Figure 5. Sample output of 5-min summaries and overall summary for data location.

DATE	TIME	W/S	PLATOONS/LEADER TOT	CA	TR	RE	OT	VEHICLE COUNTS CAR	TR	RE	OT	MAI	OPP	TOT
905	945	O D	17	12	4	1	0	19	4	1	0	24	36	60
905	950	O D	18	18	0	0	0	29	1	0	0	30	23	53
905	955	O D	18	17	1	0	0	37	1	0	0	38	26	64
905	1000	O D	17	16	1	0	0	28	3	0	1	32	47	79
905	1005	O D	17	14	3	0	0	27	5	0	0	32	42	74
905	1040	O D	18	13	5	0	0	30	6	0	0	36	28	64
905	1045	O D	10	6	3	0	1	11	3	0	1	15	16	31
905	1050	O D	14	12	1	1	0	24	2	1	0	27	30	57
905	1055	O D	25	23	2	0	0	35	2	0	2	39	32	71

DATE	TIME	PCU PER HOUR MAI	OPP	TOT	SPEED AVG	LO	HI	PERCENTILE SPEEDS 10	20	30	40	50	60	70	80	90
905	945	342.	513.	855.	91.	82.	104.	84.	86.	88.	89.	90.	91.	92.	95.	99.
905	950	372.	285.	657.	88.	75.	110.	77.	79.	80.	82.	85.	91.	94.	95.	104.
905	955	468.	320.	788.	83.	61.	98.	64.	76.	79.	81.	84.	87.	91.	93.	96.
905	1000	432.	635.	1067.	83.	74.	95.	75.	76.	78.	80.	82.	84.	87.	89.	91.
905	1005	444.	583.	1027.	87.	79.	108.	82.	83.	84.	85.	87.	88.	90.	91.	93.
905	1040	504.	392.	896.	80.	70.	98.	71.	72.	75.	77.	78.	81.	84.	86.	94.
905	1045	228.	243.	471.	81.	70.	91.	70.	73.	78.	82.	83.	83.	85.	86.	90.
905	1050	354.	393.	747.	83.	69.	96.	71.	75.	76.	78.	80.	86.	91.	94.	95.
905	1055	516.	423.	939.	90.	77.	112.	79.	83.	84.	85.	86.	89.	92.	98.	104.

***** SUMMARY OF LOCATION 7 E 1 *****

		VEHICLE	COUNTS-PERCENT		LEADS-PERCENT		VOLUMES	
5-MIN PERIODS :	132	CARS :	3994	90.8	1924	89.6	MAIN :	4398
TOT PLATOONS :	2148	TRUCKS :	266	6.0	151	7.0	OPPOS :	4023
		RECS :	71	1.6	46	2.1	TOTAL :	8421
		OTHER :	67	1.5	27	1.3		

suring speed and obtaining detailed traffic counts for both directions during periods of low-traffic demand makes the radar-platoon technique a very efficient data-collection method. A 5-min counting cycle length was selected for the Ontario study because it is long enough for statistical aggregation while it remains short enough to reflect any short-term fluctuation.

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Validation of Signalized Intersection Survey Method

A.J. RICHARDSON AND N.R. GRAHAM

The development and validation of a manual survey method for the measurement of performance at signalized intersections are described. The method is easy to use in the field and simply requires that queue lengths and flows be measured at particular times within each cycle of the traffic signals on each approach being surveyed. The output of the program includes frequency distributions and summary statistics for measures of approach delay, stopped delay, stationary queue length, and various definitions of vehicular stops. The validation of the survey method was performed by comparison of survey measurements with measures obtained from a videotape recording of intersection operation. The comparison was performed in two stages. First, results obtained from the field method were compared with results obtained by viewing a videotape of the same traffic stream and extracting the survey data from the videotape. This comparison identified the field observer error in the survey method. Second, the results obtained by using the survey method with the videotape were compared with detailed path-trace information obtained from the same videotape. This comparison identified the theoretical error in the analysis calculations associated with the survey method. The comparison shows that the field survey method produced negligible observer error while the theoretical error in the survey method was quite small and well within the bounds dictated by practical traffic engineering requirements. It is concluded that the survey method is a simple, yet accurate, way of determining signalized intersection performance levels.

