Draft 3-10-04

SIMPLIFIED CAPACITY CONCEPTS FOR ACCESS MANAGEMENT

Prepared for

SIXTH NATIONAAL CONFERENCE ON ACCESS MANAGEMENT
Kansas City, Missouri - 2004

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Revised 8-1-04

ABSTRACT

CAPACITY CONCEPTS FOR ACCESS MANAGEMENT

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Capacity estimates are essential in developing and assessing access management projects and in determining lane requirement for arterial roads. There is an important need for approaches that can quickly respond to changes in site plans and roadway configuration, both in the field and in the office.

The paper presents several capacity concepts that respond to this need and that reflect the uncertainties and variations of future traffic estimates. One approach involves estimating future lane requirements based upon daily traffic volumes per lane and available green-per-cycle ratios.

A second approach shows how signalized intersection capacity can be estimated where vehicles in left lanes move on the same phase as the through traffic. Here, the available green time is allocated between the through movement and the opposing left turns. It is an adaptation of the critical movement procedure that takes into account traffic signal timing.

A third approach describes a simplified technique for dealing with shared left turn lanes at signalized intersections. Results are compared with Australian, Canadian and HCM procedures for typical volume conditions. It shows that shared lanes are typically about 40 to 60 per cent as effective as through lanes.

Finally, the paper identifies other areas where simplified procedures would be useful.

SIMPLIFIED CAPACITY CONCEPTS FOR ACCESS MANAGEMENT

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1. INTRODUCTION

Capacity estimates are essential in developing and assessing access management projects and in determining lane requirement for arterial roads. There is an important need for approaches that can quickly respond to changes in site plans and roadway configurations, both in the field and in the office. This paper presents several capacity concepts that respond to this need and that reflect the uncertainties and variations of future traffic estimates.

2. ESTIMATING AND APPLYING AVERAGE DAILY CAPACITIES

This section shows how future lane requirements can be based upon the daily traffic volumes per lane, and the available green per cycle ratios. The number of lanes that should be provided to meet anticipated traffic demands along an arterial roadway is a discrete number; e.g. 4, 6, or 8 through lanes. The volume-to-capacity comparisons should be rounded upward to determine number of lanes that are needed. For example, when 2.3 lanes are needed in each travel direction, the total number of necessary through lanes becomes 6.0. Hence, whether the V/C ratio results in 4.3, 4.4, or 4.6 lanes, the same number lanes should be provided.

Therefore, in many situations, the average daily capacity per lane provides a reasonable basis for making design decisions. These average daily capacities should be based on actual operating experience.

Average daily freeway volumes of 25,000 to 35,000 vehicles per lane have been recorded. Assuming that 70% of the travel takes place during the busiest 12-hour period, the flows correspond to 17,500 to 24,500 vehicles per lane per 12-hour period – average flow rates ranging from 1400 to 2040 vehicles per lane per hour. The higher value assumes operation at maximum capacity during each hour – an uncommon occurrence. The lower value represents a more common occurrence.

Urban and suburban arterial roadways – unlike freeways – have both marginal and intersectional interference. And there is also lost time at signalized intersections. Accordingly, a value of about 20,000 vehicles per day per hour of green represents a reasonable maximum daily capacity for these roads.

Thus, for a 60 percent green-per-cycle ratio, the daily capacity becomes 12,000 vehicles per lane per day. This number is documented by the 100,000 vehicles per day carried on an 8-lane section of Telegraph Road in the Detroit Metropolitan Area – about 12,500 vehicles per lane per day with a 60% green-per-cycle time. These volumes move at speeds exceeding 35 mph and are suggestive of Level-of-Service "E".

In establishing future lane requirements, it is desirable to provide some capacity reserve. Accordingly, a value of about 16,000 vehicles per lane per day per hour of green is suggested for design purposes. The anticipated future daily volume can be compared with this number to estimate future lane requirements for any green-per-cycle ratio.

Table 1 gives illustrative values for various green-per-cycle ratios. It indicates that additional lanes are needed when daily volumes exceed 8,000 to 12,000 vehicles per lane per day, (depending on the green/per cycle ratio). For design purposes, daily volumes that exceed 6,400 to 9,600 vehicles per lane per day will need additional lanes.

3. PERMISSIVE LEFT TURN LANES

This section describes a simplified procedure for estimating capacities at signalized intersections with permissive left turn lanes. The procedure assumes that the available green time for any phase is shared between the through movement and the opposing left turns. It is similar conceptually to the critical movement procedure and to that for protected left turn lanes.

