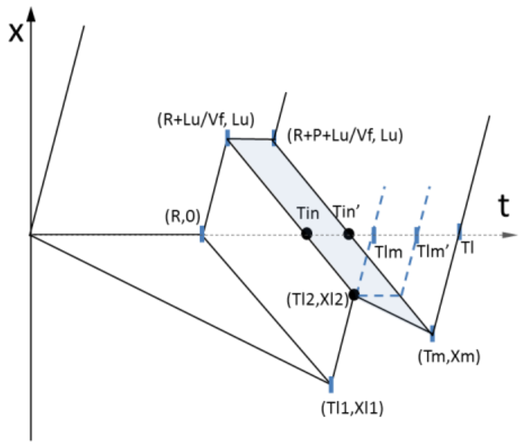
3.4 Critical time and location of the shock waves

These variables are defined assuming G is long enough such that all the shock waves at the intersection are contained within one cycle. The intersection is located at X=0, such that X<0 implies the upstream of the intersection and X>0 implies the downstream of the intersection.

If the shock wave (generated by the parking maneuver) reaches the intersection, the front of this queue reaches the intersection at time Tin' and back of the queue reaches the intersection at time Tin. The last car to be delayed by the shock wave arrives to the intersection at time Tl

. One can also find additional variables Tl1, Xl1, Tl2, Xl2, Tm, Xm, Tlm, Tlm' used in the calculation in figure 3. The exact formulas for these variables can be find in Appendix 1.

Figure 3 Variables of time and location (to be used in calculations) shown on a time-space diagram



4. Analytical Model

4.1 Questions 1: Under what condition, Lu becomes influential to the capacity of the intersection?

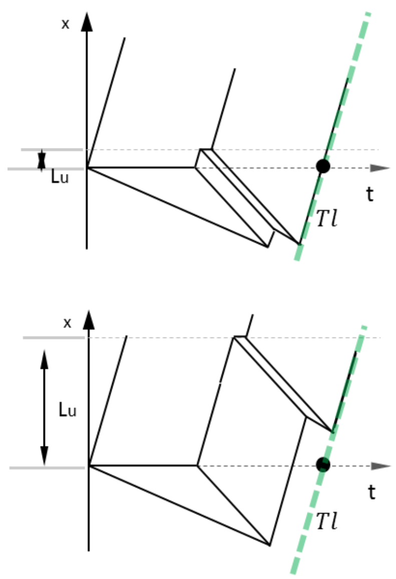
As illustrated in Figure 3, if the red light starts after Tl (i.e., C>Tl), all the cars which experienced the “parking” delay can pass the intersection during the green and there would be no capacity loss. In other words, if the ratio of the duration of parking maneuver to the length of the signal cycle is small enough, there will be no loss of the capacity at the intersection. Tl can be calculated as given in eq.2 where β is defined in eq.3.

$$Tl = \frac{R + P}{1 - \beta} \qquad \text{Eq. 2}$$

$$\beta = \frac{V_{AB} \cdot (V_{BC} - V_f)}{V_{BC} \cdot (V_{AB} - V_f)} \qquad \text{Eq. 3}$$

To illustrate that Tl is independent of Lu, Figure 4 depicts two time-space diagrams with different values of Lu, but the same value of Tl. Also it can be seen that as long as C>Tl, no capacity loss will arise.

Figure 4 An illustration of the independence of Tl from Lu



Considering a traffic signal with a fixed α, we can find a maximum ratio between P and C which guarantees no capacity loss (Tl<C). If we define δ as eq. 4, then this criteria can be written as $\delta < \alpha - \beta$.

$$\delta = \frac{P}{C} \quad \text{Eq. 4}$$

However, if eq. 5 holds, the parking maneuver could cause capacity loss at the intersection.