The evaluation of signalized intersection performance has long been an issue of concern, a concern that has intensified in recent years with the changing emphasis in urban transportation planning. Tightening budgetary constraints have led to reduced capital expenditure on transportation and have been partly responsible for the present emphasis on transportation system management. Moreover, there has been an increasing need to acquire more knowledge of demand so that the management of it is both publicly acceptable and consistent with an efficient allocation of resources, both privately and socially. To this end, energy conservation, environmental consequences, and equity (in terms of resource allocation, e.g., time savings) have become important concerns. The measurement of intersection performance, for example, should no longer be concerned solely with the motorist but with societal goals as a whole and with the equitable allocation of resources to individual members of society.

Determination of the level of performance of a signalized intersection has application in traffic engineering planning and design, in the study of the effects of physical and operational improvements,

Figure 1. Original field survey form.

QUEUE LENGTH DELAY SURVEY

INTERSECTION DATE / /

APPROACH OBSERVER

START OF GREEN				LAST VEHICLE			START OF RED			
TIME			QUEUE LENGTH				TIME			QUEUE LENGTH
H	M	S		H	M	S	H	M	S	
A			B	C			D			E

Figure 2. Revised field survey form.

QUEUE LENGTH DELAY SURVEY

INTERSECTION DATE / /

APPROACH OBSERVER

START OF GREEN				LAST VEHICLE				START OF RED			
TIME			QUEUE LENGTH	TIME			FLOW AFTER	TIME			QUEUE LENGTH
H	M	S		H	M	S		H	M	S	
A			B	C			F	D			E

and in economic analyses. In particular, analyses of traffic-signal-control strategies, air and noise pollution related to vehicular traffic, road-user costs, evaluation of bus-priority schemes, effects of different objective functions for traffic-signal timing, and capacity and level-of-service calculations all require estimates of vehicular delay, stops, or other measures of performance.

The search for a measure of level of performance at an intersection takes its roots at the birth of the traffic engineering profession. An early work by Greenshields (1) used a 16-mm camera to capture traffic flow for subsequent analysis in the laboratory. Since then, a number of researchers (2-8) have continued the search for measures of performance. Reilly and others (8) have noted that in the evolution of performance-measurement techniques there have been two major problems. First, the definition of the performance-level criteria and second, the technique for obtaining such a measurement. Unfortunately, much of the previously reported work has not clearly defined either the phenomenon to be measured or the details of the measurement techniques.

To overcome many of the deficiencies of previous techniques, a new survey method was developed to assist in the evaluation of bus-priority signals (9). This method has previously been described by Richardson (10). Partly as a result of comments by Reilly (11), it was decided that this survey method should be subjected to a comprehensive validation study where survey method results would be compared with results obtained from a videotaped recording of intersection operation.

The purpose of this paper is to summarize the results of this validation study, which was sponsored by the Australian Road Research Board. This paper will only highlight the major points of the study; more complete details of the study may be found in a separate series of reports (12-17).

SURVEY METHOD DESCRIPTION

Before describing the validation study, it is necessary to provide details of the intersection survey method that is the subject of the validation study. The method has been initially described by Richardson (10). Since that time, however, the method has been substantially revised and improved, such that the present analysis program bears little resemblance to the one described earlier. A more up-to-date description of the theoretical background to the analysis procedure may be found in Richardson (14).

The survey method may be described in terms of three components: input, output, and special features of the analysis. The method offers two options with respect to the input data to be collected. The original version of the method, as described in Richardson (10), requires four items of data to be collected in any one cycle of the traffic signals on each intersection approach being surveyed. An example of the survey form used in the field is shown in Figure 1. At the start of the green phase, the time is recorded in column A and the number of vehicles stopped in the queue is recorded in column B. A mental note is made of the last vehicle in the queue at the start of the green and, when the queue moves off, the progress of this vehicle is noted. If this end-of-queue vehicle crosses the stop line before the signal changes back to red, then the time at which it crosses the stop line is recorded in column C. The time at which the signal changes back to red is then recorded in column D (column E, in this case, is left blank). If the end-of-queue vehicle does not cross the stop line before the lights change back to red, the time at which the lights change to red is recorded in column D and the number of vehicles in front of and including this vehicle when the new queue forms is recorded in column E (column C, in this case, is left blank). This process is repeated for every cycle in the survey period.

