Left-Turn Equivalencies for Opposed, Shared, Left-Turn Lanes

JOHN H. SHORTREED

ABSTRACT

A study of intersection signal optimization in a medium-sized city indicated that there were a large number of approaches without an exclusive left-turn lane, but rather with a shared left and through lane. The study also found that the accurate determination of the capacity of a shared left-turn lane was critical to the analysis of intersection performance. Moreover a search of the literature suggested that there are no current methods of estimating the capacity of an approach containing a shared left-turn lane. A method is proposed for estimating the capacity of a shared left-turn lane. The method builds on the existing procedures for exclusive left-turn lanes first developed by the British in 1966 and since extended in Australia and the United States. The proposed method develops an estimate of the flow of through vehicles during the initial part of the green display when left-turn vehicles are blocked by the opposing flow. Subsequent gap acceptance behavior is modeled to reflect the length of the displayed-green time. Finally, the flow after green is modified to reflect the probability of the shared left-turn lane actually being blocked when the green ends. The resulting capacities compare favorably with results quoted in the literature for cases where conditions in a shared left-turn lane are similar to those in an exclusive left-turn lane situation. The results are given both in tabular form and as a set of iterative equations.

A procedure for calculating left-turn equivalencies for opposed, shared, left-turn lanes is presented. For approaches to an exclusive left-turn lane, the results are compared with observations reported in the literature.

It was observed that in the analysis and design of signalized intersections many solutions involve the use of a lane for both left and through traffic flow. The absence of explicit methods for estimating the capacity of this type of lane often leads to the exclusion of shared lanes from analysis in favor of exclusive left-turn lanes or exclusive signal displays for which analysis methods are available. This in turn often leads to nonoptimal design of signal timing.

PROPOSED METHOD

A method of estimating the capacity of a shared, opposed, left-turn lane is presented. The method is basically an extension of traditional methods for the analysis of an exclusive, opposed, left-turn lane (1-4). The main extensions of the traditional methods are

1. Through vehicles in a shared left lane are allowed to move during the period when left turns are blocked by the opposing flow;
2. The gap acceptance mechanism is modified to reflect the limitation on the possible size of gaps;
3. Flow after green is not allowed if the shared left lane experiences free flow with no blockage by left-turning vehicles; and
4. The allocation of through vehicles to the shared left lane and other lanes of the approach is modeled directly.

The results of the method are presented and where appropriate these results are compared with observed results reported in the literature. The proposed method has been incorporated in a basic computer program for the critical movement analysis of an intersection.

The opposed, shared, left-turn situation is shown in Figure 1. A critical movement analysis is assumed, and one phase is shown with an opposed, shared, left-turn lane. The flows are given in vehicles per hour (vph) but these are normally the design flow rates associated with the peak 15-min period. A movement (i.e., ( ) in Figure 1) is a lane or lanes that for analysis purposes can be separated from the total approach but cannot be further subdivided because of common directional traffic flows. The opposing flow is the movement [(1)(2)] that consists of through and right-turn flows in lanes

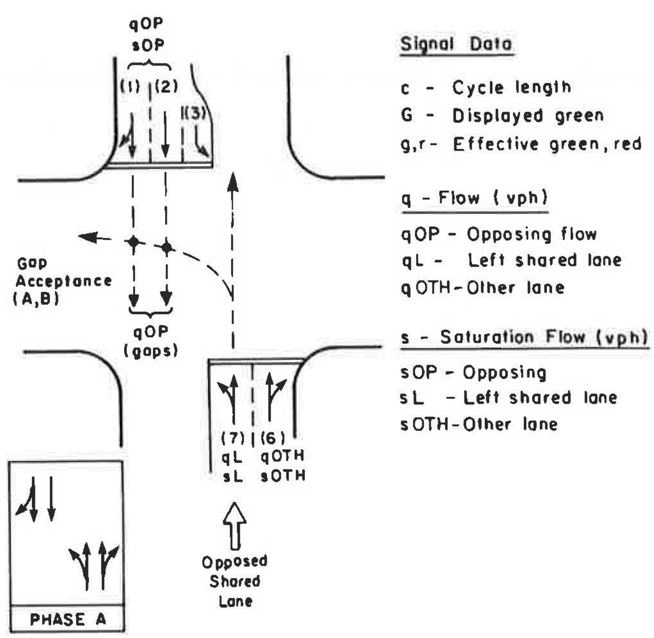

FIGURE 1 Typical opposed, shared, left-turn lane situation.

