

REPRINT

Capacity of a shared lane

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NOTE:

This paper is related to the intersection analysis methodology used in the SIDRA INTERSECTION software. Since the publication of this paper, many related aspects of the traffic model have been further developed in later versions of SIDRA INTERSECTION. Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further research.

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CAPACITY OF A SHARED LANE

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ABSTRACT

The traditional 'adjustment factor' and the new 'lane interaction' methods for estimating the capacity of a shared lane at a signalised intersection are discussed. The adjustment factor method is needed when the shared lane is combined with adjacent lanes into a lane group with the same departure characteristics. The lane interaction method as implemented in the SIDRA program employs a direct and explicit method to predict individual lane capacities without using adjustment factors. The method allows for differences in the departure characteristics of shared lanes (e.g. opposed turns and through traffic) and the adjacent lanes (e.g. through traffic only) by treating the intervals of lane blockage as effective red (lost time). This improves the prediction of not only the queue lengths and delays but also the short lane and opposed turn capacities. A generalised model of lane blockage is employed for predicting the number of departures before being blocked. A full intersection example is given with output from SIDRA to explain the lane interaction method. Using this example, the relation between the lane interaction and adjustment factor methods are explained. It is shown that substantial differences in capacity and performance predictions and timing solutions may result from the simplifying assumptions used to derive turn equivalents/adjustment factors. The adjustment factor method has been relevant to the simple manual analysis methods of the past. Computerised analysis techniques have now found widespread use in the traffic engineering profession, and the method of modelling individual lane capacities explicitly and directly can be adopted without difficulty.

INTRODUCTION

1. The traditional methods of estimating the capacity of a shared lane at a signalised intersection employ various adjustment factors, or turn equivalents, to allow for different departure characteristics of different flows in the shared lane (Webster and Cobbe 1966; Miller 1968; Allsop 1976; Peterson, Hansson and Bang 1978; Akcelik 1981; Teply 1984; Transportation Research Board 1985). This paper introduces the term 'lane interaction' to describe a new method of modelling a shared lane. In this method, a shared lane is considered to belong to two different movements that may block each other or depart together at different times during the signal cycle.

2. The method has been developed for, and implemented in, the SIDRA program (Akcelik 1984,

1986, 1987) in response to feedback from practicing engineers who identified various real-life situations that could not be modelled efficiently and accurately using the traditional turn equivalent/adjustment factor method.

3. Although the SIDRA method has the same base as the traditional methods, it is significantly different in terms of the details of formulation and results. It is a generalised method which can be applied to simple as well as complicated cases of shared lane capacity estimation. It models interactions in a shared lane explicitly without resorting to the use of adjustment factors. Importantly, it is based on a **lane-by-lane** method of capacity estimation as opposed to the traditional methods that combine various lanes of an approach road together as a **lane group** so as to apply various correction factors to allow for different traffic characteristics.

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LANE BLOCKAGE

4. At signal-controlled approach roads, it is common for two movements which share the same lane to have different signal timing characteristics because they receive right of way at different times during the signal cycle, or because one of the movements has to give way to opposing traffic or to pedestrians. A complicated case is a lane shared by through and turning traffic where turning traffic can depart freely in one green period (protected turns with a green arrow) but has to filter through the opposing traffic in another green period (permissive turns with a green disc) while the through traffic can depart freely during both green periods. In this case, there is not a clearly defined green period for the shared lane since the two movements will block each other and will depart together at different times. The departure pattern of such a lane is different from an adjacent lane which has, say, through traffic only (see the example given later in this paper). In such cases, the accuracy of the traditional method of combining these lanes together as a lane group which has the same departure pattern is limited.

5. The early method described by Peterson et al. (1978) used the lane blockage method for the special case of a shared lane with opposed left turns (driving on the right). Hegarty and Pretty (1982) applied the lane blockage method to the left-turn slip lanes (driving on the left) using a more general model compared to Peterson et al (1978). The modelling of 'capacity due to departures before being blocked' used in SIDRA is a generalised application of the model described by Hegarty and Pretty (1982). The SIDRA method applies to any shared lane case with any combination of signal phasing/timing characteristics of the two movements interacting in the shared lane.

6. The SIDRA method treats the intervals of lane blockage in shared lanes as effective red time (lost time) unlike the traditional methods which keep the green times unaffected but adjust saturation flows down in order to allow for capacity losses. The lost time method is expected to give better estimates of queue length and delay. Better estimation of queue length, in turn, improves the capacity prediction for short lanes (lanes of limited length due to physical reasons or parking on the approach road). Opposed turn capacity estimation is also improved by better modelling of the departure patterns of the opposing traffic lanes. With this method, not only the opposed turn cases (left or right turn) but also the cases of pedestrian interference and bus stop or parking interferences can be modelled as effective red times rather than as saturation flow reduction factors.

7. On the other hand, when several lanes of an approach road are combined as a lane group for the purposes of capacity estimation, the use of through car equivalents, opposed turn equivalents, right-turn or left-turn adjustment factors, etc. is necessary since the differences in the effective green and red times of individual lanes cannot be allowed for. The limitations of the method of modelling shared lanes using adjustment factors can be better understood in the light of the lane interaction method described in this paper.

8. The discussion applies equally to the conditions of left-hand and right-hand driving rule of the road although the intersection example given in this paper considers the right-hand driving rule as in the U.S.A. and Europe.

