Use of the NCHRP Signalized Intersection Capacity Method--A South African Experience

ADOLF D. MAY, WESSEL J. PIENAAR, and CECIL A. ROSE

ABSTRACT

The primary objective of this study was to assess the applicability of the proposed NCHRP operations method for signalized intersection capacity analysis to South African traffic conditions. Secondary objectives were first, to review the reactions of 90 engineers who received a 5-day intensive course on the use of the NCHRP method and second, to draw a comparison between the predictions of this new method, those that could be obtained using the Highway Capacity Manual (HCM) method, and the relevant field-measured data. The analysis was based on applying the proposed NCHRP Operations Method to ten South African intersection data sets for which not only input data but also field measurements of lane saturation flows, stopped delays, queue lengths, and percent vehicles stopped were available. The ten intersections varied from simple geometrically designed intersections with pretimed two-phase signals to more complicated intersections with actuated multiphase signals. The NCHRP method is validated by evaluating its predictive accuracy under conditions experienced at the ten South African intersections. The validation is supplemented by the following analyses: a comparison of lane saturation flows using the proposed NCHRP and HCM methods, factors influencing saturation flows, the possibility of a default value for saturation flow, an assessment of stopped delay predictions using measured saturation flow as input, and an assessment of permissive left-turn stopped delays. The conclusions include the identification of the strengths and weaknesses of the NCHRP method under South African traffic conditions and the identification and quantification of alternative procedures and default values that would enhance the method's application in that country. In general, the proposed NCHRP method providse accurate results, and its ability to estimate saturation flow is better than that of the HCM method. One of the findings was that the use of a base saturation flow of 1,900 vehicles per hour of green per lane, combined with heavy vehicle adjustment factors having twice the magnitude of the NCHRP factors, would provide saturation flow estimates with roughly 60 percent smaller mean errors under South African traffic conditions.

As part of NCHRP Project 3-28 to update the 1965 Highway Capacity Manual (HCM) (1), work has been carried out by JHK & Associates, in cooperation with the Traffic Institute, Northwestern University, leading to a proposed new method for signalized intersection capacity analysis. This work is still in progress, and a number of draft documents describing the proposed method have been made available. The three drafts of interest in this study are those dated December 1981 (2), May 1982 (3), and February 1983 (4).

In July 1982 the principal author visited South Africa at the invitation of the Southern Africa Road Federation to conduct two courses on the application of the NCHRP method. At each course location a coinstructor assisted with the presentation, and a coauthor participated in each course. At the first course, offered in Pretoria, John Sampson acted as coinstructor and coauthor Wessel Pienaar participated as a delegate. At the second course, held in Stellenbosch near Cape Town, coinstruction was offered by John Jones, and coauthor Cecil Rose participated as a delegate. As part of the courses, data were collected at five intersections at each location to allow course members to apply the method under South African conditions. These data were also used to relate certain measures of effectiveness (MOEs) predicted by the NCHRP operations method to those measured at the intersections. It is with this comparison of estimated and field-measured MOEs that this study is primarily concerned.

SCOPE OF STUDY

The primary objective of this research was to assess the applicability of the draft NCHRP signalized intersection capacity operations method to South African traffic conditions. Secondary objectives were first, to review the reactions of approximately 90 course delegates to the use of the method and second, to draw a comparison between the predictions of this new method, those that could be obtained using Chapter 6 of the 1965 HCM, and the relevant field-measured data.

The primary objective was addressed by a detailed analysis of ten intersections, supplemented by a comparison of the predicted values of four MOEs with the field-measured values where these were available. The four MOEs examined were saturation flow, average stopped delay, percent vehicles stopped, and maximum queue length. The drafts of the method used in this analysis were those dated May 1982 (3) and February 1983 (4), although the December 1981 (2) draft was used as the basis of instruction and workshop sessions during the two courses. At the completion of each course, delegates were asked to comment on the deficiencies and difficulties of the method. It was hoped that this would point to areas that require simplification, those that need further clarification in the descriptions, and those on which course instructors should place greater emphasis.

A description of courses and a summary of delegates' comments are supplied in the next section. The third section is a presentation of characteristics of the ten analyzed intersections, and a brief overview of South African urban travel conditions is supplied. In the fourth section, a validation of the method under South African conditions, supplemented by additional saturation flow and stopped delay analyses, is presented. The fifth section contains concluding remarks and a summary of the most significant results.

THE COURSES

The topic covered by the courses was the analysis of signalized intersection capacity. The subject matter was based on the proposed new NCHRP method as contained in the December 1981 draft of the documents prepared by JHK & Associates (2).

The first half of each course was intended to instruct students in the background, supporting theory, and use of the method. Both the planning and the operations applications were covered. The examples supplied in the text of the document were used in the instruction sessions. To give delegates further hands-on experience in the use of the method, five sample intersections located in the San Francisco Bay region were analyzed by groups of students using data obtained in advance by the principal author.

The latter half of each course was a workshop designed to bring delegates into contact with a particular local intersection and to have them undertake field measurements of the four major MOEs and analyze the performance of the intersection using the method. The delegates worked in groups analyzing the five local intersections at each location. Details of the ten intersections are given in the third section.

