TOTAL CAPACITY OF SHARED-SHORT LANES AT SIGNALIZED INTERSECTION – AN APPROACH BASED ON SIMULATION STUDY

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ABSTRACT

This paper presents a simulation approach for estimating the total capacity of shared-short lanes at signalized intersections. The approach takes into account the stochastic nature of traffic flow and the effect of queue blockage to the short turn lanes. Using the simulation package VISSIM, a comprehensive database was generated for estimating the capacity under different lane and control conditions. Based on this database, a calculation approach can be proposed for arbitrary lane and signal timing configurations. Monographs can be prepared for practical applications.

keywords: Signalized intersection, Short lane, Capacity, Simulation

1 INTRODUCTION

The calculation procedures in current highway capacity manuals (e.g. the American and the German Highway Capacity Manual (HCM 2000, HBS 2001)) do not exactly treat shared-short lanes at signalized intersections. The capacity of individual traffic streams (left-turn, through, and right-turn) are calculated separately. The turning lanes are treated as exclusive lanes. Such a treatment neglects the effect of queue blockage due to the short lanes. However, when traffic demand does cause queue blockages to the short-lane section, a reduced capacity is resulted. On the other side, in case that the traffic streams share a common traffic lane, the current highway capacity manuals estimate the capacity of the shared lane with an extra formula fore reduced capacities. That means the lengths of the left-turn or right-turn lanes can only be considered either as infinite or as zero. The exact lengths of the separate short turn lanes (lengths of the turn pockets) cannot be taken into account. Therefore, the capacity estimated from the methods in the current highway capacity manuals is either overestimated or underestimated.

The lack of an appropriate procedure on capacity and delay estimation under a short turn lane situation often leaves traffic engineers with a dilemma, especially when determining the design of an intersection based on future traffic demands. Normally, a longer than necessary turn pocket could be constructed.

There have been a very limited number of investigations conducted on this topic. The only well-known documents where the short-lane issue has been addressed are those that are incorporated in the German Highway Capacity Manual (Brilon et al, 1996; FGSV, 2001) and in the SIDRA (Akcelik, 1997) software package. The models included in both documents are deterministic models. The stochastic nature of blockage to the short lanes has not yet been addressed. This paper presents a simulation study for estimating the total capacity of this combination of shared and short lanes. With the simulation results, the short-lane effect and the stochastic nature of queue blockages can be investigated. The simulation study is done using VISSIM (PTV, 2003) microscopic simulation package.

From the simulation results, a comprehensive database can be produced for signalized intersections with short lane configuration. It is found out that the capacity with a short left-turn or right-turn lane is specifically related to the length of the short lane, the ratio between the through and turning vehicles and the green times both for through and turning vehicles. It turns out, like for capacities at signalized intersections in general, that the cycle time is not an explicit parameter affecting the total capacity of the shared-short lanes.

According to the presented simulation studies, the capacity enhancement with a short turn lane ranges between 5 to 30 percent compared to the shared-lane situation. This enhancement depends strongly on the green times and the length of the short lanes.

2 SIMULATION WITH THE SOFTWARE PACKAGE VISSIM

In the simulation study, the program package "VISSIM 3.70" from the PTV AG is used for determining the total capacity at signalized intersection with short turn lanes.

In the study, every simulation run has a 3-h runtime and only personal cars are considered in the traffic volume. For the driver behavior, parameters are used according to the program's default values. The desired speed is set to 45-60 km/h for standard urban streets. As a model configuration an approach at a signalized intersection with a through and a left-turn lane is constructed for the simulation study (cf. Figure 1). On the brink of the two traffic lanes, a permanent queuing saturation is produced for high traffic volume. Therefore, the capacity can be obtained by counting the output behind the stop line.

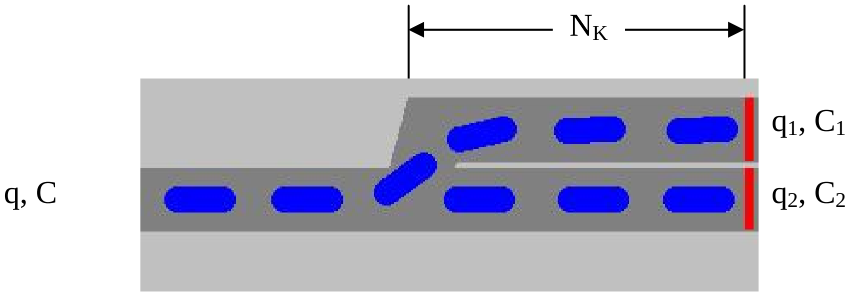


Figure 1 – Permanent queue before the prink point, screenshot from VISSIM

Denote the traffic flow and the capacity for the lane 1 and lane 2 with q_1, C_1 and q_2, C_2, and denote the total flow and capacity for the approach with q and C, the following necessary boundary conditions in Table 1 must be held.