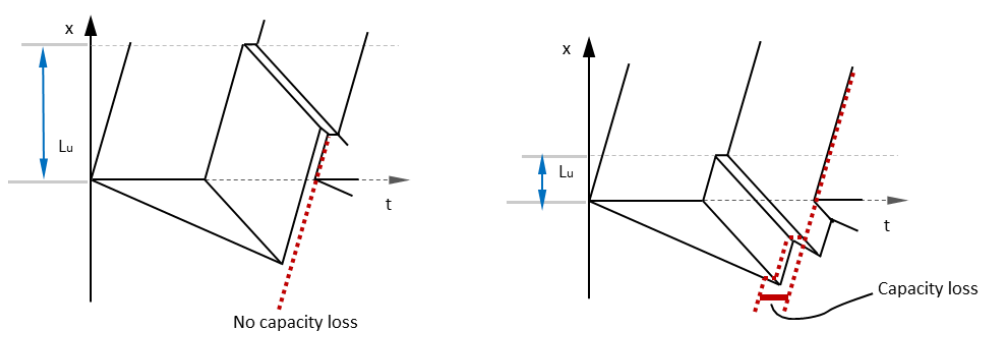
$$\delta > \alpha - \beta \quad \text{Eq. 5}$$

The values of Lu for which this capacity loss could be experienced is analyzed in the following section.

4.2 Question 2: What is the minimum Lu required to guarantee no capacity loss at the intersection?

When eq.5 holds, if a parking maneuver could cause capacity loss at the intersections is depending on the value of Lu. Two examples are provided in Figure 5 to show cases in which Lu leads to capacity loss or not. In the left graph, no capacity loss is experienced while a capacity loss is experienced in the right graph, based only on the different values of Lu.

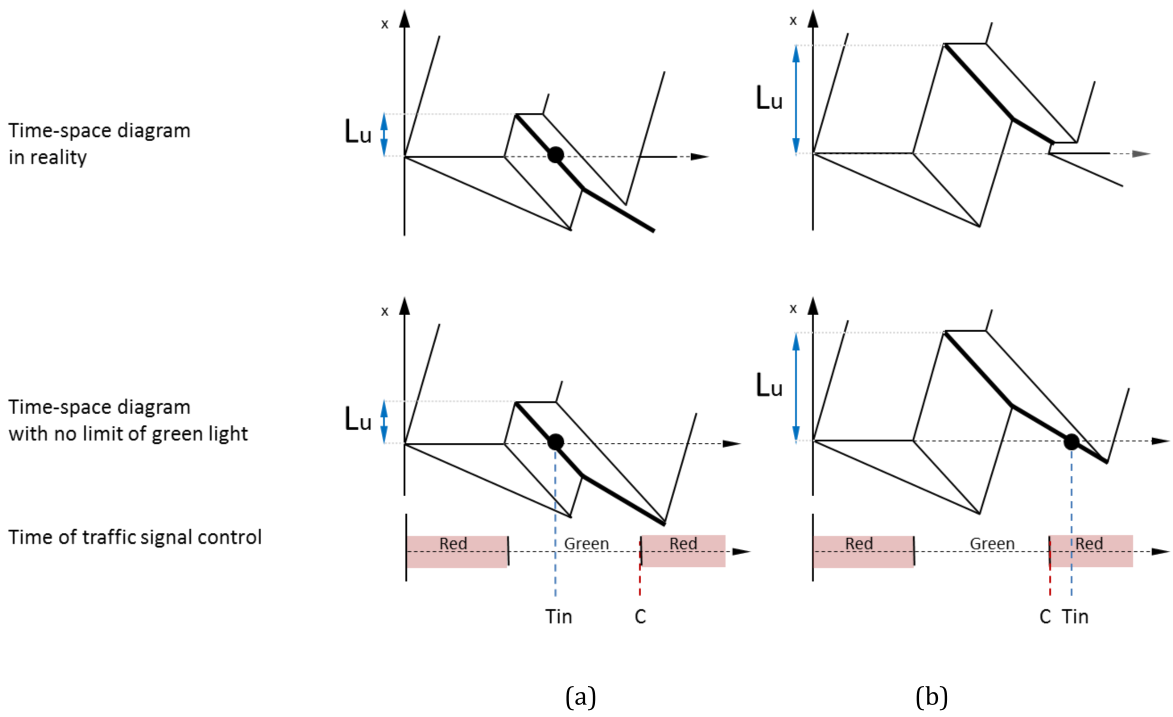
Figure 5 Examples of time-space diagrams depicting (a) no capacity loss and (b) capacity loss as the value of Lu.