Each intersection was observed by the designated groups for a period, which included the evening peak period, of 1.5 to 2 hours. Geometric data, traffic flow data, traffic conditions, and control details--in effect steps 1 to 4 of the operations application--were recorded before the visit to the sites. Groups were required to confirm the correctness of the previously collected data and then take in situ measurements of saturation flows, stopped delays, percent vehicles stopped, and maximum queue length in each lane group. Lane groups were selected by the delegates before the site visits. The site observations, therefore, served a dual purpose: first, to give the delegate groups practical experience in the operating conditions at an intersection and second, to collect the MOE data required for comparative purposes later in the analyses.

Delegate Comments on Procedural Deficiencies

On the basis of the intensive instruction sessions and the experience gained from the use of the method on at least two example intersections and one locally analyzed intersection, delegates were asked to note the difficulties and deficiencies they perceived in the use of the method under South African operating conditions. Only those statements made by two or more persons have been included. The comments made by the course delegates on the procedures included in the operations application, in order of decreasing frequency of occurrence, were

1. The procedure for determining left-turn (S.A. right) delay was inadequate;
2. The application was long, tedious, and cumbersome considering the perceived accuracy;
3. Saturation flows were underestimated because of adjustment factors relating to area type;
4. Greater clarity is needed in lane group selection guidelines;
5. Stopped delay calculated by the Appendix C procedure was unreasonably high;
6. Results are too heavily dependent on user's judgment;
7. The treatment of heavy left turns, especially in double turn lanes, is inadequate;
8. Improvement is needed in the handling of left turns from single lane approaches;
9. Confident use of the method requires considerable learning and practice time;
10. It is difficult to determine critical lane groups in the event of overlapping phases; and
11. The two applications use different level of service concepts.

In the ongoing development and refinement of the proposed method, several issues raised in this section have in fact been receiving further attention. Subsequent drafts of the document (3,4) have incorporated changes in response to similar comments from other sources.

Comments 1-6 are dealt with to an extent in the fourth section of this paper where comparisons are drawn between measured saturation flows and stopped delays and those predicted by using different procedures included in the operation application.

DESCRIPTION OF STUDY AREA

The location and characteristics of the ten intersections to which the new NCHRP operations method, taught at this course, was applied are described. In addition, a brief overview is supplied of South African urban travel conditions, which could have influenced the accuracy of the method and possibly underlay certain comments made by delegates.

Location and Characteristics of Intersections

The ten intersections analyzed were selected before the courses began. A variety of design and control features as well as relative proximity to the course locations were considered. The five intersections analyzed at the Pretoria course are located within the municipal area of that city. Two of the intersections have four approaches, one is formed by the intersection of two one-way streets, and the remaining two intersections are in the form of skewed T-junctions. The five intersections analyzed at the Stellenbosch course are situated within the Cape Town metropolitan area. All the Cape Town intersections have four approaches. The locations of the ten intersections are given in Table 1. A summary containing ranges of the most pertinent intersection input data is given in Table 2.

South African Travel and Vehicle Characteristics

Driving conditions in South Africa differ from those experienced in the United States, where the method

TABLE 1 Location of the Ten Analyzed Intersections

Center	No.	Street Location
Pretoria	1	Duncan Street and Lynnwood Road
Pretoria	2	Burnett Street and University Road
Pretoria	3	Pretorius Street and Schoeman Street
Pretoria	4	Curson Street and Walton Jameson Avenue
Pretoria	5	Curson Street and Kirkness Street
Cape Town	1	Darling Street and Buitenkant Street
Cape Town	2	Hertzog Boulevard and Pirow Street
Cape Town	3	Main Road and Campground Road
Cape Town	4	Weltevreden Road and Duinefontein Road
Cape Town	5	Modderdam Road and 35th Street

TABLE 2 Range of Values of Input Variables

Input Variable	Range		Input Variable	Range	
	Pretoria	Cape Town		Pretoria	Cape Town
Approach Widths (meters)	5.0-11.0	6.1-14.8	Approach Volume (vph)	97-1776	336-2196
Lane Widths (meters)	3.0-5.0	2.6-4.0	Left Turning Volume	0-216	25-412
Lanes per Approach	1-3	2-4	Right Turning Volume	0-492	0-683
Grade of Approach	0	0 to 4	Percentage Heavy Vehicles	0-7	1-17
Peak Hour Factor	0.85	0.71-0.98	No. of Buses	0-4	0-7
Bus Stops	1Y - 14N	1Y - 19N	Pedestrian Volumes (P/hr)	<10 - 65	<10 - 519
Parking	None	1Y - 19N	Arrival Type	3 and 5	1 - 5
No. of Parking Maneuvers	None	None	Phases/Cycle	2 and 3	2,3 and 4
Area Types	5 other	2BD 3 other	Cycle Lengths (secs.)	55-80	72-143

is being developed and validated. First, the typical South African car has manual transmission and the exterior dimensions of a compact car. These features might lead to greater maneuverability at intersections with tight geometric design. In addition, observations indicate that South Africans drive at faster cruising speeds, accelerate faster after stops, allow for shorter headways, and are less inclined to yield the right-of-way to pedestrians than are their U.S. counterparts. In combination, these factors have the potential to increase vehicle throughput (volume) at South African intersections.

Second, signal timing and law enforcement practices differ in the two countries. South African practice favors short amber periods and common use of all red periods. Further, South African road ordinances require that an intersection be clear at the commencement of red. Turning on red is not permitted. Collectively, these control practices not only reduce effective green time but also inhibit the capacity of turning lanes.