Table 1 - Necessary boundary conditions for the capacity of an approach

No.	boundary condition	note
1	$C_1 \leq f_1 \cdot q_{S1}$	a)
2	$C_2 \leq f_2 \cdot q_{S2}$	a)
3	$C = f_1 \cdot q_{S1}$ for $q_1 = 0$	b)
4	$C = f_2 \cdot q_{S2}$ for $q_2 = 0$	b)
5	$C \rightarrow \min(f_1 \cdot q_{S1} \cdot (q_1+q_2)/q_1,\ f_2 \cdot q_{S2} \cdot (q_1+q_2)/q_2)$ for $N_K \rightarrow \infty$	c)
6	$C = C_{shared}$ for $N_K = 0$	d)

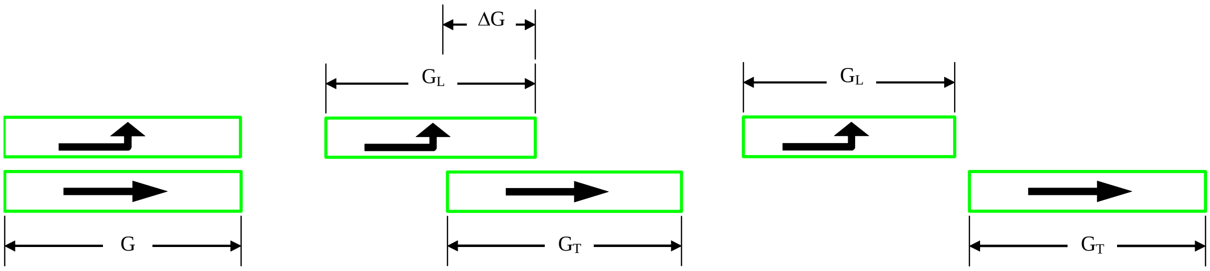
a) The capacity of a short lane is always smaller than the capacity of an exclusive lane
b) The capacity of the approach is equal to the capacity of an exclusive lane if the flow rate of one of both lanes is zero
c) The ratio between the flow rates of both lanes remains constant
d) The capacity of the approach is equal to the capacity of a shared lane for N_K=0

Here q_S is the saturation flow rate, N_K the length of the short lane area, and f the green time ratio for lanes under consideration.

In the conducted simulation, q_1 is the flow of the left turn (L) lane and q_2 is the flow of the combined through and right turn (T) lane. The through and right turn flow are treated as a combined single flow because they diverse from each other not before the stop line. Because of the symmetry of the configuration, the simulation results apply also to the configuration of a through flow (T) and a right turn flow (R) with short lanes.

For this configuration, there are generally three possible basic constellations of signal controls:

1. The green times of both flows (L, T) are included each other (e.g. both flows have the same green time, Figure 1a).
2. The green times of both flows (L, T) are excluded each other (e.g. the green times of both flows are turned on one after another, Figure 1c).
3. The green times of both flows (L, T) are intercepted (Figure 1b).



a) Case 1 b) Case 3 c) Case 2

Figure 2 – Possible basic constellations of green times a) green times included each other b) green times intercepted c) green times excluded each other

In case 1 that the green times of both flows (L, T) are included each other, following initial parameters are used for the simulation:

- circle time, C
- green time, G
- ratio of left turn flow, a_L, and
- number of possible stop places in the short lane area, N_K

The circle time C is varied form 60s to 90s with a step of 10s. The green time G is varied from 10s to 40s with a step of 10s. The applied ratios of left turn flow a_L are 50%, 20% and 0%. The number of stop places in the short lane area N_K is chosen to 0, 3, 6, and 9. For each parameter combination, simulation for 3 h is conducted.

In case 2 that the green times of both flows (L, T) are excluded each other, the combinations for the initial parameters are modified slightly. The variation of the circle time C, ratio of the left turn flow a_L, and the number of possible stop places N_K in the short lane area remains unchanged. Additionally, the green time for the through lane G_T is varied from 10s to 40s with a step of 10s. The green time for the left turn lane G_L is varied from 5s to 20s with a step of 5s. The green time for the left turn lane begins 1s after the green time for the through line is terminated. Again, 3 h simulation is conducted for each parameter combination.

In case 3 that the green times of both flows (L, T) are intercepted, the intercepted length of green time ΔG is taken into account additionally.