(1) and (2). This opposing flow (qOP) and its associated saturation flow (sOP) are used to determine the time when no left turns can be made from the shared lane (7). In Figure 1 qOP(gaps) is the opposing flow that interfers with the gap acceptance of the left-turn movement. Typically qOP(gaps) is just qOP less any opposing flows that do not interfere with left turns. If in Figure 1 the opposing right turns in lane (1) interfered with the left turns in lane (7) (e.g., if both turned into the same lane), the opposing right turns would be included in qOP(gaps); otherwise they would be excluded. This decision is left to the analyst.

The criterion for selecting the critical movement for the partial situation shown in Figure 1 is to select the movement with the greatest degree of saturation or the largest ratio of flow to capacity. Capacity is the saturation flow (s) times the ratio of effective green time to the cycle length (g/c). For purposes of explanation it is assumed that the movement lost times are all equal and that all movements in Figure 1 have the same g/c ratio. Critical movement for phase A is the largest degree of saturation (x) between

$$x[(1)(2)] = qOP/[sOP(g/c)]$$

and

$$x(6) = x(7) = qOTH/[sOTH(g/c)]$$

The shared left-turn lane (7) is a part of movement [(6)(7)], and it is assumed that at capacity both lanes will have an equal degree of saturation. That is, at capacity the through movement would be distributed between lane (6) and lane (7) so that both lanes would have the same degree of saturation. This condition results in a requirement for a trial-and-error solution for determining the saturation flow for the opposed, shared, left-turn lane because, as will be seen, its capacity is a function of the percentage of through vehicles in the lane.

In Figure 1 the critical movement in phase A will be one of movement [(1)(2)] or movement [(7)(6)]. Given the flows and signal timing, this largely depends on the estimated saturation flow. The calculation for the saturation flow is relatively straightforward except for the shared left-turn lane.

Saturation Flows

Saturation flows in Figure 1 are given in vph and are defined as

$$s = \sum_{\substack{\text{lanes}\\ \text{in}\\ \text{movement}}} [s(\text{lane type}) \cdot f(w) \cdot f(Lt) \cdot f(Rt) \cdot f(gr) \ldots] \qquad (1)$$

where

s(lane type) = the basic saturation flow measured for local drivers for a specified lane type,
f(w) = lane-width adjustment factor,
f(Rt) = right-turn adjustment factor,
g(gr) = grade adjustment factor,
f(Lt) = left-turn adjustment factor, and
.... = other adjustment factors (e.g., trucks).

The left-turn factor is defined as

$$f(Lt) = 100/[(\%Lt \cdot LTE) + (1-\%Lt)] \qquad (2)$$

where %Lt is the percentage of left turns in the movement and LTE is the left-turn equivalent (the number of through cars that would use up just as much capacity as one left-turning vehicle).

In Equation 1 there is a right-turn adjustment factor, f(Rt), based on a right-turn equivalent (RTE) analogous to f(Lt) and LTE. The LTE in Equation 2 is found by estimating the capacity of lane (7) with left turns and then comparing this with the capacity with no left-turning vehicles in the lane.