Third, there are differences in design principles that can affect intersection capacity:

1. South African practice favors midblock bus stops instead of the commonly found near-side or far-side bus stops at intersections in the United States.
2. With the exception of certain central business districts, on-street parking in South Africa is clearly divorced from intersections.

Both of these design principles should lead to greater intersection capacity, and hence increased saturation flows, in South Africa.

Although these differences in travel conditions are not exhaustive, they should set the scene for the validation attempt described in the next section.

VALIDATION OF THE NCHRP OPERATIONS APPLICATION UNDER SOUTH AFRICAN CONDITIONS

The groups of course delegates were assigned to measure the values of the four MOEs at the previously mentioned intersections. After taking the measurements, each group supplemented the values it obtained with estimates made using the method. These group estimates were subsequently revised by the two teaching assistants. Their revisions were again reviewed and verified by the authors. The validation discussed here makes use of these values.

Two of the MOEs, average queue length and percent vehicles stopped, are not analyzed because they are derivatives of average stopped delay and do not require any other independent variable as input.

It should be noted that, although South African rules of the road require driving on the left-hand side, all references to left and right are reversed to coincide with U.S. terminology. All units of length are metric. In the following analysis, it is assumed that the field-measured values are correct and that any differences between predicted and measured values are ascribable to errors in the methods.

Validation of Saturation Flow Estimates

Field-measured saturation flow and directly comparable saturation flow predicted by the NCHRP method and the HCM method are available for 35 of the 74 originally analyzed lane groups. Because of low flows, saturation flow measurements could not be made at the remaining lane groups. A summary of these saturation flows is given in Table 3. The intersection number, direction of movement, permitted traffic movement, and number of lanes per lane group are identified. The columns represent the previously mentioned saturation flows. The error of estimate per lane group is also supplied for both the NCHRP and the HCM methods. Statistical analyses were performed and their results are given in Table 4. The table gives data on four classes of lane groups: single lane exclusive left turn (S.A. right), single lane through and shared through and turn, two-lane through and shared through and turn, and three-lane through and shared through and turn.

The table also gives the total sample of lane groups collectively. The following statistics are calculated: overall mean saturation flows, standard deviation, mean error, and linear regression analyses between measured and estimated values. To assess the degree of similarity between calculated and measured flows on a qualitative basis, it was decided to regard all estimates closer than 10 percent to the measured values as "good." Those predictions further than 10 percent but up to 20 percent are regarded as "fair," and those further than 20 percent astray from the measured values are regarded as "poor." A summary of this qualitative assessment of the NCHRP method's ability to predict saturation flow per lane group is given in Table 5. This table shows that approximately 50 percent of the method's lane group saturation flow estimates are good predictions, and 75 percent are fair estimates or better. The method very slightly underestimates saturation flow.

Comparative Analyses of Lane Saturation Flow Estimates Using the NCHRP and HCM Methods

Saturation flow estimates obtained using the NCHRP method and those obtained using the 1965 HCM method are compared, and these saturation flow estimates are related to the field-measured saturation flows. The reason for attempting this analysis is twofold. First, because the NCHRP method is meant to replace the HCM method, it would be useful to know whether it is superior to the method it is to replace. Second, although the course delegate comment that the method underestimates saturation flow cannot be

TABLE 3 Lane Group Saturation Flow Results (vphgl)

Intersec. Number	Direction Movement	Movement	No. Lanes Per Group	Measured Saturation Flow	Predicted Saturation Flow: NCHRP Method Calculated	NCHRP Method Error	1965 HCM Method Calculated	1965 HCM Method Error
P1*	NB	[illegible]	2	2449	3335	+886	2600	+151
P1	SB	[illegible]	2	2975	2863	-112	2270	-705
P1	EB	[illegible]	2	3302	3801	-001	2560	-742
P3	NB	↑	1	1860	1782	-078	1583	-277
P3	NB	↑	1	1880	1782	-098	1583	-297
P3	NB	↑	1	1640	1782	+142	1583	-057
P3	WB	←	1	1860	1755	-105	1535	-325
P3	WB	←	1	1800	1755	-045	1535	-265
P3	WB	←	1	1800	1755	-045	1535	-265
P4	SB	[illegible]	1	1072	1120	+148	835	-237
P4	WB	←	1	1455	1676	+221	1300	-155
P4	WB	[illegible]	1	906	1592	+686	1300	+394
P5	SB	↓	1	1800	1728	-072	2154	+354
P5	WB	[illegible]	2	3600	3492	-108	3109	-491
C2**	NB	[illegible]	3	6056	5324	-732	4585	-1471
C2	NB	[illegible]	1	103	88	-015	185	+082
C2	SB	[illegible]	1	1154	1024	-130	808	-346
C2	SB	[illegible]	3	5562	4879	-683	4023	-1539
C2	EB	[illegible]	2	3858	3452	-406	3156	-702
C2	WB	[illegible]	1	270	88	-182	248	-022
C2	WB	[illegible]	3	4018	4331	+313	4681	+663
C3	NB	[illegible]	1	1420	1463	+043	1430	+010
C3	SB	↓	1	1700	1516	-184	1859	+159
C3	EB	[illegible]	1	1976	1475	-501	1385	-591
C3	WB	←	1	1993	1494	-499	1681	-312
C4	SB	[illegible]	2	3066	3326	+260	3050	-016
C4	EB	[illegible]	2	2696	3143	+447	2644	-052
C4	EB	[illegible]	1	338	558	+220	592	+254
C4	WB	[illegible]	2	2620	3259	+639	2584	-036
C5	NB	[illegible]	2	2660	2908	+248	2441	-219
C5	SB	[illegible]	1	1856	1226	-630	1197	-659
C5	EB	[illegible]	2	3103	3420	+317	3111	+008
C5	EB	[illegible]	1	1765	1454	-311	1140	-625
C5	WB	[illegible]	1	1869	1287	-582	1287	-582
C5	WB	[illegible]	2	3600	3449	-151	3357	-243
Total				80082	78982	-1100	70926	-9156