SHARED LANE CAPACITY WHEN THERE IS NO DIFFERENCE IN TIMING CHARACTERISTICS OF INTERACTING MOVEMENTS

9. The traditional adjustment factor/turn equivalent methods of capacity estimation for shared lanes are suitable for the case when the movements in a lane have no difference in signal timing characteristics, i.e. when the effective green and red times are the same. The traditional method given in ARR No. 123 (Akcelik 1981) is explained by means of an example given in Table I. In this example, the basic (ideal) saturation flow (s_b) for a lane with left-turning and through vehicles including both light (LV) and heavy (HV) vehicles is 1800 through car units per hour (tcu/h). The tcu equivalent (e_i) for vehicle type i , converts the basic saturation flow to saturation flow in vehicles per hour:

$$s_i = s_b / e_i \tag{1}$$

where s_i is the saturation flow for traffic consisting of vehicle type i only. In Table I, the tcu equivalent for left-turning light vehicles is $e_i = 1.25$ tcu's per vehicle. In this case, the saturation flow of a lane consisting of left-turning light vehicles only would be $s_i = 1800 / 1.25 = 1440$ veh/h.

10. To find the mixed stream saturation flow, a traffic composition factor (a composite tcu equivalent) can be calculated as the ratio of a weighted flow to the total flow from

$$e_c = (\sum e_i q_i) / q = \sum p_i e_i \tag{2}$$

where q is the total flow ($= \sum q_i$), q_i is the flow of vehicle type i , and p_i is the proportion of flow type i ($p_i = q_i / q$).

The saturation flow of the traffic stream is then

$$s = s_b / e_c \tag{2a}$$

For the example in Table I, $s = 1800 / 1.225 = 1469$ veh/h is found.

11. The lane saturation flow can also be calculated from saturation headways (h_i) weighted by flow proportions (p_i):

$$h_s = \sum p_i h_i \tag{3}$$

where $h_i = 3600 / s_i$ and h_s = saturation headway for the traffic stream (h_i and h_s in seconds). Then,

$$s = 3600 / h_s \tag{3a}$$

In Table I, $s = 3600 / 2.45 = 1469$ veh/h is found.

12. The above relationships were explained in ARR No. 123. Another relationship which can be used to calculate a mixed lane saturation flow is

$$y = \sum y_i = \sum (q_i / s_i) \tag{4}$$

TABLE I

A shared lane with mixed flows ($s_p = 1800$ tcu/h)

Movement	Left turning		Through		
	LV	HV	LV	HV	Composite
Vehicle type	LV	HV	LV	HV	Composite
Arrival flow, q_i	200	50	650	100	$q = 1000$
tcu equivalent, e_i	1.25	2.5	1.0	2.0	$e_c = 1.225$
Weighted flow, $e_i q_i$	250	125	650	200	$\sum e_i q_i = 1225$
Saturation flow, s_i	1440	720	1800	900	$s = 1469$
Saturation headway, h_i	2.5	5.0	2.0	4.0	$h_s = 2.45$
Flow proportion, p_i	0.20	0.05	0.65	0.10	$\sum p_i = 1.0$
Weighted headway, $p_i h_i$	0.50	0.25	1.30	0.40	$\sum p_i h_i = 2.45$
Flow ratio, y_i	0.1389	0.0694	0.3611	0.1111	$y = 0.6806$

where y is the well known 'flow ratio' parameter. This relationship is interesting since it explains the flow ratio of a lane as the sum of flow ratios of various flow types in the lane. The saturation flow for the lane can be calculated from

$$s = q / y = q / \sum (q_i / s_i) \tag{4a}$$

where q is the total arrival flow for the lane ($= \sum q_i$). For the example in Table I, $s = 1000 / 0.6806 = 1469$ veh/h.

13. The flow ratio method for the calculation of shared lane saturation flow is attractive since it is based on a direct relationship. For example, when modelling the opposed turns, the opposed turn saturation flow (s_o) is calculated first. Traditionally, this has been converted to an opposed turn equivalent (e_o). Using the flow ratio method, the need for e_o calculation is avoided, and the saturation flow for a lane shared by opposed turns and another movement can be calculated directly.

14. The flow ratio method is used in SIDRA to calculate shared lane saturation flows for the intervals of a green period which are common to the two movements sharing a lane. An important aspect of eqn (4) is that it is a general relationship that applies to any traffic stream, at intersections or mid-block.

15. Unsignalised intersections and freeway cases can be considered to have 100 per cent green, and hence the capacity is equal to the saturation flow. For a signalised intersection lane, the well-known capacity relationship is

$$Q = sg / c \tag{5}$$

where Q is the capacity (veh/h), g and c are the effective green and cycle times, and s is the average saturation flow for the lane. For the example in Table I, if $g = 30$ and $c = 100$ s, the lane capacity is $Q = 1469 \times 30 / 100 = 441$ veh/h.

16. The point to be emphasised here is that the saturation flow in eqn (5) is not necessarily the steady-state departure rate used to define 'basic' saturation flows. As a general relationship, s in

eqn (5) should be understood as a time weighted average of different saturation flows which operate at different intervals of the green period. This is important in the case of a lane shared by movements with different signal timing characteristics, which is discussed in the following section.

SHARED LANE CAPACITY WHEN THE INTERACTING MOVEMENTS HAVE DIFFERENT TIMING CHARACTERISTICS

17. In reality, even the simplest case of a lane shared by opposed turns and other traffic (e.g. through) is a case of movements with different timing characteristics in a shared lane. This is because the opposed turns will block the through vehicles in the lane while they are waiting for gaps in the opposing stream. This interval corresponds to the saturated portion of the opposing movement green period (g_s) which is effectively red for the opposed turns. During the unsaturated portion of the opposing movement green period (g_u), the opposed turns will depart by filtering through gaps in the opposing stream. Thus, the latter is a common green interval during which the opposed turns and through vehicles in the shared lane will depart together, whereas the former is a 'blockage' interval during which only some through vehicles can depart before being blocked by opposed turns.

18. Another case commonly found in practice is when turning traffic gives way to pedestrians, and blocks through traffic in the lane for a while, and then through and left-turning traffic depart together during a common green interval.