The resulting capacity estimates are generally comparable to those obtained by the Highway Capacity Manual (HCM)[1] procedures for signalized intersections with protected left turn phases (but appear to be more conservative than those obtained by the established HCM procedure). The method is easy to visualize, simple to use, and well suited for access management and site planning analysis and design.

A. BACKGROUND

There is a complementary relationship between the through and opposing left turn flows when both move on the same phase; the sum of both movements, each expressed on a per-lane basis, must be accommodated. When the through and opposing left turn volumes (both expressed in through passenger car equivalents) are less than the available capacity, there are three basic options for dealing with the "unused" green time.

1. It can be allocated to the through movement.
2. It can be allocated proportionally to both movements. This results in equal volume-to-capacity ratios.
3. It can be allocated to the left turns.

Thus, for a through capacity (with no left turns) of 700 vph, and existing volumes of 400 and 100 for the through and opposing left turns, the "reserve" capacity of 200 vph could be allocated by each of these options. The potential "capacities" would be as follows:

	Through	Left	Total
Case 1	600	100	700
Case 2	560	140	700
Case 3	400	300	700

In many respects, these relationships imply a “surrogate” traffic signal for the left turns, with set phasings for each movement. However, for the permissive case, there is some flexibility in how much capacity can be allocated to left turns.

B. THE BASIC APPROACH

The complementary relationship between through traffic, and the opposing left turns can be applied to any green time, cycle length, and mix of through and opposing left turn volumes.

Assuming that all volumes (flow rates) are expressed in through passenger car units, the capacity can be estimated as follows for a single lane approach.

$$c = \frac{(g - 2l)S}{C} \qquad (1)$$

Where S = saturation flow rate = 1800 vph

C = cycle length seconds

g = green time, seconds

l = lost time 3 to 4 seconds per cycle for each movement

c = capacity in through plus opposing left turn vehicles expressed in passenger car units

There are two lost times per cycle since the opposing left turns can start up only after the through movement clears the intersection. The use of an 1800 vph saturation flow rate, and 4 seconds lost time per movement per cycle are realistic values for planning purposes, since they allow for some commercial vehicles in the traffic.

The “reserve” volume – the difference between the capacity and the actual flows can be allocated by each of the three methods. Illustrative calculations are set forth in Table 2 for 30 seconds of total green time per 60 second cycle for various combinations of through and opposing left turn volumes. The number of opposing left turns (e.g. flow rates) ranges from 50 to 150.

- For volumes less than 50 per hour it can be assumed that the left turns can clear on the yellow interval (e.g. about 1 per cycle) with no adverse impact on the through traffic.

- For volumes more than 150 per hour it can be assumed that some type of protected left turn phasing will be provided.

The effects of multiple lanes on the through movement are straightforward. For purposes of capacity losses due to opposing left turns, the volumes per lane should be used, and the per-lane capacities computed. These can be doubled to yield the effective approach capacity. Thus, if the resulting through lane capacity were 700 vphpl, it would be doubled for a two lane approach.

Approach Capacities. The capacity of a given intersection approach represents the sum of the through capacity and left turn capacity in the same direction of travel. However, the left turn capacity depends upon the opposing through volume stated symbolically.

$c_1 = c_{t(1)} + c_{l(1)}$ (2)

c_1 = the total approach capacity in direction 1

$c_{t(1)}$ is the through capacity in direction 1

$c(l_1)$ is the left turn capacity in direction 1

Each capacity depends in part on the conflicting opposing volumes,

Approach Delay. The uniform approach delay per vehicle represents the weighted average of the delays to same-direction through and left turn traffic. Both can be estimated by the standard delay equations. However, because left turns must wait until the opposing through traffic clears, there is an additional "red" time that must be included. The additional delay for the permissive left turn lane depends upon the number of opposing through vehicles per cycle. Thus, if there were 8 opposing vehicles per lane per cycle, the additional delay would be approximately 2(8) or 16 seconds per cycle.

Application. The application is straightforward. The critical conflict volumes are estimated for each phase. The required capacity is compared with the available capacity and the reserve is then allocated to the two movements and establish the east-west and north-south capacities.