*P denotes Pretoria **C denotes Cape Town

TABLE 4 Statistical Analysis of Lane Group Saturation Flow Results

Sample and Calculation	Measured	Estimate NCHRP	Estimate 1965 HCM
Single lane exclusive left turn (S.A. right)			
Number of groups	7	7	7
Mean saturation flow	1051	818	780
Standard deviation	802	573	454
Mean error	N/A	296	367
Single lane through and shared			
Number of groups	14	14	14
Mean saturation flow	1654	1627	1521
Standard deviation	330	171	297
Mean error	N/A	205	264
Lane groups with two lanes			
Number of groups	11	11	11
Mean saturation flow	3084	3268	2807
Standard deviation	463	214	356
Mean error	N/A	325	306
Lane groups with three lanes			
Number of groups	3	3	3
Mean saturation flow	5212	4845	4430
Standard deviation	1063	497	355
Mean error	N/A	576	1224
All lane groups			
Number of groups	35	35	35
Mean saturation flow	2288	2257	2027
Standard deviation	1313	1268	1117
Mean error	N/A	293	380
Linear regression			
Y-intercept	N/A	+53	+43
Slope	N/A	+0.991	+1.108
Corr. coef. (r)	N/A	0.96	0.94

Note: N/A = not applicable.

TABLE 5 Qualitative Assessment of the Method's Ability to Predict Saturation Flow on a Lane Group Basis

	Good		Fair		Poor		Total	
	No.	%	No.	%	No.	%	No.	%
Overestimate	6	17.2	3	8.6	4	11.4	13	37.1
Underestimate	11	31.4	6	17.1	5	14.3	22	62.9
All	17	48.6	9	25.7	9	25.7	35	100.0
Pretoria	10	28.6	2	5.7	2	5.7	14	40.0
Cape Town	7	20.0	7	20.0	7	20.0	21	60.0

supported statistically in this study, it would be interesting to establish the performance of the NCHRP method relative to the HCM method. Lane group saturation flow results of both methods are summarized in Table 3, and a statistical analysis thereof is given in Table 4. A comparative analysis of saturation flow results for through and shared through and turn groups, expressed on a per lane basis, is given in Table 6. Despite the bias in flow volumes between the cities, Tables 4 and 6 show that the NCHRP method not only estimates saturation flows more accurately per city and per type of lane group, but in each case it also predicts values higher than does the HCM method.

TABLE 6 Comparative Analysis of Through and Shared Lane Group Saturation Flow Results

Calculation	Saturation Flow (vphgl.)								
	Measured			NCHRP			HCM		
	Pret.	Cape Town	Total	Pret.	Cape Town	Total	Pret.	Cape Town	Total
No. of Groups*	14	14	28	14	14	28	14	14	28
No. of Lanes	18	27	45	18	27	45	18	27	45
Avg. Sat. Flow	1578	1650	1621	1657	1592	1617	1416	1497	1465
Std. Dev.	297	275	284	152	117	131	276	176	216
Mean Error	N/A**	N/A	N/A	128	201	172	262	223	239
Over-ests.	N/A	N/A	N/A	7	14	21	4	7	11
Under-ests.	N/A	N/A	N/A	11	13	24	14	20	34
Range of Errors per Sgl. Ln.	N/A	N/A	N/A	1 - 686	43 - 501	1 - 686	57 - 371	8 - 659	8 - 659

* Single lane exclusive turning movement groups are summarized in the top row of Table 4.

** N/A denotes "not applicable."

Factors Influencing Saturation Flows

In the determination of saturation flow the NCHRP method considers the effect of nine variables. In this analysis it was necessary to eliminate five of these variables because of an insufficient range of pertinent data. Also, because essentially only through and shared through and turn lane groups were being analyzed, the left-turn factor (S.A. right) was also omitted. The only remaining factors were lane width, heavy vehicle, and right-turn factors (incorporating pedestrian volumes and percentage of right turns).

Table 7 gives the ratio of measured to calculated saturated flows (M/C) for both areas and the values of the four remaining variables analyzed. The table is arranged in order of decreasing M/C ratio of each area. The data for the Pretoria group show less variation in the ratio, when the extremely low value of 0.57 is disregarded, than is shown by the Cape Town data. There is no discernible correlation between the value of the ratio and any of the values of the four input variables. Note also that in the case of percent heavy vehicles these data range only between 0 and 7 percent, with eleven of the values between 2 and 5 percent. This compares with a range of 1 to 17 percent heavy vehicles in Cape Town. The Pretoria data also lack sufficient range for the right-turn percentage and pedestrians, leaving little opportunity to draw conclusions.