19. A more complicated case is a lane shared by through and turning traffic where turning traffic is opposed (unprotected) in one green period and unopposed (protected) in another as described earlier in the paper. This problem is by no means limited to shared lanes with opposed turns. A complicated real-life case of shared lanes with no opposed turns where lane interaction results from

different movements having right of way in different signal phases is given in an earlier paper (Akcelik 1984).

20. The effective timing characteristics of such shared lanes may be very different from adjacent exclusive lanes (e.g. through flow only). Thus, it may not be possible to combine such lanes into a single lane group, or if done so, it will be at the expense of a substantial loss of accuracy. Solution to this problem using traditional turn equivalent/adjustment factor techniques is either not possible or not accurate enough. The 'lane interaction' method which has been developed as a general analytical solution to this problem is explained in the following section.

THE LANE INTERACTION METHOD FOR SHARED LANE CAPACITY ESTIMATION

21. The lane interaction method is used in the SIDRA program as part of its lane-by-lane capacity estimation method. This method considers the two movements in a shared lane as two completely different movements that interact in a common lane. In terms of SIDRA input process, the same lane is specified as belonging to two movements.

22. A simple intersection example is given in Fig. 1 where right-hand rule of driving applies. In Fig. 1, Movements 3 and 4 interact in the first lane of the East approach road, and Movements 5 and 6 interact in the second lane of the West approach road (the lanes numbered from left to right). The lane interaction specification for West approach road is necessary because Movement 6 is delayed at the start of green period due to pedestrians. It is also assumed to have an extra gain at the end of the same green period for the purpose of demonstrating the general method (more realistically, Movement 6 would have been specified with two green periods).

23. In Figs 2(a) to 2(c), the relevant sections of output from SIDRA are shown. In Fig. 3, the application of lane interaction method to Movements 5 and 6 is shown. It should be noted that the results given here are the final results found by SIDRA after many iterations which include the calculation of lane flows (Akcelik 1984). The signal timings have been specified for simplifying the example.

24. The **lane interaction method** as implemented in SIDRA is explained in the following paragraphs.

25. Firstly, the durations of the first and second 'blocked intervals' (g_x, g_z) and the 'common green interval' (g_y) are calculated. A blocked interval is determined by matching the green periods of the two interacting movements. It is identified as an interval during which one movement receives red signal (blocking movement) and the other receives green signal (blocked movement). The common green interval is identified as an interval during which both movements receive green signal, hence there is no blockage. In Fig. 3, the durations of these intervals are $g_x = 10, g_y = 15$ and $g_z = 6$ seconds.

26. For each blocked interval, the number of possible departures by one movement before being blocked by the other (S_d) is estimated from the following formula:

$$S_d = P_b^{F+1} \sum_{i=1}^{M-1} \frac{P_d^i (i+F)!}{F!(i-1)!} + M P_d^M \sum_{j=1}^{F+1} \frac{P_b^{F+1-j} (M+F-j)!}{(M-1)!(F+1-j)!}$$

for $P_b > 0$ (6)

= M for $P_b = 0$

where p_b and p_d are the proportions of blocking and blocked flows ($p_d = 1 - p_b$), F is the free queue parameter and M is the maximum possible value of blocked departures. The free queue is the number of vehicles that can queue away from the lane without blocking the other movement. An example with a left-turn slip lane is shown in Fig. 4. The maximum number of blocked departures is found as the product of the duration of the blocked interval (g_d) and the saturation flow (s_d) of the movement which is being blocked, $M = s_d g_d$ where s_d is in veh/s. In this notation, subscript d has been used for x in the first blocked interval, and for z in the second blocked interval.

27. For the case when $F = 0$, i.e. the first vehicle to queue in the lane will block the other movement, the number of possible blocked departures is given by

$$S_d = (p_d/p_b) (1 - p_d^M) \quad \text{for } P_b > 0 \quad (7)$$

= M for $P_b = 0$

28. The values of S_d for the case when $M = 4$ is shown in Fig. 5 for various values of the free queue parameter, F .

29. The following results are found for the example in Fig. 3 (using $F = 0$ for both movements). For the first interval, $s_d = s_x = s_5 = 0.50$ for Movement 5, and

$$M = s_5 g_x = 0.50 \times 10 = 5.0 \text{ vehs,}$$

$$P_d = q_5/q = 100/150 = 0.667 \text{ and } p_b = 1 - p_d = 0.333, \text{ hence}$$

$$S_x = 1.74 \text{ vehs is found.}$$

Similarly, for the second interval, $s_d = s_z = s_6$ for Movement 6, and

$$M = s_6 g_z = 0.35 \times 6 = 2.1 \text{ vehs,}$$

$$P_d = q_6/q = 50/150 = 0.333 \text{ and } p_b = 0.667, \text{ hence}$$

$$S_z = 0.45 \text{ is found.}$$

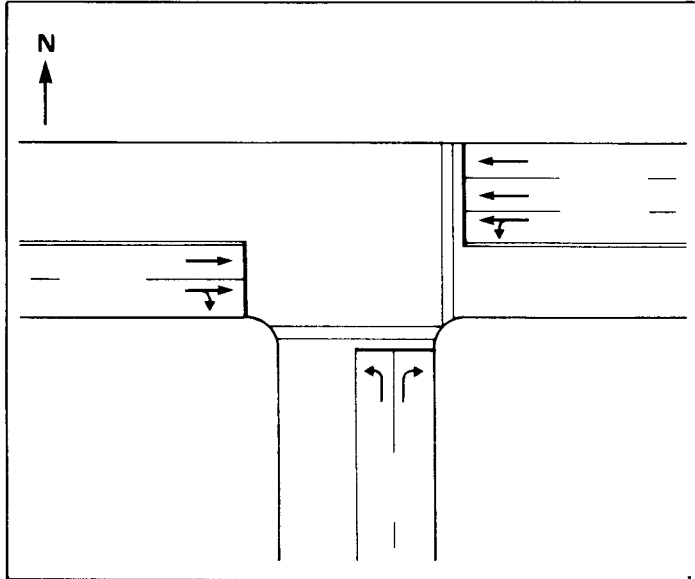
30. For each blocked interval, the effective green time corresponding to the blocked departures is calculated from