(a) (b)

A capacity loss at the intersection is possible to be caused when the back of the queue reaches the intersections. As defined above, Xm<0 implies that the maximum reach of shock wave (caused by parking maneuver) is upstream of the intersection and Tin is the time this wave reaches the intersection (where X=0). When Tin is earlier than the time that the next cycle starts (i.e., Tin < C), there will be a capacity loss; on the contrary, if Tin>C, there will be no capacity loss. Figure 6 illustrate two examples in respect to these two situations.

Figure 6 (a) Traffic states when Tin<C, a capacity loss is caused. (b) Traffic states when C<Tin, no capacity loss is caused.



Based on previous analysis, a capacity loss will be generated when the following conditions are met:

$$\begin{cases} C < Tl \\ Xm < 0 \\ Tin < C \end{cases} \qquad \text{eq. 6}$$

Based on the definition, we can define them mathematically:

$$Xm = L_u + (R + P) \cdot \frac{V_{BC} \cdot V_{BC}}{V_{BC} - V_{AB}} \qquad \text{eq. 7}$$

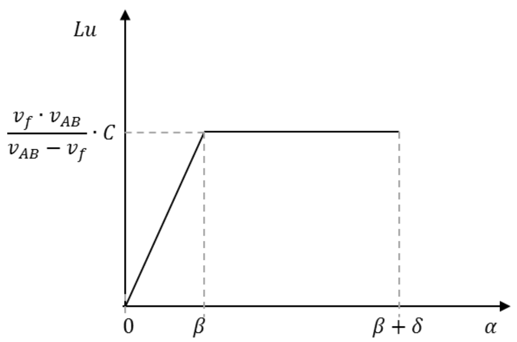
$$Tin = \begin{cases} \left(\frac{1}{V_f} - \frac{1}{V_{AB}}\right) \cdot L_u, \; when\ Xl2 > 0 \\ R + \left(\frac{1}{V_f} - \frac{1}{V_{BC}}\right) \cdot L_u, \; when\ Xl2 < 0 \end{cases} \qquad \text{eq. 8}$$

Based on the conditions in eq.6 (together with eq. 5), we can find the maximum value of Lu which will generate a capacity loss. This value, as a function of α, it is written as in eq.9. Figure 7 illustrates this relation.

$$\begin{cases} Lu < \frac{v_f \cdot v_{BC}}{v_{BC}-v_f} \cdot C \cdot \alpha & if \quad \alpha\epsilon[0,\beta] \\ Lu < \frac{v_f \cdot v_{AB}}{v_{AB}-v_f} \cdot C & if \quad \alpha\epsilon[\beta,\beta+\delta] \end{cases} \qquad \text{eq. 9}$$

In other words, when eq.9 holds, a parking maneuver will lead to a capacity loss at the upstream intersections.

Figure 7 The minimum required value of Lu to cause no capacity loss as a function of α



From Figure 7, it is clear that the ratio of the length of the green signal to the length of the whole cycle (i.e., α) is decisive of maximum value of Lu. As α increases, the required Lu also increases. However, when $\beta+\delta \geq \alpha \geq \beta$, the required distance stays at a constant value and when $\alpha \geq \beta+\delta$, there is always no capacity loss.