Examination of the Cape Town data set of 14 lane groups reveals no apparent correlation between the M/C saturation flow ratios and lane widths, percentage right turns, or pedestrians. This is despite the fact that the values of the variables show greater variation than do those for the Pretoria intersections. It can, however, be observed that there is a correlation between the variation of the M/C ratio and the percentage of heavy vehicles in the traffic stream. It was found that as the M/C ratio decreases, the percentage of heavy vehicles increases.

As a further check, the adjustment factors for the other eight variables influencing saturation flow were aggregated to see whether in combination they displayed any trend that could have an effect on the M/C ratio. It was found, however, that the values of combined adjustment factors, minus the heavy vehicle factors, are uniformly distributed, yielding an average of 0.926 with a standard deviation of only 0.073. A regression analysis of the value of the M/C ratio versus the percentage of heavy vehicles (%HV) yields the following equation:

$$M/C = 1.20-0.022(\%HV) \; : \; r = -0.67 \quad (1)$$

TABLE 7 Factors Affecting Saturation Flow

I/S #	Appr.	# Lanes	Sat. Flow / Lane Meas.	Calc.	M/C	Lane Width (M)	% HV	% RT	Peds.
P3*	WB	1	1860	1755	1.06	3.7	5	0	0
P3	NB	1	1880	1782	1.05	3.7	2	0	0
P1	SB	2	1487	1431	1.04	3.0	3	55	50
P3	NB	1	1860	1782	1.04	3.7	2	0	0
P5	SB	1	1800	1728	1.04	5.0	7	0	0
P5	WB	2	1800	1746	1.03	3.7	7	0	0
P3	WB	1	1800	1755	1.03	3.7	5	0	0
P3	WB	1	1800	1755	1.03	3.7	5	0	0
P1	EB	2	1651	1650	1.00	3.0	3	7	65
P3	NB	1	1640	1782	0.92	3.7	2	0	0
P4	SB	1	1072	1220	0.88	3.0	7	45	25
P4	WB	1	1455	1676	0.87	3.0	4	0	10
P1	NB	2	1225	1667	0.73	3.0	0	23	25
P4	WB	1	906	1592	0.57	3.0	4	19	10
C3**	EB	1	1976	1475	1.34	3.3	2.4	21	20
C3	WB	1	1993	1494	1.33	3.0	5.6	0	18
C2	NB	3	2019	1775	1.14	3.7	7.3	0	490
C2	SB	3	1854	1626	1.14	3.7	2.4	35	10
C2	EB	2	1929	1726	1.12	3.7	1.6	17	183
C3	SB	1	1700	1516	1.12	3.0	3.9	0	156
C5	WB	2	1800	1725	1.04	3.6	7.5	2	10
C3	NB	1	1420	1463	0.97	3.3	8.5	10	96
C2	WB	3	1339	1444	0.93	3.7	1.1	28	516
C4	SB	2	1533	1663	0.92	3.7	7.7	16	10
C5	NB	2	1330	1454	0.91	3.6	13.4	48	10
C5	EB	2	1551	1710	0.91	3.6	9.8	0	15
C4	EB	2	1348	1571	0.86	3.7	17.1	21	36
C4	WB	2	1310	1630	0.80	3.7	14.9	16	10

* P denotes Pretoria. ** C denotes Cape Town.

From Equation 1 it can be deduced that when the M/C ratio equals 1.2, the percentage heavy vehicles is zero. Likewise, when M/C = 1.0, the percentage heavy vehicles is 9.1. Among the 14 lane groups investigated, three sizes of groups can be identified: four groups consist of one lane each; seven groups contain two lanes; and three groups have three lanes each. For each lane group size a regression analysis of the field-measured versus calculated saturation flows was performed. Using these regression analyses, the expected flows were calculated for each lane group size that would yield M/C ratios of 1.0 and 1.2, respectively. It was found that for groups with one, two, and three lanes, an M/C of 1.0 can be expected when the actual flows equal 1,368, 1,750, and 1,502 vehicles per hour of green per lane (vphgl). When these flows are multiplied by 1.2 to represent the saturation flows where the expected M/C ratio would equal 1.2, a weighted average base saturation flow of 1,906 vphgl (∿1,900) is found. At 0 percent heavy vehicles, the average combined adjustment factor of 0.926 will reduce the re-estimated base saturation flow of 1,900 vphgl to an adjusted saturation flow of 1,760 vphgl.

With a weighted average actual saturation flow of 1,588 vphgl containing 9.1 percent heavy vehicles, the adjusted flow of 1,760 vehicles will have to be scaled down by a factor of 0.902 to represent the actual effect these heavy vehicles have on saturation flow. This compares with an adjustment factor of 0.955 used in the NCHRP method for 9.1 percent heavy vehicles. This leads to the conclusion that heavy vehicles in the study area tend to affect the flow of cars twice as adversely as do heavy vehicles in the United States. Re-estimated heavy vehicle factors for South African conditions are given in Table 8.