Capacity of Opposed, Shared, Left Lanes

Figure 2 shows the basis for calculating the per cycle capacity of an opposed, shared, left lane. In Figures 2a and 2b the opposing flow builds up a queue during the effective red phase. This queue discharges at the saturation flow and then the opposing flow occurs at the average level of qOP. It is assumed that the opposing flow arrives at random, that the intersection is not oversaturated, and that there are usually no vehicles left over from the previous cycle. The time taken for the opposing queue to discharge (i.e., the saturation time for opposing flow) is

$$stOP = qOP\ [(c - g)/(sOP - qOP)] \qquad (3)$$

In period 1, which is stOP seconds long, only through vehicles usually can proceed. The average number of vehicles that can proceed per cycle is

$$T1 = \sum_{i=1}^{n} [1 - (\%Lt/\%L)]^{i} \qquad (4)$$

where

T1 = through vehicles per cycle in time period 1;
%Lt = percentage left turns in the total movement (e.g., movement [(6)(7)] in Figure 1);
%L = percentage of the movement traffic in the left lane; that is, 100 [qL/(qL + qOTH)]; and
n = maximum number of through vehicles in stOP (i.e., stOP/sL where sL is the unopposed saturation flow rate for the left lane).

In Equation 4 (%Lt/%L) is the proportion of left-turning vehicles in the shared lane, and one less this is the proportion of through vehicles. The probability of there being one through vehicle per cycle is just the probability that the first vehicle in the left lane is a through vehicle and this is equal to the proportion of through vehicle in the left lane. The probability of a second through vehicle is the joint probability that the first vehicle is a through vehicle and the second vehicle is also a through vehicle (i.e., the proportion of through vehicles squared). This continues for the number of through vehicles per cycle that could proceed in stOP seconds. As shown in Figure 2 the flow rate for through vehicles falls off as there is a higher and higher probability of having the lane blocked by a left-turning vehicle.

In time period 2 of Figure 2 there will be a number of queued left-turning vehicles that will flow at the left-turn saturation flow. The flow in time period 2 then is

$$L2 = T1\ \{[\%Lt/\%L]/[1 - (\%Lt/\%L)]\} \qquad (5)$$

where

L2 = left-turning vehicles per cycle in time period 2 and the time taken for L2 is t2 = L2(3600/sLgap) (Equation 6) where t2 is time for period 2 (sec) and

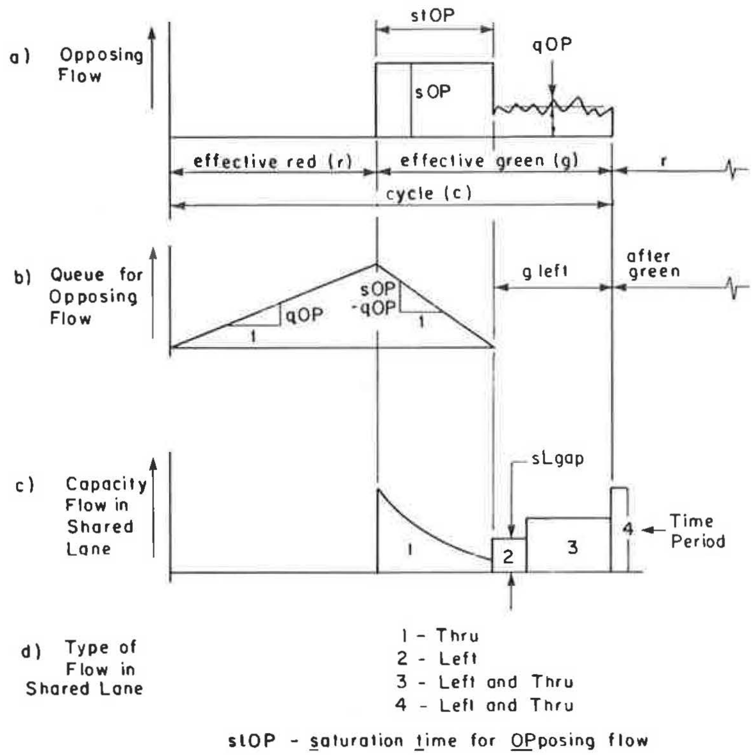

FIGURE 2 Basis for calculating capacity of an opposed, shared, left lane.

sLgap = saturation flow for left-turning vehicles through gaps in the opposing flow.