$$g_{dr} = S_d/s_d \quad (8)$$

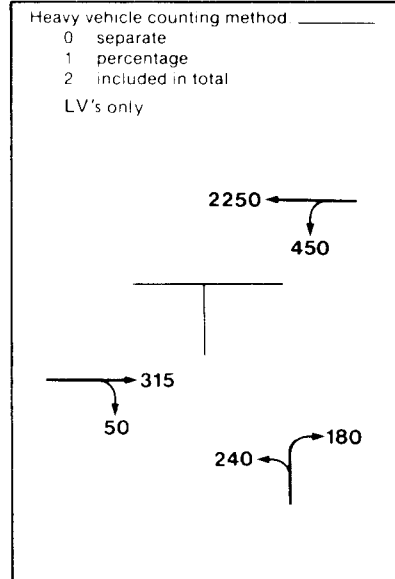
SIDRA INPUT DATA PREPARATION FORM

Prepared by : Rahmi Akcelik Computer File Name : LINR1
 Date : May 1987 Reference No. : _____
 Intersection Title : Lane Interaction Example 1 (Right-hand driving)
 Run Description : Three-Phase Option with Leading Left Turn

INTERSECTION LAYOUT (Description: _____) FLOW COUNT (Unit time: 60)

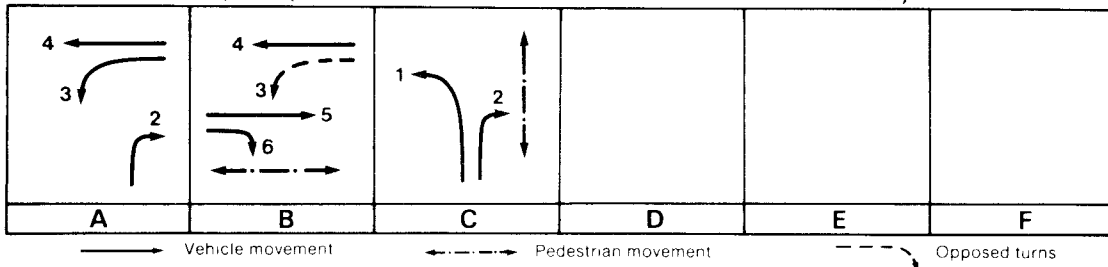


Include lane disciplines, short lane lengths, grades, etc. Enter a description such as existing or proposed



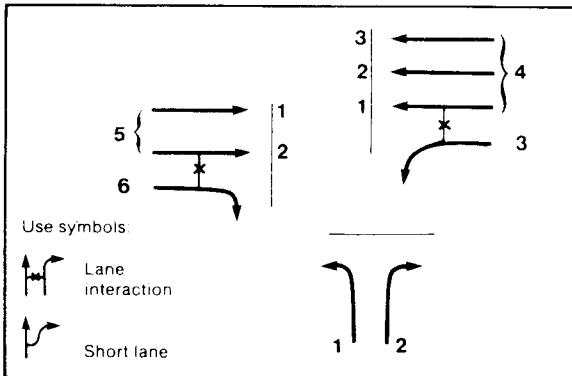
Show pedestrian flow data if necessary

SIGNAL PHASING (Description: Three phases with leading LT)



Vehicle movement (solid arrow), Pedestrian movement (dashed arrow), Opposed turns (dotted arrow)

MOVEMENT AND LANE DESCRIPTION



OTHER FEATURES

- Saturation flows:
 $s_T=1800, s_R=1260, s_L=1440$
- Mov. 3 : $n_f=1.2$
- All free queues=0
- $c=100, F_i=0.44, 74$ specified
- $G_{min}=19$ (Mov. 1)
 16 (Mov. 5)

Specify environment class, restricted turns, special movement types, etc.

Fig. 1 - Description of intersection data with lane interaction between Movements 3 and 4 (East approach road) and between Movements 5 and 6 (West approach road)

AKCELIK — CAPACITY OF A SHARED LANE

ARRB SIDRA 3.10 - RUN ON 88/05/13.
 LANE INTERACTION EXAMPLE 1 (RIGHT-HAND DRIVING) * LINR1 *
 THREE-PHASE OPTION WITH LEADING LT

CYCLE TIME = 100

TABLE S.5 - MOVEMENT OPERATING CHARACTERISTICS

MOV NO.	DISTANCE TRAVELED (VEH-KM/H)	AVER. SPEED (KM/H)	TOTAL DELAY (VEH-H/H)	AVER. DELAY (SEC)	TOTAL STOPS (VEH/H)	STOP RATE	LONGEST QUE PER LANE (VEHS)	QUE (M)	PERF. INDEX	FUEL RATE (ML/KM)
SOUTH APPROACH ROAD										
1	240.00	35.4	2.77	41.6	217	.90	6.7	40	14.66	104.7
2	180.00	51.9	.47	9.4	83	.46	2.3	14	6.27	88.9
EAST APPROACH ROAD										
3	450.00	45.8	2.33	18.7	393	.87	11.9	71	20.52	94.5
4	2250.00	49.1	8.31	13.3	1524	.68	21.1	127	99.86	91.5
WEST APPROACH ROAD										
5	315.00	38.8	2.87	32.8	244	.77	5.1	30	17.00	100.6
6	50.00	38.0	.48	34.7	40	.79	3.7	22	2.75	101.5