TABLE 8 Re-estimated Heavy Vehicle Saturation Flow Adjustment Factors for South Africa

%HV	0	2	4	6	8	10	20
f_{HV}(US)	1.00	0.99	0.98	0.97	0.96	0.95	0.91
f_{HV}(SA)	1.00	0.98	0.96	0.94	0.92	0.90	0.81

TABLE 9 Analysis of Through Lane Saturation Flow

Calculated Statistic	Saturation Flow/Lane			
	Field Measured	Calculated (NCHRP Method)	Default Value of 1800	Calculated (Using base flow of 1900 vehicles and reestimated heavy vehicle factor.)
Median	1800	1755	1800	1792
Mean	1797	1721	1800	1758
Standard Deviation	172	86	0	94
Mean Error	N/A	156	127	63
Maximum	2019	1782	1800	1860
Minimum	1455	1494	1800	1526

Default Value for Adjusted Saturation Flow

In Appendix E of the May 1982 draft of the NCHRP operations method it is stated that the median saturation flow for through lanes under fair to good geometric and traffic conditions was found to be approximately 1,600 vphgl. For comparative purposes all 13 lane groups (representing 17 lanes) in the sample, which involved exclusive through movements and for which field-measured saturation flows are available, were analyzed to determine whether a reliable default value could be established for South African conditions. The results of this analysis are given in Table 9.

From the data in Table 9 it can be concluded that the use of a default value of 1,800 vphgl to represent adjusted saturated flow for through lanes with good geometric conditions, in the absence of more detailed knowledge of traffic conditions, is likely to provide accurate results. Note that the use of a base saturation flow of 1,900 vphgl, and the use of the re-estimated heavy vehicle factors, will provide saturation flow estimates with 60 percent smaller mean errors than do the values used by the NCHRP method.

Validation of Stopped Delay Results

To validate stopped delay, 45 sets of the originally analyzed 74 sets of lane group data are available for analysis. Intersections 3, 4, and 5 of Cape Town are omitted from the analysis because stopped delays were not measured at those intersections. Table 10 gives the field-measured and estimated stopped delay results for the lane groups analyzed. These estimated stopped delays were calculated using predicted saturation flows as input. An assessment of stopped delay predictions using measured saturation flows as input is presented hereafter.

To assess the degree of correlation between calculated and field-measured stopped delays on a qualitative basis, it was decided to regard all estimates closer than 5 sec to the measured values as "good." Those predictions that deviate between 6 and 10 sec are judged "fair," and all predictions further than 10 sec astray from the observed delays are judged "poor." A summary of this qualitative assessment of the NCHRP method's ability to predict stopped delay per lane group is given in Table 11. The data in this table indicate that 65 percent of all stopped delay estimates are good predictions, and approximately 82 percent are fair estimates or better. Although the sample contains 10 permissive-only left-turn (S.A. right) lane groups constituting 22 percent of the sample, they contribute 71 percent of all poor estimates. This issue was also raised as a matter of serious concern at the courses and is therefore dealt with separately later. The sample contains only two protected or permissive left-turn lane groups. One estimate was good and one was fair, and they do not warrant further investigation. The sample contains no protected-only left-turning movements.

A statistical analysis of through and shared through and turn lane group stopped delay results is given in Table 12. The following statistics are calculated: overall mean, standard deviation, and mean error of stopped delays.

Assessment of Stopped Delay Predictions Using Measured Saturation Flows as Input

Of the 45 lane groups used for stopped delay analysis there are 18 lane groups for which saturation flows were field measured. Comparative analysis of stopped delays for these 18 lane groups, using measured and estimated saturation flows as inputs, is

TABLE 10 Measured and Estimated Stopped Delays (sec)

Int. No.	Approach	Direction	Stopped Delay: Field Measured	Stopped Delay: Calculated Using Estimated Sat. Flows	Stopped Delay: Calculated Using Measured Sat. Flows
P1	NB		99	41	74
P1	NB		10	14	25
P1	SB		11	121	*
P1	SB		41	40	40
P1	EB		14	47	*
P1	EB		11	16	42
P1	WB		15	14	*
P1	WB		4	7	*
P2	NB		18	15	*
P2	NB		21	15	*
P2	EB		7	6	*
P2	EB		9	12	*
P2	WB		4	8	*
P2	WB		5	8	*
P3	NB		13	13	11
P3	NB		18	13	11
P3	NB		8	13	21
P3	WB		10	8	8
P3	WB		6	8	8
P3	WB		9	8	8
P4	NB		6	12	*
P4	SB		13	13	19
P4	EB		2	4	*
P4	EB		4	4	*
P4	EB		9	11	*
P4	WB		9	11	*
P4	WB		4	4	4
P4	WB		4	4	4
P5	SB		16	15	15
P5	WB		1.3	1.5	1.5
C1	NB		10	8	*
C1	NB		5	16	*
C1	SB		23	16	*
C1	SB		16	8	*
C1	EB		5	8	*
C1	EB		16	23	*
C1	WB		8	25	*
C1	WB		9	11	*
C2	NB		9	9	9
C2	NB		35	26	26
C2	SB		6	12	13
C2	EB		20	49	22
C2	EB		34	148	66
C2	WB		10	47	48
C2	WB		7	16	16

P denotes Pretoria. C denotes Cape Town.
* denotes that saturation flow was not measured.

given in Table 10. A statistical analysis detailing the effect of measured saturation flows on stopped delay estimates is given in Table 13. The table also shows the effect that the application of estimated saturation flows to a base saturation flow of 1,900 vphgl and the re-estimated heavy vehicle factors have on stopped delay estimates. The data in this table indicate that, for the 18 lane groups where it was possible to calculate stopped delays based on measured saturation flows, there was no significant change in the estimates. It therefore appears that there exists a need for further research to develop stopped delay correction factors for both through and shared through and turn lanes under South African conditions.