4. SHARED LEFT TURN LANES

Estimating the capacity of shared left turn lanes at signalized intersection is both complex and elusive. The left turns are impeded by opposing traffic, and in turn, may block through traffic in the shared lane. Over the years, several methods have evolved to address this problem. These methods use turn adjustment or blockage factors to reduce saturation flows and capacities as a function of left turn and opposing traffic volumes. Most methods are difficult to use and understand. This section describes a simplified procedure, and compares the results to the procedures used in the U.S., Canada and Australia. It is a synthesis and extension of an analysis contained in a paper entitled "The Capacity of Shared Left Turn Lanes – A Comparative Approach. (2)

A. Overview of Methods

A brief overview and description of the various methods follows.

The **1997 Highway Capacity Manual Method** (1) applies special procedures to calculate left turn adjustment factors for permitted phasing. The procedures apply to both exclusive and shared lanes. The effective green time is divided into three distinct periods: (1) g_f, the period before the first left-turn arrives; (2) g_q-g_f, the period when left turns arrive during the opposing queue and (3) g_u, the period after the opposing queue clears.

A series of equations indicate how g_f and g_q can be obtained as a function of green time, left turns per cycle, lost time, opposing flow rate per lane per cycle; number of opposing lanes, platooning, and the propagation of opposing vehicles in the opposing queue. Another equation shows how the proportion of left turns in the shared lane (presumably as a percent of the vehicles in that lane) can be estimated. Finally, basic equations give the left turn adjustment factors for multiple and single lane approaches. These equations include the effective green time, g_f, g_u, the through car equivalents for left turns, and the proportion of left turns on the approach.

The **Canadian Method** (3) set forth in The Canadian Capacity Guide calculates the left turn saturation flow as if it were for a permissive lane. Next, it allocates the saturation flow to the available lanes. It then calculates the saturation flow for the shared lanes by weighting the proportions of through and left turns by their perspective saturation flows (or headways). Finally, capacity is computed by applying the ratio of (a) the actual green time plus one second to (b) the cycle length.

The **SIDRA (Australian) Method** (4, 5, 6) (permissive) uses direct and explicit approaches to predict individual lane capacities, and then adds capacities to obtain the total capacity of a lane group. The method uses a gap-acceptance-based opposed turn model to determine the left turn saturation flow and the associated lost (effective red) time due to opposing queue clearance (blocked) times.

While the SIDRA model is similar to the HCM model in identifying distinct intervals of green period, it differs in predicting the capacity for each interval and in simply adding them to find the total capacity for the lane. The gap-acceptance model considers the number of opposing lanes in assessing the unsaturated part of the opposing movement green period. It also considers the actual number of departures after the end of the displayed green period.

Platooned arrivals affect opposed turn capacities since the queue clearance times and opposing flow rates change. With good signal coordination, the proportion of traffic arriving during the green period (therefore the opposing flow rate after queue clearance) increases, and the opposing queue clearance time decreases. For each case, SIDRA computations were developed for random arrivals and platooned arrivals with 80 percent of traffic arriving during green on both opposed and opposing approaches.

The SIDRA computations use the HCM version of SIDRA. This version is calibrated according to HCM model parameters; however, the general SIDRA model applies (i.e., lane-by-lane calculations, SIDRA gap-acceptance and lane blockage formulas).

Levinson (7) developed a simplified approach to through and shared lane capacities that was reported in Transportation Research Record 1225[(7)]. A series of equations assume that the capacities of shared-lanes at signalized intersections are reduced by either (a) the blockage effect of left turns in the same direction or (b) the conflicts with opposing left turns; the capacity of a shared lane represents the minimum of these two computations.

The discussions that follow describe this simplified approach, compares it with the other methods, and gives comparative results for the condition when there are 100 left turns per hour.

B. Description of Simplified Method

The basic equations for the simplified method are shown in Table 3. These equations subtract "non-available" green time rather than applying a multiplicative reduction factor. They estimate the capacity per traffic signal cycle on a lane-by-lane basis for four typical conditions.

(1) Through lane with no opposing left turns, or shared lanes with no opposing traffic, (e.g. one-way street).

(2) Through lane with opposing left turns (this applies when there are heavy defacto opposing left turns). It is assumed that the through movement takes precedence over conflicting left turns, then condition one applies.

(3) Shared lanes with a single opposing traffic lane.

(4) Shared lanes with two or more opposing traffic lanes.

A "modified" blockage for single approach lanes emerged from initial comparisons with other models. The revised equation, $c_s = g - (\underline{BO_2 - l_2})$ is subject to the constraint that c_s is never more than g.