In time period 3 a mixture of through and left-turning vehicles will proceed with a capacity of

$$LORT3 = [(g - stOP - t2)/3600]/s3 \quad (7)$$

where

LORT3 = left or through vehicles per cycle for time period 3,
s3 = saturation flow rate for period 3 found from the average headway for left-turning and through vehicles, and

$$s3 = 3600/[(\%Lt/\%L) \cdot (3600/sLgap)] + [(1-\%Lt/\%L) \cdot (3600/sL)]$$

The other variables are as before.

Finally, in time period 4, the after-green period, left-turning or through vehicles proceed (LORT4). The maximum number depends both on the geometry of the intersection and on the characteristics of the drivers. Maximum values are 1.0 to 2.0 vehicles per cycle and a typical value is 1.5. The minimum value of LORT4 is zero, which occurs either when there are very few left-turning vehicles or when there is very little opposing traffic. Under these conditions the traffic in the left lane is not blocked by left-turning vehicles and the traffic proceeds smoothly for the whole of the effective green period. As a result there are no blocked vehicles to move after the green. Thus, LORT4 is

$$LORT4 = 1.5 \text{ if } [(3600 \times \%Lt)/(sLgap \times \%L)] > 1.8 \quad (8)$$

$$LORT4 = 1.5\ [(3600 \times \%Lt)/(sLgap \times \%L)] \text{ otherwise}$$

$$(\text{s.t. } LORT4 \geq 0)$$

where

LORT4 = left-turning or through vehicles per cycle in period 4,
%Lt = percentage left turns in the movement, and
%L = percentage of movement in the left lane.

In Equations 6, 7, and 8 the value of sLgap, the opposed left-turning flow, must be estimated. This is usually based on the following formula (2,5):

$$sLgap = qOP(gap) \times \{[\exp(-A \times qOP'(gap))]/[1 - \exp(-B \times qOP'(gap))]\} \quad (9)$$

where

sLgap = saturation flow for opposed left turns in vehicles per hour,
qOP'(gap) = opposing flow for gaps in vehicles per second,
qOP(gap) = opposing flow in vehicles per hour,
A = average critical gap acceptance for the first left-turning vehicle in any gap, and
B = average critical gap acceptance for any following left-turning vehicles in any gap.

Equation 9 is for the situation where there is no limit to the size of gaps in the opposing flow. However, in the most extreme case, a gap in the opposing traffic cannot be greater than (g-stOP) or (gleft) seconds. Moreover, when the opposing flow is in only one lane, the opposing flow cannot be less than a minimum value. When this is recognized, sLgap is less than the value given by Equation 9, and, assuming either an exponential or shifted exponential distribution, sLgap can be estimated as follows:

$$sLgap = qOP(gap)\{\exp[-(A/qOP')]$$

$$+ \exp[-(A + B)/qOP'] + \exp[-(A + 2B)/(qOP')]$$

$$+ \ldots\} \quad (qOP \text{ is multilane})$$

$$sLgap = qOP(gap)\ \{\exp[-(A - Hmin)/(qOP' - Hmin)]$$

$$+ \exp[-(A + B - Hmin)/(qOP' - Hmin)]$$

$$+ \ldots\} \quad (qOP \text{ is 1 lane}) \tag{10}$$

where

- sLgap = saturation flow for opposed left turns,
- qOP(gap) = opposing flow for gaps (vph),
- qOP' = opposing flow for gaps (sec/vehicle),
- A,B = gap acceptance parameters [A = 4.5 sec for one lane (+ 0.5 sec/additional lane) and B = 3600/sL for one lane (+ 0.5 sec/additional lane)],
- Hmin = minimum headway for single lane flow 2 (seconds), and
- + ... = terms continue while $A + nB \leq$ gleft.