TABLE 11 Qualitative Assessment of the Method's Ability to Predict Saturation Flow on a Lane Group Basis

	Good		Fair		Poor		Total	
	Number	%	Number	%	Number	%	Number	%
Overestimates	13	29	4	8	7	16	24	53
Estimates deviating less than 0.5 second	7	16	--	--	--	--	7	16
Underestimates	9	20	4	9	1	2	14	31
Pretoria	25	56	2	4	3	7	30	67
Cape Town	4	9	6	13	5	11	15	33
ALL	29	65	8	17	8	18	45	100

TABLE 12 Statistical Analysis of Lane Group Stopped Delay Results: Through and Shared Through and Turning Lane Groups

Calculation	Pretoria		Cape Town		Total	
	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
Number of Lane Groups	22	N/A*	10	N/A	32	N/A
Mean Delay (seconds)	9.9	10.7	11.0	15.3	10.2	12.1
Standard Deviation	8.7	7.8	6.4	12.3	8.0	9.5
Mean Error	N/A	2.3	N/A	7.7	N/A	4.0

* N/A denotes "not applicable."

Assessing Exclusive Left-Turn (S.A. right) Stopped Delays

The foremost procedural deficiency identified at the courses was the technique for determining permissive exclusive left-turning (S.A. right) stopped delay. It was contended that the results obtained by scaling up through delay with a factor of 3 to represent permissive left-turn delay are suspect. The argument underlying this concern is probably that left-turn delay is a function of opposing flow rather than of adjacent through delay.

The May 1982 (3) and February 1983 (4) drafts of the NCHRP method do, however, in their Appendix G, suggest an alternative technique for determining such delays. This alternative technique was used and its results were compared with those obtained using the original December 1981 (2) procedure and with measured delays. Table 14 details the results obtained for exclusive or permissive left-turning movements.

The data given in Table 14 clearly indicate that the alternative Appendix G technique for estimating left-turning stopped delay supplies substantially better predictions for lanes with a volume-to-capacity (V/C) ratio of less than 1.0 than does the December 1981 procedure. However, the last estimate given in the table indicates that refinement of the alternative technique is still necessary in cases where the V/C ratio exceeds a value of 1.0.

TABLE 13 Statistical Comparison of Stopped Delay Estimates Using Predicted Versus Measured Saturation Flows as Input

Calculation	Stopped Delay			
	Field Measured	Estimated Using Predicted Saturation Flow	Estimated Using Measured Saturation Flow	Estimated Using Base Sat. Flow of 1900 Veh. and Reestimated % HV Factors
Number of Lane Groups	18	18	18	18
Mean Delay (seconds)	11.5	14.3	15.4	12.8
Standard Deviation	8.9	11.9	11.4	9.3
Mean Error	N/A*	3.9	5.5	2.8

* N/A denotes "not applicable."

TABLE 14 Permissive Left-Turning (S.A. Right) Stopped Delay Results

			Stopped Delay in Seconds		
Intersection	Approach	V/C Ratio	Measured	December 1981	Appendix G
Pretoria					
1	NB	1.00	99	41	102
1	SB	0.23	11	121	19
1	EB	0.76	14	47	21
4	EB	0.06	9	11	10
4	WB	0.20	9	11	11
Cape Town					
1	EB	0.82	16	23	30
1	WB	0.29	8	25	20
2	NB	0.77	35	26	35
2	EB	0.85	34	148	33
2	WB	1.43	40	47	352
Overall mean			27.5	50.0	63.3
Standard deviation			27.9	46.8	104.8
Mean when V/C < 1.0			26.1	50.3	31.2
Standard deviation			29.3	49.6	28.0
Mean error			N/A	39.1	5.3

Note: N/A = not applicable.

CONCLUSIONS

The NCHRP operations method estimates approximately 50 percent of saturation flows under South African conditions within a 10 percent range from measured values, and 75 percent of all estimates lie closer than 20 percent from the real saturation flows.

The NCHRP method very slightly underestimates saturation flows but still predicts them higher than the HCM method. The mean error of all saturation flow estimates using the NCHRP method is 172 vphgl compared with a mean error of 239 vphgl using the HCM method.

No evidence was found that the NCHRP method overestimates the effect of pedestrians on saturation flows. However, the method does not accurately take account of the effect of heavy vehicles on saturation flows under South African conditions. It was found that the use of a base saturation flow of 1,900 vphgl and the use of heavy vehicle factors with approximately twice the magnitude of the NCHRP factors (suggested for the United States), would provide saturation flow estimates with roughly 60 percent smaller mean errors.

The use of a default saturation flow of 1,800 vphgl for through lanes with good geometric conditions, in the absence of more detailed knowledge of conditions, is likely to provide accurate results.

Just over 64 percent of all stopped delay estimates range within 5 sec of the measured values, and approximately 82 percent range closer than 10 sec. In general, the NCHRP method very slightly overestimates average stopped delays.

The use of measured saturation flows, rather than estimated saturation flows, as input to calculate average stopped delays does not improve the accuracy of the delay estimates. It appears that there exists a need for further research to develop a stopped delay correction factor for both through and shared through and turn lanes in South African conditions.