Initially, the opposing traffic per lane was based upon the actual number of opposing lanes, e.g. on a two lane approach, the volume would divide equally among the two lanes. However, this was found to overstate capacity along multi-lane roads. Accordingly, factors were developed to account for the uneven distribution of traffic among opposing lanes.

The effective opposing traffic per lane is computed by dividing the total opposing traffic by the following factors, when there are shared left-turn lanes on that approach:

1 lane	1.0
2 lanes	1.5
3 lanes	2.5

The following values of the blockage or impedance factors, B were derived from probability analysis:

Left Turns Per Cycle	**B**
0.5	0.30
1.0	0.48
2.0	0.72
3.0	0.84
4.0	0.90
5.0	0.96
6.0 or more	1.00

C. Summary Comparison

The general features of the four procedures are compared in Table 4.

- The Canadian and SIDRA models produce information on capacity, delay, and queues; the HCM model gives capacity and delay as outputs; the Levinson model just gives capacity.

- The Canadian, SIDRA and Levinson models obtain capacity by individual lanes; the HCM gives lane group capacity.

- The SIDRA and HCM models incorporate capacity adjustments for platooned arrivals.

- The HCM and Canadian models utilize saturation flow adjustment factors, while the SIDRA and Levinson models reduce the effective green time available.

- The Levinson and Canadian models are easy to understand and use. The HCM and SIDRA models are more complicated, require computerized applications, and are not well suited for field computations.

D. Assumptions and Results

A sensitivity analysis of the various shared left turn models was performed by comparing capacities for 16 sets of conditions. Overall, more than 700 individual computations were performed. Computations were initially made for the 1994 Highway Capacity Manual (HCM) procedures. Since then, adjustments were made in the HCM factors, and the analyses were repeated using the 1997 adjustments; however, some of the 1994 HCM results were retained for comparative purposes. In addition, several calculations for the SIDRA and the Levinson models were refined.

The basic input assumptions for the present comparisons were as follows:

(1) Shared left-turn and through lanes, on single and two-lane approaches.

(2) A basic saturation flow of 1,800 vehicles per lane per hour. This corresponds to a 2-second headway.

(3) Zero right-turn volumes.

(4) Effective green times of 30 seconds for a 60-second cycle.

(5) Two basic volume scenarios were analyzed – in the equal volume scenario, the flow rates were the same in both directions. In the unequal scenario, the flows were heavier in one direction.

(6) Under the equal volume scenario, the peak 15-minute flow rates for both through traffic and left turns were assumed to be the same in each direction. The through volumes were 600 vph for the single lane approach and 1200 vph for the two-lane approach assuming no left turns. The left turns were then assumed as 100 vph resulting in 500 through vph on the single lane approach and 1100 vph on two lane approach.

(7) Under the unequal turn scenarios the peak 15-minute flow rates in each direction of travel, in vph were assumed to be as follows, assuming no left turns.

	Eastbound Direction 1	Westbound Direction 2
Single-Lane Approach	600	400
Two-Lane Approach	1200	800

The left turn volumes for direction 1 were 100 vph. The left turn volumes for direction 2 were 60 vph.

Tables 5, 6, 7 and 8 compare the results of the four cases.

- For the single lane approaches with equal volumes in both approaches the simplified method falls in the middle of the 6 computations. The 1997 HCM value appears to be an outlier – giving at least 100 more vph than the other three methods.

- For the two-lane case with equal volumes on both approaches, the simplified method gives the highest capacities – about 30 vph more than that for the Canadian method.

- For the single-lane case with unequal volumes, the 1997 HCM is the highest in both the major and minor directions. The simplified method is about the same as the Canadian method in the "heavy" direction; it is about 50 vph higher than the SIDRA method.

- For the two-lane case with unequal volumes on each approach, the simplified method gives the highest capacities in both the "heavier" and "lighter" travel directions. It is about 50 vph higher than the HCM in the heavy direction, and about 40 vph in the lighter direction.

Overall, the simplified method provides reasonable results for both planning and operations purposes. A slight downward adjustment in the lane-utilization factors (e.g. for 2 lanes from 1.5 to 1.4) would bring the results closer to the other models for the multi-lane cases.

The relative efficiencies of shared left turn lanes – based on the examples given and also with 150 left turns as shown in Table 9. These values suggest that shared lanes on single-lane approaches are about 65 to 70% as effective as a through lane. On a two-lane approach, they can be 40% as effective. These values can be used as a "first estimate" of capacities for initial planning purposes.