TABLE S.7 - LANE OPERATING CHARACTERISTICS

MOV NO.	LAN NO.	EFFECTIVE RED AND GREEN TIMES (SEC)				ARV FLOW CAP DEG. (VEH (VEH SATN X			AVER. DELAY (SEC)	STOP RATE	BACK OF QUE (VEHS) (M)		SHORT LANE (M)
		R1	G1	R2	G2	(/H)	(/H)						
1	1	78	22	0	0	240	317	.758	41.6	.90	6.7	40	
2	1	4	40	40	16	180	706	.255	9.4	.46	2.3	14	
3, 4	1, 1	30	41	17	12	629	765	.822	18.7	.87	11.9	71	
4	2	30	70	0	0	1036	1260	.822	12.8	.66	21.1	127	
	3	30	70	0	0	1036	1260	.822	12.8	.66	21.1	127	
5	1	75	25	0	0	215	450	.477	31.9	.77	5.1	30	
5, 6	2, 1	79	21	0	0	150	315	.477	34.7	.79	3.7	22	

Fig. 2(a) - SIDRA output for the Example in Fig. 1:
 Movement and lane operating characteristics

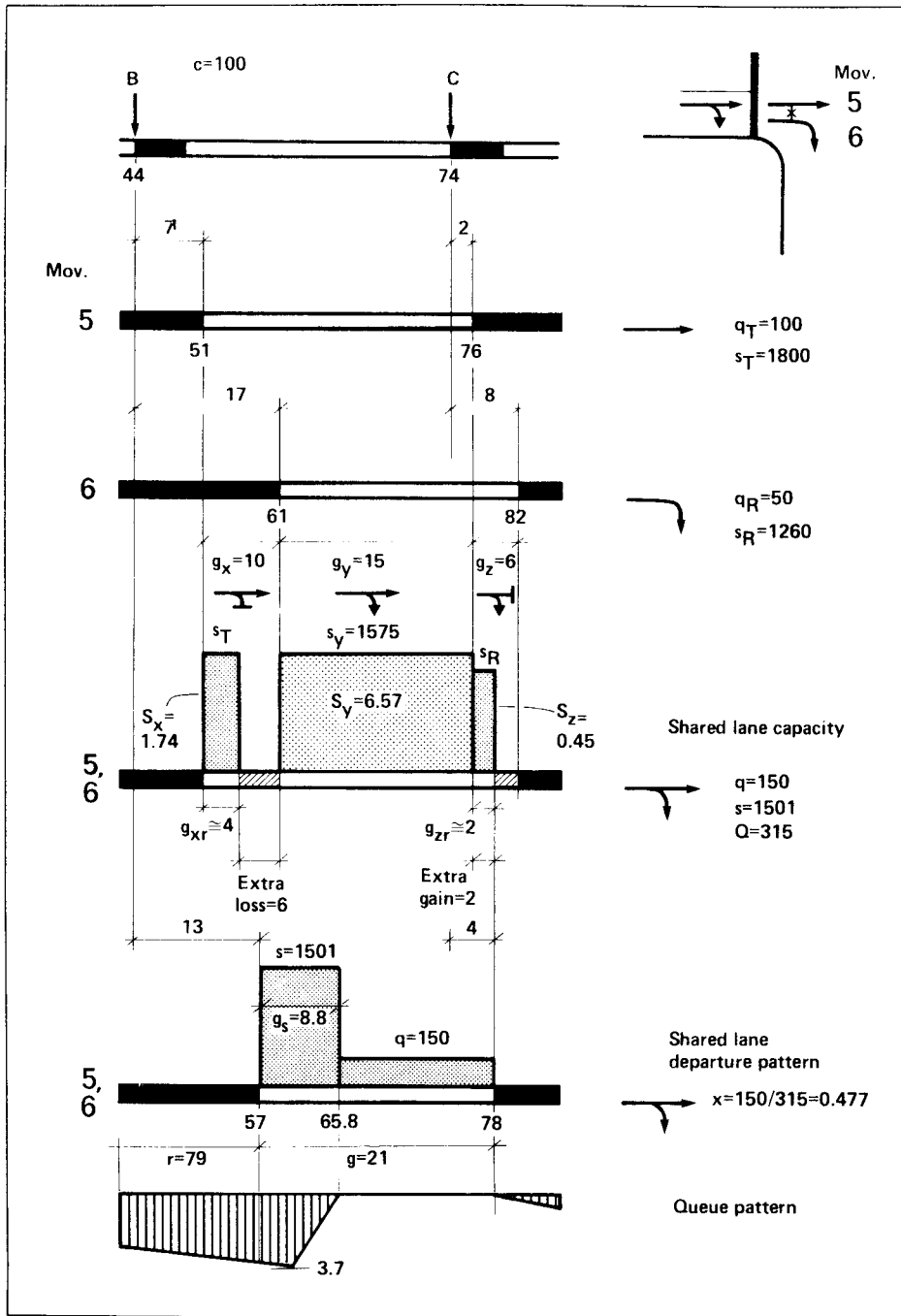


Fig. 3 - Application of the SIDRA lane interaction method to Movements 5 and 6 in Fig. 1

where S_d and s_d are as in eqn (6), and subscript d is used for x in the first blocked interval, and for z in the second blocked interval. In Fig. 3:

$$g_{xr} = 1.74/0.50 = 3.5 \approx 4 \text{ seconds,}$$

$$g_{zr} = 0.45/0.35 = 1.3 \approx 2 \text{ seconds (approximated up to the nearest integer value).}$$