Given T1, L2, LORT3, and LORT4, the capacity of the left lane per cycle or per hour can be found. At capacity for the combined movement (e.g., movement [(6)(7)] of Figure 1), the capacity of the left lane must correspond to %L, the percentage of the approaching traffic choosing the left lane. If this is not the case, then %L is changed and Equations 4-8 and 10 must be re-evaluated with the new value of %L. This iterative procedure continues until %L does not change. The capacity of the left-turn lane has then been estimated and a check is made to see that there is capacity for left turns:

$$\%L > \%Lt \tag{11}$$

Finally, the LTE can be calculated by

$$LTE = \{[sL \times (g/3600) - (T1 + L2 + LORT3 + LORT4)]/[(\%Lt/\%L) \times (T1 + L2 + LORT3 + LORT4)]\} + 1 \tag{12}$$

where LTE = left-turning vehicles' equivalent in terms of through cars.

Figure 3 shows an example calculation of an LTE. In Figure 3 the initial estimate of the percentage of traffic in the left lane (%L) was very accurate and no further iterations were necessary. Had this not been the case, further calculations would have been needed. This process is not onerous if a computer program is available, but for hand calculations it is clearly not very useful and some other procedures are needed. In the remainder of this paper, tabulated results of LTE values as calculated by the proposed equations for opposed, shared, left-turn lanes are presented, and these results are compared with those in the literature.

Tabulated Values of LTE

At the outset it should be recognized that LTE values will depend on the gap acceptance parameters and the number of vehicles after green. These will vary among situations. Table 1 gives the LTE for some typical situations calculated using Equations 4, 5, 10, 6, 7, and 8. In addition, Table 1 provides the LTE estimates for opposed left turns in exclusive left-turn lanes given by both the old Australian method (2) and the new Australian method (1).

The new Australian method suggests that "when the opposed turning vehicles and through vehicles share the same lane, the saturation flow be calculated

Data

qOP	= 600 vph	A	= 5 sec.
qOP(gaps)	= 600 vph	B	= 3600/1440
sL	= 1440 vph	g	= 24 sec.
sOTH	= 1500 vph	c	= 60 sec.
SOP	= 1550/lane	RTE	= 1.0
%Lt	= 10%	2	Opposing lanes
%Rt	= 10%		

Calculations

Equ (3) $\quad stOP = 600 \dfrac{(60 - 24)}{(3100 - 600)} = 8.6$ sec.

Assume %L = 41%

Equ (4) $\quad T1 = \sum_{i=1}^{3} (1-(.1/.41))^{i} = 1.76$ thru vehicles/cycle

Equ (5) $\quad L2 = 1.76\ (10/41)/(1-(10/41)) = .57$ left veh./cycle

Equ (10) $\quad sLgap = 600(e^{-5/6} + e^{-8/6} + e^{-11/6} + e^{-14/6}) = 559$ vph

Equ (6) $\quad t2 = .57 \times (3600/559) = 3.7$ sec.

Equ (7) $\quad s3 = 3600/((\frac{10}{41} \times \frac{3600}{559}) + ((1 - \frac{10}{41}) \times \frac{3600}{1440}))$

$= 1040$ vph

$LORT3 = \dfrac{(24-8.6-3.7)}{3600} \times 1040 = 3.38$ veh/cycle

Equ (8) $\quad \left\{3600 \times \dfrac{\%Lt}{SL*\%L}\right\} = \dfrac{3600 \times 10}{559 \times 41} = 1.57$, thus

$LORT4 = 1.5(1.57/1.8) = 1.31$ veh/cycle

Left lane capacity = T1 + L2 + LORT3 + LORT4

= 1.76 + .57 + 3.28 + 1.31 = 7.02 veh/cycle

or = 427 vehicles/hour

Capacity of Other lane = (24/60) 1500 = 600

Check % in left lane = (422/(422/600))x100 = 41.3% (close enough to 41% assumed)

Check capacity for % left turns : 41.3% > 10% - o.k.

Equ (12) $\quad LTE = \dfrac{1440(24/3600) - (1.76+.57+3.28+1.31)}{(10/41)(1.76+.57+3.28+1.31)} + 1$

$= 2.51$

FIGURE 3 Example calculation of the capacity of shared, opposed, left-turn lane and LTE.