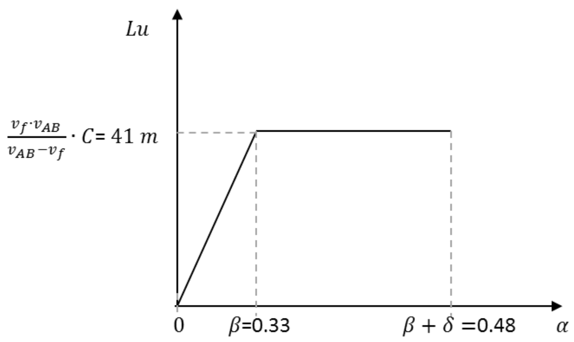
5. Numerical examples

Traffic conditions: $\mathrm{Ka} = 10\ \mathrm{veh/km}, \mathrm{Qa} = 500\ \mathrm{veh/h}$; $\mathrm{Kb} = 200\ \mathrm{veh/km}$, $\mathrm{Qb} = 0\ \mathrm{veh/h}$; $\mathrm{Kc} = 30\ \mathrm{veh/km}, \mathrm{Qc} = 1500\ \mathrm{veh/}$. $\mathrm{Vf} = 50\ \mathrm{km/h}$, $\mathrm{VAB} = -2.6\ \mathrm{km/h}$, $\mathrm{VBC} = -8.8\mathrm{km/h}$, $\beta = 0.33$.

Signal control: $\mathrm{C} = 60\mathrm{s}$ and variables for parking maneuver: $\delta = 0.15$. The value of α and L_u will be shown later with the calculation.

According to eq.9, the minimum required Lu is shown in Figure 8.

Figure 8 Numerical example: the minimum required value of Lu to cause no capacity loss



6. Conclusion

In this paper, we have discussed the traffic problem generated by on-street parking and how a parking maneuver can affect the discharge rate of an intersection. Through our analysis, we can see that on-street parking, depending on its distance to the intersection and the duration of maneuver, can cause different results for capacity loss. These variables can also influence whether a lingering delay, a local delay or no delay is generated. Moreover, this paper analytically determined the required distance from on-street parking to the intersection upstream to guarantee no capacity loss of this intersection. The results should apply to a broad range of cases, and could be used as a foundation for developing guidelines for the design of on-street parking areas, especially related to their location with respect to the neighboring intersections.

In future work, we would like to quantify the capacity loss of the intersection and the total additional delay of the traffic caused by the parking maneuver.

7. Acknowledgements

The authors are very grateful to Dr. Ilgin Guler for her helpful comments on this study.

8. References

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9. Appendix 1

$$\begin{cases} Tl1 = \dfrac{V_{BC}}{V_{BC} - V_{AB}} \cdot R \\ Xl1 = \dfrac{V_{BC} \cdot V_{AB}}{V_{BC} - V_{AB}} \cdot R \end{cases}$$

$$\begin{cases} Tl2 = Tl1 + \dfrac{L_u}{V_f} = \dfrac{V_{BC}}{V_{BC} - V_{AB}} \cdot R + \dfrac{L_u}{V_f} \\ Xl2 = Xl1 + L_u = \dfrac{V_{BC} \cdot V_{AB}}{V_{BC} - V_{AB}} \cdot R + L_u \end{cases}$$

$$\begin{cases} Tm = \dfrac{L_u}{V_f} + (R + P) \cdot \dfrac{V_{BC}}{V_{BC} - V_{AB}} \\ Xm = L_u + (R + P) \cdot \dfrac{V_{BC} \cdot V_{BC}}{V_{BC} - V_{AB}} \end{cases}$$

When Xm<0 :

$$Tin' = R + P + \frac{L_u}{V_f} - \frac{L_u}{V_{BC}}$$

$$Tl = (R + P) \cdot \frac{V_{BC} \cdot (V_{AB} - V_f)}{V_f \cdot (V_{AB} - V_{BC})}$$

When Xm<0, Xl2>0 :

$$Tin = \left(\frac{1}{V_f} - \frac{1}{V_{AB}}\right) \cdot L_u$$

When Xm<0, Xl2<0 :

$$Tin = R + \left(\frac{1}{V_f} - \frac{1}{V_{BC}}\right) \cdot L_u$$

$$Tlm = Tl2 - \frac{Xl2}{V_f} = R \cdot \frac{V_{BC} \cdot (V_{AB} - V_f)}{V_f \cdot (V_{AB} - V_{BC})}$$

$$Tlm' = Tlm + P = P + R \cdot \frac{V_{BC} \cdot (V_{AB} - V_f)}{V_f \cdot (V_{AB} - V_{BC})}$$