IMPLICATIONS AND EXTENSION

The various "simplified" approaches to estimating highway capacity provide reasonable results for access management analysis, planning, and design. There are either several other areas where simplified methods should be considered. These include (but are not limited to) two way "stop" controls, "four way stop controls," and "weaving" sections along freeways and arterial roadways.

ACKNOWLEDGEMENTS

The insights of Professor Elena Prassas of the Polytechnic University, New York are appreciated.

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TABLE 1

TYPICAL DAILY CAPACITY VALUES

Uninterrupted Flow Capacity	Green/Cycle		
	40%	50%	60%
20,000/lane/day (E)	8,000	10,000	12,000
16,000/lane/day (C, D)	6,400	8,000	9,600

Source: Computed

TABLE 2

<u>CAPACITY ANALYSIS</u>
<u>30" GREEN, 60" CYCLE</u>
<u>EQUIVALENT THROUGH CAR UNITS</u>

Capacity = 660/vph

ITEM	**CASE**					
	1	**2**	**3**	**4**	**5**	**6**
Through Volume	400	400	400	500	500	500
Opposing Left Turn Volume	50	100	150	50	100	150
Total Volume	450	500	550	550	600	650
Reserve Volume[(1)]	210	100	110	110	60	10
<u>CONDITION 1</u> (Reserve Volume Allocated to Through Movement)						
Through Capacity	610	560	510	510	560	510
Left Turn Capacity	50	100	150	50	100	150
Total Capacity	660	660	660	560	660	660
<u>CONDITION 2</u> (Reserve Volume Allocated Proportionately)						
Through Capacity	587	528	480	600	550	508
Left Turn Capacity	73	132	180	60	110	152
Total Capacity	660	660	660	660	160	660
<u>CONDITION 3</u> Reserve Volume Allocated to Left Turns)						
Through Capacity	400	400	400	500	500	500
Left Turn Capacity	260	260	260	160	160	160
Total Capacity	660	660	660	660	660	660

Source: Computed – Capacity (660) minus total volume.

TABLE 5

<u>30' CYCLE 60" GREEN EFFECTIVE</u>
<u>EQUAL TURNS SCENARIOS</u>

SINGLE LANE APPROACH
100 LEFT TURNS/HOUR
500 THROUGH

	Capacity	Rank
1994 HCM	632	1
1997 HCM	790	6
Canada	647	5
SIDRA Random Arrivals	635	2
SIDRA 80% Arrive During Green	640	4
Levinson	616	3
Average	660	

Note: Rankings from Low to High

Source: (2)

TABLE 6

30” EFFECTIVE GREEN 60” CYCLE
EQUAL TURNS SCENARIO
2 LANE APPROACH
1100 THROUGH
100 LEFT TURN

	Capacity	Rank
1997 -2000 HCM	1231	3
Canada	1255	4
SIDRA Random Arrivals	1034	2
SIDRA 80% Arrive During Green	1033	1
Levinson	1288	5
Average	1163	

Note: Rankings from Low to High

Source: (2)

TABLE 7

SINGLE LANE APPROACH
60" CYCLE 30" EFFECTIVE GREEN

	EASTBOUND 500 THROUGH 100 LEFT **WESTBOUND 340 THROUGH 60 LEFT**		**WESTBOUND 340 THROUGH 60 LEFT** **EASTBOUND 500 THROUGH 60 LEFT**	
	Capacity	Rank	Capacity	Rank
HCM 1994	727	3	659	3
HCM 1997 2000	821	5	818	5
Canada	727	2	634	1
SIDRA Random Arrivals	769	4	659	2
Levinson	703	1	712	4
	___		___	
Average	749		697	

Note: Rankings from Low to High

Source: (2)

TABLE 8

TWO APPROACH LANES
60” CYCLE 30” EFFECTIVE GREEN

	EASTBOUND 1100 THROUGH 100 LEFT TURNS		WESTBOUND 740 THROUGH 60 LEFT TURNS	
	Capacity	Rank	Capacity	Rank
1997 HCM	1369	3	1262	3
Canada	1189	1	1189	2
SIDRA	1200	2	981	1
Levinson	1416	4	1300	4

Note: Rankings from Low to High

Source: (2)

TABLE 9

TYPICAL VALUES FOR THE EFFICIENCY OF SHARED LEFT TURN LANES

	Left Turn Volumes	
	100	150
Single Lane Approach	0.70	0.65
Two Lane Approach	0.40	0.25

Source: Computed
(Equal volume scenarios)