A limitation inherent in using the survey method with only these data is that it must be assumed that the arrival rate that was observed during the red period in each cycle continues through the following green period. Similarly, the move-off rate observed for vehicles up until the last vehicle in the queue at the start of the green is assumed to continue for all vehicles that depart in the current cycle. As noted by Reilly (11), both these assumptions may be invalid under certain circumstances (e.g., coordinated signals or flared intersection approaches). To enable the survey method to be used in such situations, a modification was made to the data-collection procedure that, while slightly increasing the workload in the field, allows for different arrival rates during the red and green phases and for changing move-off rates during the green phase. The modified field survey form is shown in Figure 2. The procedure is identical to that described above with respect to Figure 1 except that after the last vehicle in the queue at the start of the green has crossed the stop line, the observer counts the number of vehicles that then cross the stop line before the signals turn red and records this flow in column F. If the end-of-queue vehicles does not cross the stop line before the signals turn red, then columns C and F are left blank and column E is completed as before.

Given these relatively meager input requirements, the survey method produces a very comprehensive range of output statistics. Specifically, it produces frequency distributions and summary statistics (mean and standard deviation) for the following performance measures: approach delay, stopped delay, number of complete stops, number of effective stops (for use in fuel-consumption calculations), and maximum stationary queue length in the cycle. The total flow across the stop line and a complete record of signal phasing and timing are also obtained from the analysis program.

In calculating these output statistics, the analysis program (QDELAY) makes use of a number of special features that have hitherto not been incorporated in intersection survey method calculations. The analysis program is based on the construction of trajectory diagrams for vehicles that pass through the intersection. In calculating approach delay, use is made of the finding of Allsop (18) that, by considering vehicles with infinite acceleration and deceleration rates, the approach delay is equal to the length of the horizontal sections of the trajectories. The QDELAY program, however, extends this concept to include approach delay that is incurred after the vehicle crosses the stop line (i.e., while the vehicle is accelerating back up to cruise speed). This extension overcomes a problem that is evident in most, if not all, previous survey methods where approach delay is confined to being upstream of the stop line. Such a restriction may be most significant in situations where the average queue length is short, with a substantial amount of approach delay being incurred downstream of the stop line.

In calculating stopped delay, the time spent in deceleration and acceleration maneuvers is subtracted from the approach delay for each vehicle to reveal the time spent stopped. In many cases, the stopped delay may be zero when the vehicle does incur approach delay. The rates of acceleration and deceleration used in this calculation are user specified and may be chosen to suit the particular site in question.

The calculation of vehicular stops allows for two basic options. First, it is possible to calculate conventional measures of vehicular stops, such as the average number of complete stops per vehicle or the proportion of vehicles that are stopped. Second, because the number of vehicular stops is often used to calculate fuel consumption, it is possible to calculate a more appropriate measure of vehicular stops (termed effective stops) that allows for the effects of partial stops (that is, vehicles that slow down but do not completely stop) and queue-shuffling stops (where vehicles in saturated traffic conditions stop and "shuffle" forward several times before clearing the intersection). From the above discussion, it is obvious that the survey method can be used in saturated, as well as unsaturated, traffic conditions.

One final point that concerns the survey method is that, as described in Richardson (10), it can be used on approaches with more than one lane by defining a representative end-of-queue vehicle. The only restriction in using the method in this way is that flow characteristics (in particular, the move-off rate) should be similar in each lane.

VALIDATION OF STUDY DESIGN

The objectives of the validation study were to identify both the theoretical and observational errors in the survey method. To this end, the validation study incorporated three distinct data-collection phases:

1. Field observers used the survey method to measure intersection performance.
2. Concurrently, intersection operation was recorded on videotape. Later, observers viewed the videotapes in a laboratory and used the same survey method to record the level of intersection performance.
3. By using the same videotaped recording of intersection operation, independent measures of intersection performance were obtained, to a high level of precision, by tracing the individual movements of a sample of vehicles through the intersection.

By comparing the results of phases 1 and 2, the observational error could be ascertained. A comparison with the results from phases 2 and 3 would reveal the theoretical error in the survey method calculations.