It turns out that the cycle time is not an explicit parameter affecting the total capacity of the shared-short lanes. Only the capacities per circle are decisive. Thus, in the results of the simulation study, the cycle time is not more considered as explicit parameter.

3 EVALUATION OF THE SIMULATION RESULTS

3.1 Total capacity of the approach for case 1: The green times of both flows (L, T) are included each other

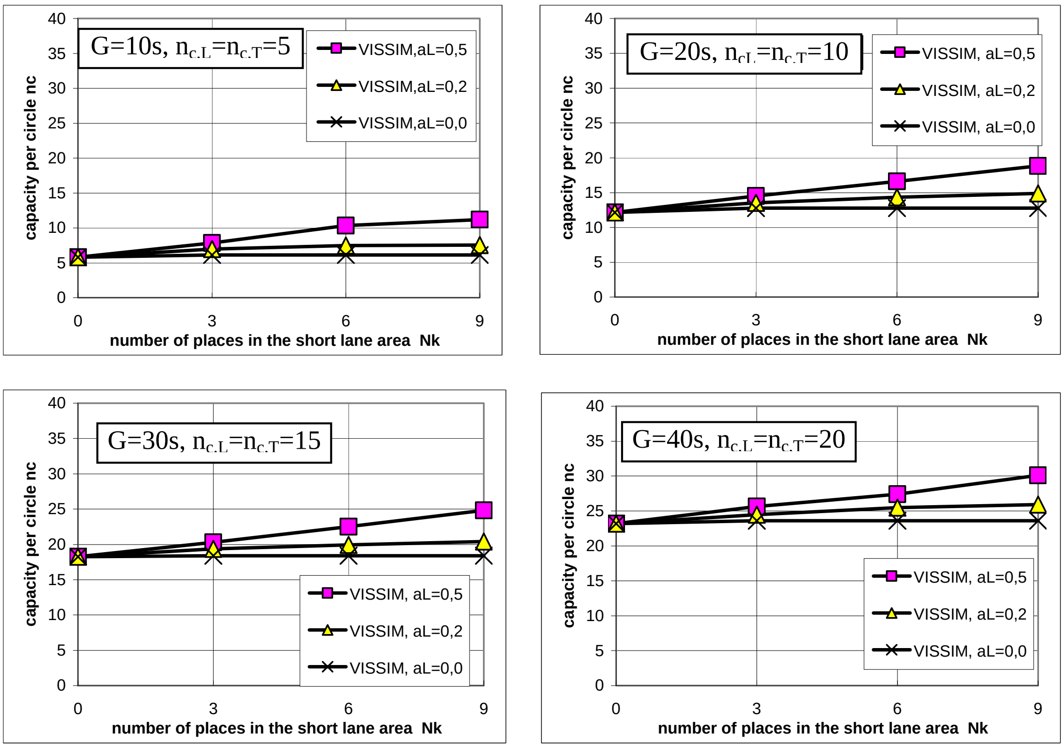


Figure 3 – Simulated total capacity of an approach with a short lane area, case 1: The green times of both flows (L, T) are included each other, $n_{c,L}$ = capacity of the left turn flow (L) per circle, $n_{c,T}$ = capacity of the through (T) per circle, G green time

In Figure 3, the simulated total capacity of the approach for the case that the green times of both flows (L, T) are included each other is illustrated. It is obviously that the capacity is at lowest if there are no left turn vehicles at all. The approach capacity increases with increasing ratio a_L (max. to 0.5) of left turn flow and increasing number of places N_K in the short lane area. It can be recognized that there is an upper boundary of capacity because the capacity curve shows an asymptotic shape (cf. also Table 1, Boundary condition 5).

3.2 Total capacity of the approach for case 2: The green times of both flows (L, T) are excluded each other

In Figure 4, the simulated total capacity of the approach for the case that the green times of both flows (L, T) are excluded each other is illustrated. The total capacity per circle is a function of the number of places in short lane area and the capacities per circle of both lanes. It can be seen that the ratio of the left turn flow does not have an unequivocal influence on the total capacity of the approach. Depending on the number of places in the short lane area, the influence can be positive or negative. As in the case 1, the total capacity of the approach increases with increasing number of places in the short lane area. Again, this increase has an asymptotic shape (cf. also Table 1, Boundary condition 5).