31. For the common green interval (g_y), the composite saturation flow (s_y) is calculated using the flow ratio method (eqn 4, 4a) as a case when the

timing characteristics are the same for both movements in the lane. Then the number of departures during this interval is calculated as $S_y = s_y g_y$. In Fig. 2:

$$y_5 = 100/1800 = 0.0556$$

$$y_6 = 50/1260 = 0.0397$$

$$y = y_5 + y_6 = 0.0953 \text{ and}$$

$$s_y = q/y = 150/0.0953 = 1575 \text{ veh/h} = 0.438 \text{ veh/s}$$

$$g_y = 15$$

$$S_y = 0.438 \times 15 = 6.57.$$

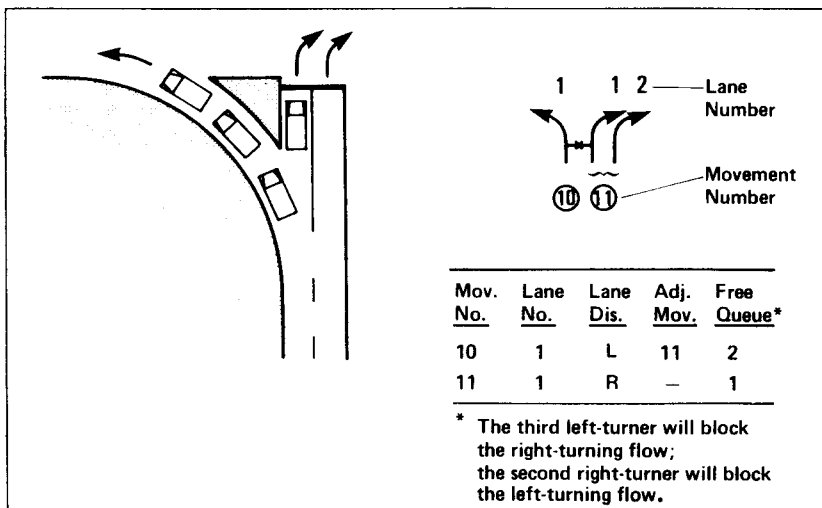


Fig. 4 - The free queue parameter in the lane interaction model (example of a left-turn slip lane for driving on the left).

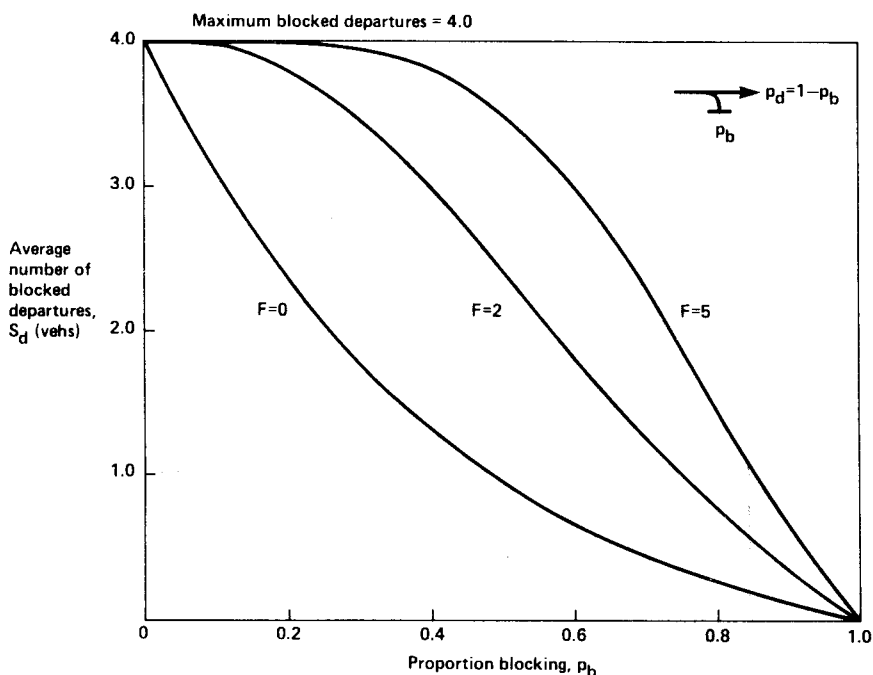


Fig. 5 - Average number of blocked departures as a function of the proportion of blocking flow, p_b , and the free queue, F , for maximum blocked departures, $M = 4.0$

32. The total lane capacity per cycle is calculated as the sum of the capacities in the g_x , g_y and g_z intervals:

$$S = S_x + S_y + S_z \quad (9)$$

and the total effective green time for the lane is found as the sum of the effective green times:

$$g = g_{xr} + g_y + g_{zr} \quad (10)$$

This means that, effectively, $(g_x - g_{xr})$ is added to the start lag (a), and g_{zr} is added to the end gain (b). Finally the average saturation flow for the shared lane is found from

$$s = S/g = (S_x + S_y + S_z)/(g_{xr} + g_y + g_{zr}) \quad (11)$$

The following results are found for the example in Fig. 3:

$S = 1.74 + 6.57 + 0.45 = 8.76$ vehs,
 $g = 4 + 15 + 2 = 21$ seconds and
 $s = 8.76/21 = 0.417$ veh/s = 1501 veh/h.
 Start lag, $a = 7 + (10 - 4) = 13$,
 End gain, $b = 2 + 2 = 4$, hence
 Lost time, $\ell = a - b = 9$ and
 Effective green time, $g = F_B - F_a - \ell = 74 - 44 - 9 = 21$ seconds (as found above).
 Lane capacity, $Q = 1501 \times 21/100 = 315$ veh/h (eqn 5).

33. For the lane performance calculations, the shared lane saturation flow and effective green and red time values as calculated above are used. These

values are different from the adjacent lane of the West approach road which has through traffic only (see Figs 1, 2(a) and 2(b) for detailed data). These different performance values are taken into account in the opposed turn calculations for Movement 3 from the East approach road where a more complicated (two-green) case of lane interaction exists. The results for this approach road are also seen in Figs 2(a) to 2(c).