. . . [in] the same method as . . . exclusive lanes" (1,p.15). The method is to adjust the left-turning vehicles only by the LTE found from

$$LTE = [(sL/3600)g]/[(sLgap \cdot gleft) + LORT4]$$

where

- sLgap = [qOP'(gap) exp(-A qOP'(gap))]/[1 - exp(-B qOP'(gap))] (vehicles/second) (see Equation 9),
- g = effective green time for the movement, and
- gleft = g - stOP - t2.

The values of sL, sOP, A, and B are the same for all values of LTE in Table 1. This removes any variation in results caused by different characteristics of drivers. For example, Michalopoulos (3) in studying exclusive left-turn lanes did not control for the parameters used to reflect driver characteristics in different countries when this was in fact the only difference between several of the models he was evaluating. The LTE results given in Table 1 for Miller's procedure (2) are based on the same parameters for driver characteristics as the proposed method. Miller's LTE values were developed for exclusive left-turn lanes but are recommended for use for left-turning vehicles only in shared left-turn lanes. The recommended equation (2) is

TABLE 1 Comparison of Left-Turn Equivalencies for Opposed, Shared, Left-Turn Lanes (sL = 1440; sOP = 1550; A = 4.5, 5.0; B = 2.5, 3.0)

	ONE opposing lane (A=4.5; B=2.5)		TWO opposing lanes (A=5; B=3)		
c = 60	(g/c)=.4	(g/c)=.6	(g/c)=.2	.4	.6
qOP = 400	2.9 2.7 2.6 2.0 2.4	1.8 1.6 1.7 1.6 1.9	3.2 2.7 2.7 1.8 1.9	1.9 1.8 1.9 1.7 1.7	1.7 1.6 1.7 1.6 1.7
600	6.2 6.0 6.0 5.4 5.6	3.0 2.8 2.6 2.3 2.7	2.4 3.1 3.2 1.8 1.9	2.5 2.5 2.4 2.2 2.3	2.1 2.0 2.0 2.0 2.1
800	*	6.2 5.2 5.2 4.1 4.7	*	3.3 3.3 3.2 3.0 3.0	2.6 2.6 2.6 2.5 2.5
c = 90					
qOP = 400	3.4 2.8 2.6 2.3 2.8	2.0 1.8 1.8 1.7 2.1	3.6 3.4 3.2 2.3 2.3	2.0 1.9 1.9 1.8 1.9	1.7 1.7 1.7 1.7 1.8
600	8.7 9.4 9.4 7.4 7.8	3.4 3.0 2.9 2.5 3.0	4.3 4.7 4.7 4.4 4.4	2.8 2.7 2.6 2.5 2.5	2.3 2.2 2.2 2.2 2.2
800	*	7.2 6.2 6.1 4.8 5.6	*	4.1 3.6 3.6 3.5 3.5	2.8 2.8 2.8 2.8 2.8
c = 120					
qOP = 400	3.7 2.9 2.7 2.4 3.0	2.2 1.9 1.8 1.7 2.1	3.9 3.6 3.5 2.6 2.7	2.1 2.0 2.0 1.9 2.0	1.9 1.8 1.8 1.8 1.9
600	12.4 12.4 12.4 9.2 9.8	3.8 3.2 3.0 2.6 3.2	6.3 6.2 6.2 5.7 5.7	3.1 2.8 2.7 2.7 2.7	2.4 2.3 2.3 2.3 2.3
800	*	7.6 6.9 6.9 5.2 6.2	*	4.6 3.9 3.9 3.9 3.9	3.1 3.0 2.9 2.9 2.9

LEGEND

* opposing flow exceeds capacity

(2.7) - not enough capacity for left turns

Table Entries

Proposed Equation	
10% lefts	
20% lefts	new Australian method *(1)*
30% lefts	old Australian method *(2)*

$$LTE = [(sL/3600) \times g]/[((f/B) \times gleft) + LORT4] \quad (13)$$

f was determined by simulation (i.e., where qOP is 0, 200, 400, 500, or 800, f is 1.0, .81, .65, .54, or .45, respectively)

where

B = average unopposed headway for the lane (e.g., 3600/sL),
g = effective green time for the movement, and
gleft = g - stOP.