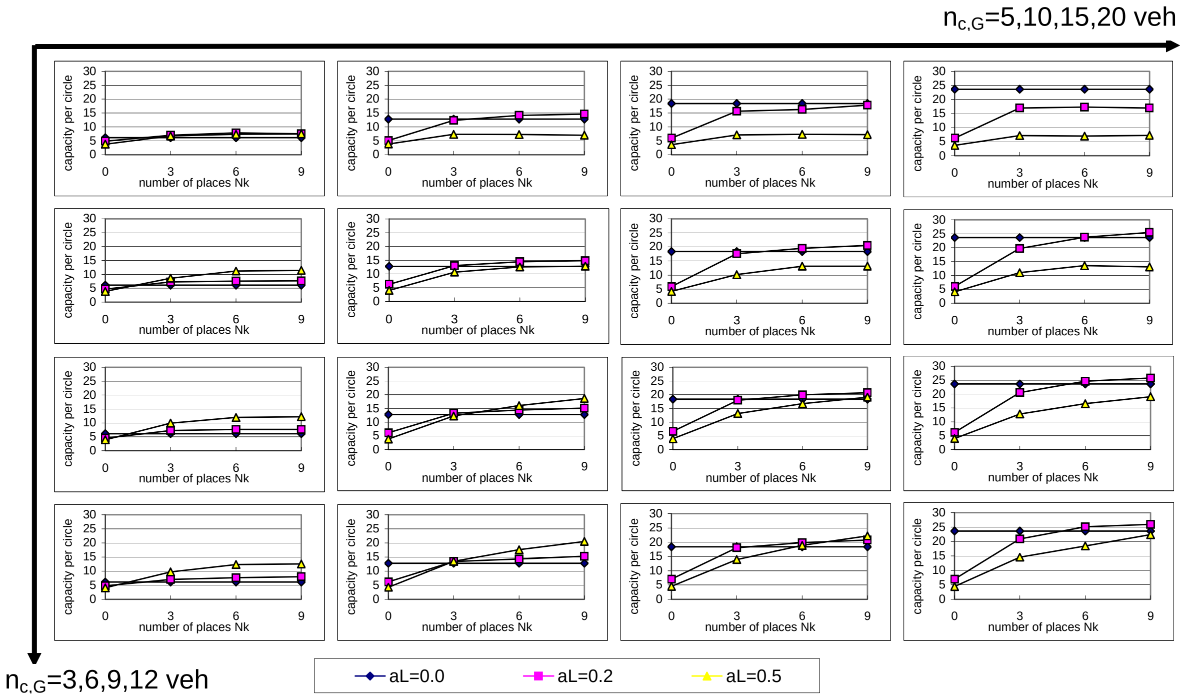


Figure 4 – Simulated total capacity of an approach with a short lane area, case 2: The green times of both flows (L, T) are excluded each other, $n_{c,L}$ = capacity of the left turn flow (L) per circle, $n_{c,T}$ = capacity of the through flow (T) per circle

3.3 Solution for case 3: The green times of both flows (L, T) are intercepted Interpolation between case 1 and 2

For the case 3 that the green time of both flows (L, T) are intercepted, the total approach capacity can be obtained by interpolating the results of case 1 (green time are included) and case 2 (green time are excluded). The interpolation parameter is the intercepted duration of the green times, ΔG (cf. Figure 2).

The formulation of the interpolation is:

$$n_{c,M,III} = n_{c,M,II} + (n_{c,M,I} - n_{c,M,II}) \cdot \frac{\Delta G}{\min(G_{L,}\ G_T)} \qquad (1)$$

with $n_{c,M,III}$ = total capacity of the approach per circle for case 3 (the green times of both flows (L, T) are intercepted)

$n_{c,M,II}$ = total capacity of the approach per circle for case 2, from Figure 4

$n_{c,M,I}$ = total capacity of the approach per circle for case 1, from Figure 3

G_L = green time for the left turn flow

G_T = green time for the through + right turn flow

ΔG = duration of the interception

4 SUMMARY AND CONCLUSIONS

Using the simulation package VISSIM, a comprehensive database was generated for estimating capacities of shared and short lanes under different lane and control conditions. From this database monographs for the total capacities of shared and short lanes can be produced. Combined with an interpolation technique, those monographs can be used for arbitrary lane and signal timing configurations at signalized intersections. The here presented approach fills out a leak in the current version of highway capacity manuals (HCM 2000, FGSV, 2001).

It is found out that the capacity with a short left-turn (or a right-turn lane) is specifically related to the length of the short lane, the ratio of through/turning vehicles and the green times both for through and turning vehicles.

Based on the simulation studies, the capacity enhancement with a short turn lane ranges between 5 to 30 percent compared to the shared-lane situation without short lanes. This enhancement depends strongly on the green times and the length of the short lanes.

For applications in the practice, more detailed monographs are constructed for different lane and traffic conditions. These monographs can be obtained from the author directly.

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