34. The formulation of a very general method of lane interaction is rather complicated, but this has been achieved in the algorithms of SIDRA program. The complications arise from many possibilities of matching the green periods of interacting movements including the cases of movements with two green periods per cycle. Possibility of zero g_y values also complicates the algorithm.

35. A further complication arises for lane interaction in a short lane. The shared lane capacity calculated by the lane interaction method must be checked against the possible short lane capacity and the smaller value chosen for the lane. The short lane capacity method of SIDRA is to be reported elsewhere.

36. One further step in the lane interaction method is to split the shared lane saturation flow into saturation flows for the interacting movements according to the contribution of each movement to the lane capacity. This is only necessary for signal timing calculations since all capacity and performance estimates are calculated on a lane-by-lane basis in SIDRA. These calculations and other aspects of the lane interaction method are to be given in a more detailed report on the subject.

RELATION BETWEEN THE LANE INTERACTION AND ADJUSTMENT FACTOR METHODS

37. The traditional methods use adjustment factors, e.g. opposed turn equivalents, to allow for the effects of reduced saturation flows for turning movements. These methods usually assume that the effective green time is not affected in spite of any loss time. In ARR No. 123, a 'lost time method' which adjusts the effective green time for opposed turns is described, but it applies to exclusive turning traffic lanes only. The lane interaction method described in this paper extends the lost time/effective green time adjustment method to shared lanes.

38. It is possible to convert the saturation flow calculated using the lane interaction method to a 'turn equivalent' that can give the same capacity estimate. For example, using the flow ratio method (eqn 4), it can be shown that the turn equivalent for Movement 6 in Figs 1 to 3 is given by

$$e_R = 1 + \frac{q}{q_R} \left(\frac{s_T g_a}{S} - 1 \right) \quad (12)$$

where q , q_R = total and right-turn flows in the shared lane, s_T = through movement saturation flow in veh/s, S = total lane capacity per cycle estimated by the lane interaction method, and g_a = the green time used for combining the shared lane with other

lanes into one lane group (this is the main movement green time, e.g. Movement 5 in Figs 1 to 3). Using the values shown in Fig. 3, $q = 150$, $q_R = 50$, $s_T = 0.50$ veh/s, $S = 8.76$ vehs, and $g_a = 25$, $e_R = 2.28$ is found.

39. It is seen from eqn (12) that the turn equivalent is affected by many factors including the turning flow proportion, relative saturation flows and green times for the through and turning traffic, and the parameters influencing shared lane saturation flows (including the strong influence of signal timings).

40. Various aspects of the relation between the lane interaction and adjustment factors are discussed in the following paragraphs using the example of Movements 6 and 3 in Figs 1 to 3.

41. When the right-turn flow (Movement 6) is increased to 150 veh/h, $q = 172$, $q_R = 150$ and $S = 7.31$ in the shared lane, and hence $e_R = 1.81$ is found. If $q_R = 250$ is specified, then no thru flow uses the same lane, i.e. the lane turns into an exclusive right-turn lane. Still using $g_a = 25$, $e_R = 1.70$ is found, but unequal lane utilisation needs to be taken into account before combining the lane saturation flows in this case. The importance of lane-by-lane calculations to identify any 'effective' (or 'de facto') exclusive lane cases cannot be overemphasised (e.g. see Dunn 1982).

42. Instead of the specified timings in Figs 1 to 3 ($c = 100$, $F_i = 0,44,74$), SIDRA determines $c = 90$ and $F_i = 0,44,65$ (cycle time and phase change times). This gives $q = 134$, $q_T = 50$, $S = 4.62$ and $g = 12$ for the shared lane. Using $g_a = 16$ (Movement 5 green time), $e_R = 2.96$ is found.

43. If $e_R = 2.28$ (as for the conditions in Fig. 3) is specified with Movements 5 and 6 combined as one lane group ($g_a = 25$), the same lane flows and lane capacity, and hence the same lane degree of saturation are found by SIDRA. However, the performance results differ, e.g. shared lane delay is predicted to be 32 seconds instead of 35 seconds. Because of the change in the performance of the shared lane, the capacity of Movement 3 which is opposed by Movements 5 and 6 is also changed. Fig. 6 illustrates the steps involved in applying the SIDRA opposed turn and lane interaction methods in this case (two green periods per cycle for Movement 3). The performances of both Movements 3 and 4 are affected as a result. For example, the estimated capacity of the lane shared by Movements 3 and 4 is changed from 765 to 828 veh/h, and the estimated delay is changed from 19 seconds to 13 seconds.

44. The left turn equivalent for Movement 3 in Figs 1 to 3 which has opposed plus unopposed green periods is calculated from eqn (10) as $e_L = 1.90$ using a single green period which is the same as Movement 4 green ($g_a = 70$, $S = 21.25$, $q = 629$, $q_L = 450$). However, under the conditions of para. 43, $e_L = 1.77$ is found ($g_a = 70$, $S = 23.00$, $q = 668$, $q_L = 450$). For comparison, the 1985 U.S. Highway Capacity Manual predicts a saturation flow adjustment factor which is equivalent to $e_L = 1.38$ for this case, but it varies only with the opposing volume.