The results given in Table 1 for the proposed method and the Australian results differ because of three considerations:

1. The proposed method considered the movement of through vehicles during stOP (saturation flow period for the opposing traffic);
2. The proposed method estimates sLgap only for the available gap sizes; and
3. The proposed method discounts LORT4 (flows after green) when the flow in the left lane approaches a free flow condition because of a low percentage of left turns or a low opposing flow.

Because the two Australian methods (Table 1) were derived for exclusive left-turn lanes, they do not vary with the percentage of left-turning vehicles for the approach. The proposed method with 30 percent left turns is the closest result to an exclusive left-turn lane. All three methods give similar values, with Miller's method generally giving values closer to those of the proposed method. For higher cycle times and large g/c ratios all methods are essentially equivalent for heavy left-turn movements in the left lane.

With lower, more typical values of the percentage of left turns (Table 1) the use of LTE from an exclusive left-turn lane analysis underestimates the effective LTE of the left-turning vehicles. The use of the proposed LTE values given in Table 1 is preferred.

Gap Acceptance Parameter Values

In the proposed method, the LTE given in Table 1 will vary with sL, the saturation flow for the shared left lane and the gap acceptance parameters A (initial vehicle) and B (following vehicles). The suggested values were taken from average North American values given in Table 2 (1). The proposed method varies gap acceptance parameters A and B as the number of opposing lanes is varied.

TABLE 2 Gap Acceptance Parameters Used in the Literature (*1*)

	Initial Gap A (sec)	Saturation Flow sL (vph)	Following Headway B (sec)	LORT4 After Green
Gordon and Miller (*8*)	5	1,200	3.0	1.5
Webster and Cobbe (*4*)	5 and 6 (1 & 2 lanes)	1,400	2.5	
Fambro et al. (*5*)	4.5	1,440	2.5	1.6
Peterson et al. (*9*)	4.8-5.8		0.54A	

Michalopoulos (3) gives two regression equations for finding sLgap based on observed data for five intersections in upstate New York. The equations for signalized intersections are

$$sLgap = -1.245\ qOP + .000\ 014\ qOP^2\ A + 1165 \quad \text{(1 lane)} \tag{14}$$

$$sLgap = -0.875\ qOP + .000\ 012\ qOP^2\ A + 1145 \quad \text{(2 lanes)} \tag{15}$$

Table 3 gives some selected comparisons of sLgap as estimated by the proposed method with those predicted by Equations 14 and 15. The sLgap estimates of Michalopoulos have a constant value and do not vary with the percentage of left turns. There is good agreement between the two results for two-lane opposing traffic and longer cycle lengths. The calculated results vary with the situation, and the Michalopoulos values do not. No information is given about signal conditions; however, it appears that in general the proposed typical gap acceptance parameters produce results that are comparable with those observed by Michalopoulos.

OTHER ANALYSIS METHODS

Not much data has been found in the literature related to left-turn equivalencies for shared left-turn lanes. The 1965 Highway Capacity Manual (HCM) (6) provides an adjustment factor for an approach with a shared left-turn lane. If a 12-ft lane width is assumed, then Table 6.5 of the HCM implies a constant value for LTE of 4.0 for a one-lane approach containing the shared left lane and a value of 2.0 for a two-lane approach. The present study has investigated only a two-lane approach for the shared left lane.

For an exclusive left-turn lane the HCM (6) suggested a value of sLgap:

$$sLgap = 1200 - qOP(gap) \tag{16}$$

where the opposing flow for gaps assumes 5 percent trucks. Moreover, if the left-turn capacity due to sLgap was less than LORT4, then the LORT4 capacity was used. However, LORT4 and sLgap would not be used in combination.

The proposed TRB critical lane analysis (7) deals with shared left turns in two different ways. At step 7 in the procedure for checking for critical lanes an LTE for either a shared or an exclusive left-turn lane is proposed:

Flow qOP	LTE
1-299	1
300-599	2
600-999	4
>1000	6

Comparison with the data in Table 1 suggests that these values are of appropriate magnitudes, but these values do not respond to changes in the percentage of left turns, the number of opposing lanes, and so forth.