Using Appendix G of the May 1982 and February 1983 versions of the NCHRP method, rather than the December 1981 scaling technique, markedly improves permissive left-turning stopped delays for lanes with V/C ratios of less than 1.0. The mean error of estimate for such lanes dropped from 39.1 to 5.3 sec.

A comment made at the course was that the application of the NCHRP method was too long, tedious, and cumbersome considering its perceived accuracy. The authors of this paper believe, however, that when the method has been mastered it gives better results for saturation flow than does the HCM method, which is currently in widespread use in South Africa; provides a broader range of MOEs; and allows greater diversity in the selection of the analysis unit.

These positive features allow for the possibility of making analyses that extend further than the conventional traffic engineering and planning analyses previously done on intersections. One such example is the ability of the NCHRP method to estimate stopped delay. The disadvantages of delays are wasted fuel, lost time, and increased air pollution. These three aspects are receiving increasing attention in South Africa and their inclusion would certainly enhance the application of the method in that country.

ACKNOWLEDGMENTS

The authors wish to thank the following organizations and persons who contributed to the course proceedings and data inputs used in this study: NCHRP for releasing the December 1981 draft of the method for use at the courses; the Southern Africa Road Federation for convening the courses; the two co-instructors, John Sampson and John Jones, for their invaluable assistance during the course proceedings and careful analysis of the studied intersections; and the 90 course delegates for their valuable analyses and constructive criticism of the applications.

REFERENCES

1. Highway Capacity Manual 1965. HRB Special Report 87. HRB, National Research Council, Washington, D.C., 1965, 397 pp.
2. JHK & Associates and Traffic Institute, Northwestern University. Urban Signalized Intersection Capacity. Draft Report, NCHRP Project 3-28(2). TRB, National Research Council, Washington, D.C., Dec. 1981.
3. JHK & Associates and Traffic Institute, Northwestern University. Urban Signalized Intersection Capacity. Draft Report, NCHRP Project 3-28(2). TRB, National Research Council, Washington, D.C., May 1982.
4. JHK & Associates and Traffic Institute, Northwestern University. Urban Signalized Intersection Capacity. Draft Report, NCHRP Project 3-28(2). TRB, National Research Council, Washington, D.C., Feb. 1983.

Publication of this paper sponsored by Committee on Highway Capacity and Quality of Service.

Evaluating Capacities of One-Lane Roads with Turnouts

FONG-LIEH OU

ABSTRACT

Speed-flow relationship models for one-lane roads with two-way traffic are developed. Each model considers a composite variable of speed divided by the traffic distribution ratio as a dependent variable and both traffic distribution ratio and volume as independent variables. The traffic distribution ratio represents the degree of traffic conflict and is measured as the percentage of one-way traffic on the heavy-traffic direction to total traffic. A 1982 traffic survey of four study sites in the Mount St. Helens Monument region forms the data base. The following are specific findings of the study: (a) Model specification and coefficients, including elasticities, are stable. (b) The capacity of a single-lane road with turnouts may exceed 400 vehicles per day without reaching the congested-flowing situation when the majority of traffic is controlled by citizen band radios. (c) Speed is more sensitive to traffic distribution than to volume. (d) The predictive ability of the developed models has been validated at nine study sites with satisfactory results. The results of this study provide road engineers and managers some guidelines for selecting the most cost-effective design standard and management strategy for one-lane roads with turnouts.

The Highway Capacity Manual (1,p.5) defines capacity as "the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a road in one direction (or in both directions for a two-lane or a three-lane highway) during a given time period under prevailing roadway and traffic conditions." This definition is not applicable to a one-lane road with turnouts that is managed for two-way traffic. The reason for building one-lane roads with two-way operation is that low traffic demand cannot economically justify building multilane roads. Multilane roads provide a high level of service, but they require a great amount of traffic demand to offset high construction and maintenance costs. The configuration of a typical one-lane road with turnouts is shown in Figure 1. The width of one lane ranges from 12 to 14 ft.

The U.S. Department of Agriculture Forest Service is probably the largest organization in the world to promote and manage two-direction traffic on one-lane roads with turnouts. Over the years, the Forest Service has built a 270,000-mile forest road system. More than 72 percent of the system consists of one-lane roads. The design standards of one-lane roads were determined by either speed or travel-time delay based on the 1960 Logging Road Handbook: The Effect of Road Design on Hauling (2). It was not until 1981 that volume was considered one of the criteria for evaluating traffic service (3). However, because the mathematical relationship between volume and traffic performance has not been defined, there is difficulty implementing this new concept. Volume is used primarily for determining long-term traffic demand (such as daily, seasonal, and annual traffic) rather than short-term system supply (such as hourly volume) in terms of capacity.

Defining capacity of forest roads is difficult because the traffic on them rarely reaches capacity. In 1982 it was expected that certain road segments in the Mount St. Helens Monument region might exceed their design capacity because, as a result of the May 18, 1980, volcanic eruption, approximately 900 million board feet of salvage timber were scheduled to be hauled to market in two seasons. The Forest Service took this opportunity to select 22 sites for a traffic study. Although the preliminary results concerning speed related to design standards have been reported elsewhere (4), the data collected in this study also permit an analysis of the relationship between volume and traffic performance to assess the capacity of low-volume roads.