45. When $e_R = 2.28$ is specified for Movement 6 as in para. 43, and the corresponding $e_L = 1.77$ is

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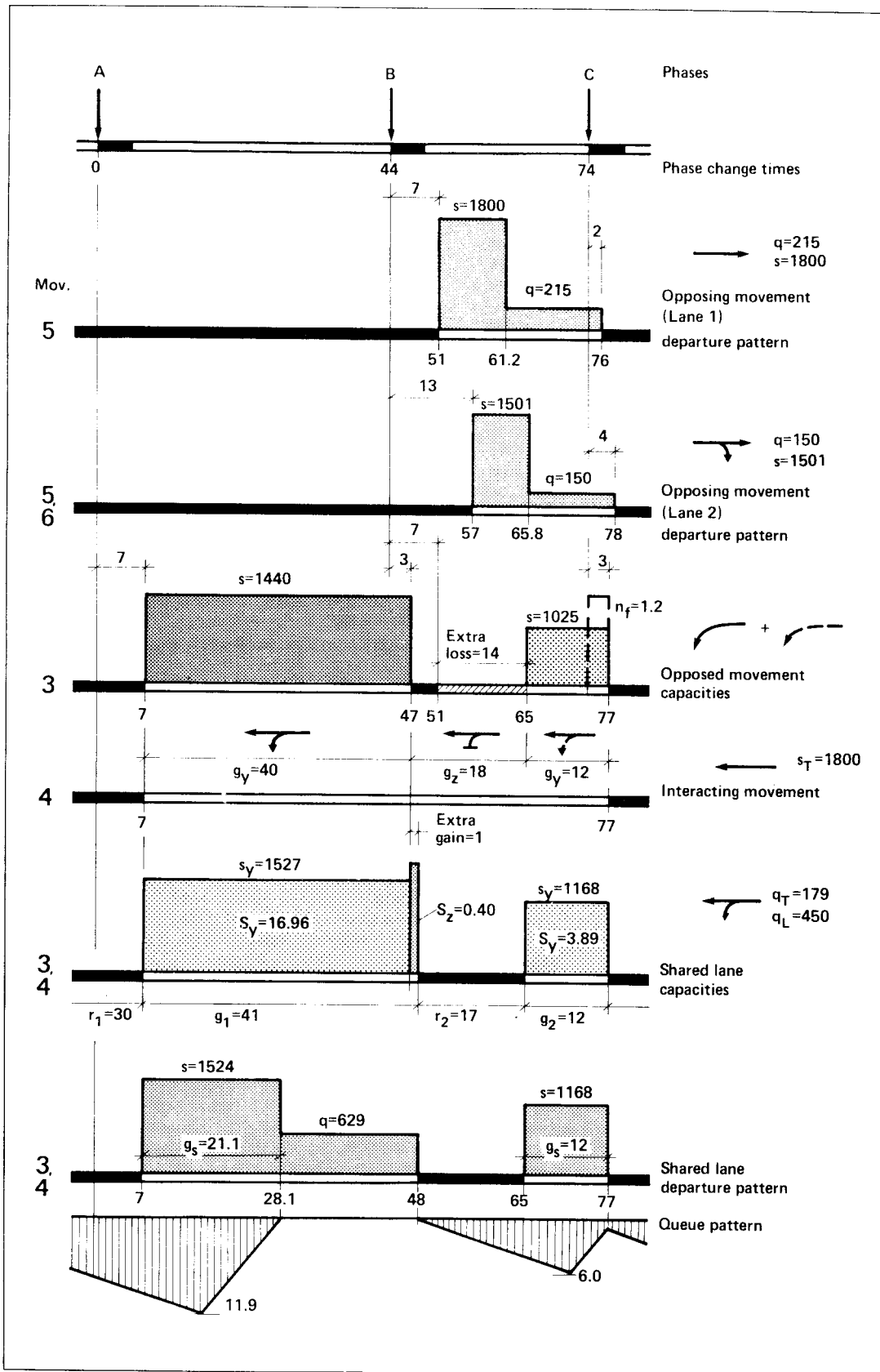


Fig. 6 - Application of the SIDRA lane interaction and opposed turn methods to Movements 3 and 4 in Fig. 1 (the case of two green periods per cycle).

specified for Movement 3 with Movements 3 and 4 combined as one lane group ($g = 70$), the same lane flows, capacity and degree of saturation are found by SIDRA. The shared lane delay is estimated as 14 seconds which is close to 13 seconds found under the conditions of para. 43. On the other hand, queue length is changed from 63 metres to 81 metres because of the single green effect (one long red interval instead of two short red intervals).

46. When $e_R = 2.28$ and $e_L = 1.77$ are specified as in para. 45, SIDRA determines $c = 80$ and $F_i = 0.11, 56$. These are substantially different from the timings found by SIDRA when capacities are determined by the lane interaction method (para. 42). Under these timings, the shared lane delays are 11 seconds for Movements 5 and 6, and 20 seconds for Movements 3 and 4, whereas the corresponding delays under para. 42 are 25 and 42 seconds.

CONCLUSION

47. The results for the example given in this paper demonstrate that the turn equivalents (saturation flow adjustment factors) estimated under one set of conditions are hardly applicable under another set of conditions. Substantial differences in capacity and performance predictions and timing solutions are seen to result from simplifying assumptions used to derive turn equivalents/adjustment factors.

48. Better expressions could be derived for turn equivalent/adjustment factors for specific cases, but a very general expression which can cope with all combinations of 'lane interactions' would be either too complex or impossible to derive. In fact, the turn equivalent/adjustment factor method has been relevant to the manual analysis methods using lane groups. With computerised analysis methods, it is an unnecessary simplification since an explicit and direct modelling approach such as the lane interaction method used in SIDRA is expected to give more accurate results.

49. An additional advantage of the explicit modelling of lane capacities and flows is the identification of the cases when shared lanes turn into 'de facto' exclusive lanes. It is important that signal designer is aware of such cases so that steps can be taken for better lane utilisation (Dunn 1982).

50. The equal flow ratio method for finding lane flows is suitable when the green time is the same for all lanes, as assumed in the case of adjustment factor method. On the other hand, the lane interaction method produces different effective green times for different lanes when there is lane

blockage in a shared lane. In this case, the lane flows are calculated according to the equal degree of saturation method which was explained in ARR No. 123 and implemented in the SIDRA program.

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