In the proposed TRB critical lane analysis (7) at step 4 there is a left-turn check to establish the adequacy of the left-turn capacity. It is similar to the HCM 1965 in that it uses the maximum of LORT4 or the capacity due to sLgap but not both. The proposed formula for sLgap (7) is

$$sLgap = [(g/c)(1200)] - qOP(gap) \tag{17}$$

The original British procedure for saturation flow analysis suggested two ways to deal with shared, opposed, left-turning vehicles (4). The first suggestion was to use an LTE of 1.75 for all left-turning vehicles. The second procedure was to use sLgap for a period of gleft and then set up an extended green phase to handle any excess traffic. This method did not deal with through movements

TABLE 3 Comparison of Vehicles per Hour as Calculated and as Observed (*3*)

qOP	One Lane g/c = .4	One Lane .6	Two Lane .4	Two Lane .6
c = 60				
200	764/898	1006/898	652/992	823/992
600	271/421	684/421	589/662	657/662
1000	*	*	316/350	440/350
c = 90				
200	949/898	1118/898	803/992	924/992
600	52/421	691/421	643/662	662/662
1000	*		394/350	441/350
c = 120				
200	1053/898	1159/898	886/992	962/992
600	67/421	691/421	657/662	663/662
1000	*	*	423/350	441/350

as calculated/Equ (14) or (15)

* opposing flow greater than capacity

during stOP nor did it explicity suggest the use of LORT4, the flow after green.

The British method was extended by Miller (2) who developed LTE for exclusive left-turn lanes and then recommended its use for shared lanes. The left-turn capacities were estimated by sLgap for gleft and to this was added LORT4 for the after-green flow. The value of sLgap was found from simulation, and Table 1 gives the resulting LTE. Recently the Australian procedure has been revised in that sLgap is estimated by Equation 9 rather than Equation 13, and gap acceptance parameter and saturation flow values were changed. The basic procedure was unchanged.

Fambro et al. (5) applied the Australian procedure to traffic in Texas. They estimated gap acceptance parameters and LORT4 after-green flows and found there was good agreement between the observed LTE for exclusive left-turn lanes and the Australian procedure. They also found that below ultimate capacity levels traffic had a tendency to concentrate in one lane of a multilane approach. This tended to increase the estimate of the time of saturation flow for the opposing movement (stOP). This refinement has not been included in the proposed procedure. Fambro et al. (5) estimated the capacity for a shared left-turn lane by assuming a 50-50 split of through and left-turning vehicles in the shared lane. This assumption is very restrictive and is not representative of many situations.

Fambro et al. (5) found, for limited data, that the after-green LORT4 flow was 1.41 vehicles per cycle for separate left-turn lane and 1.03 vehicles per cycle when there was no separate left-turn lane. The proposed method suggests 1.5 vehicles for a shared left lane and these can be left-turning or through vehicles (LORT4).

CONCLUSIONS

A proposed procedure is presented for estimating left-turn equivalents (LTE) for left-turning vehicles in shared left-turn lanes. The method is an extension of the Australian procedure for estimating LTE for exclusive left-turn lanes.

It is proposed that the opposed saturation flow for left-turning vehicles (sLgap) be reduced to reflect the length of available green time (gleft) left after the time of saturation flow for the opposing flow (stOP). These results appear to be consistent with observed results reported in the literature.

It is proposed that the vehicles after green (LORT4) are reduced under conditions where blockage of the shared left lane by left-turning vehicles is not likely to occur.

The results indicate that, for higher cycle times and heavy percentage of left turns, Equation 13 can also be used to estimate LTE, but for other situations it is better to use the proposed method.

It is recommended that field studies be carried out to gather more data on shared lanes because there are few results in the literature. The results indicate that many shared left lanes can have quite high capacities and should be considered as a viable alternative to other approaches such as the use of an exclusive left-turn lane or an exclusive phase.

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