The main difficulty in the survey design was to find study site locations, given a rather formidable list of constraints in camera location, traffic flow conditions, general site characteristics, and time and budget constraints. Two isolated, signalized intersection sites were finally chosen (Nicholson Street and Beaconsfield Parade). Both sites are located approximately 3 km from the Melbourne central business district (CBD). The sites were chosen to give a wide variety of traffic conditions, including both peak and off-peak periods. At the Nicholson Street site, a total of 15 h of data was collected, comprising 4 h in the morning peak, 4 h in the evening peak, and 7 h during the afternoon off-peak. At the Beaconsfield Parade site, a total of 4 h of data was collected, all in the morning peak period. At the Nicholson Street site, where there were two approach lanes, data were collected separately for each lane. At the Beaconsfield Parade site, where there were three through lanes, data were collected for both separate and multiple-lane situations. By allowing for different combinations of the times of the surveys and the lane configuration, a total of 50 data sets was obtained for comparison.

The collection of data by using the survey method in the field was relatively straightforward by using the techniques described earlier in this paper [and in Richardson (15)]. When using the survey method in the laboratory, observers made full use of the stop-frame action of the videotape playback in order to make observations with great accuracy (e.g., to count the number of vehicles in a long queue).

In using the path-trace method, a number of factors needed to be accounted for. The definition of an approach-delay section was an essential prerequisite to the collection of path-trace data. The upstream end of the section was defined to be an easily identified point some 100-m upstream from the longest expected queue. The downstream end was defined to be the stop line at the intersection. This was necessary in order to ensure that the video-camera was close enough to the intersection to obtain a reasonable view of the stationary queue. The definition of the approach-delay section in this way, however, required that the ability of the QDELAY program to calculate approach delay incurred after the stop line be neglected for the validation study comparisons.

In using the path-trace method, it is necessary to make an assumption about the free speed of vehicles through the approach-delay section in order to calculate the delay in this section. The free speed was calculated in two ways. First, the speeds of vehicles that passed through the section unimpeded were obtained from the path-trace records, and the free speed was set equal to the 85th percentile point of the distribution of unimpeded speeds for that approach and time of day. Second, as part of a study to determine deceleration rates at the intersections, an estimate was obtained of the speed at which all vehicles, whether impeded or not, approached the intersection. Both methods gave very similar results at both Nicholson Street and Beaconsfield Parade.

Extraneous vehicles (that is, vehicles that do not cross both the upstream and downstream ends of the approach-delay section) were eliminated from all path-trace calculations because of the difficulties of defining delays for such vehicles. At each site, extraneous vehicle activity was approximately 20 percent of the total flow across the stop line. Since many delay measurements were made on a lane-by-lane basis, it was necessary to allocate each vehicle in the path-trace survey to a particular lane. As with Reilly and others (8), vehicles were allocated to the lane in which they crossed the stop line. Although it is acknowledged that the path-trace method does not give completely accurate results, it was considered that such results were as close to the true situation as could be obtained within reasonable budgetary limits. Support for this contention may also be found in Reilly and others (8), which indicates that path-trace results provide a reasonable basis against which to compare the survey method results.

Figure 3. Comparison of survey results when used in field and in laboratory.

Table 1. Regression of path-trace results against measures obtained from use of survey method in laboratory.

Variable	Regression Coefficients[a]		Correlation Coefficients		
	Intercept a	Slope b	r[b]	r^2	E
Approach delays					
Total	-456 ± 847	0.94 ± 0.06	0.98	0.96	0.92
Avg	-1.72 ± 1.44	0.99 ± 0.05	0.99	0.97	0.95
SD	-0.45 ± 1.23	0.91 ± 0.06	0.97	0.95	0.87
Stopped delays					
Total	43.3 ± 4563	1.06 ± 0.05	0.99	0.98	0.97
Avg	0.50 ± 1.14	1.01 ± 0.05	0.98	0.97	0.96
SD	-0.80 ± 1.28	1.01 ± 0.07	0.97	0.94	0.93
Number of stops					
Total	9.00 ± 18.5	1.06 ± 0.04	0.99	0.98	0.96
Avg	0.10 ± 0.04	0.92 ± 0.05	0.98	0.96	0.91
SD	0.18 ± 0.10	0.56 ± 0.20	0.62	0.39	-0.63
Number stopped					
Total	-0.80 ± 19.0	1.11 ± 0.05	0.99	0.98	0.94
Proportion	0.13 ± 0.04	0.88 ± 0.06	0.97	0.94	0.83
Vehicular volume–total	0.00 ± 0.00	1.00 ± 0.00	1.00	1.00	1.00

[a]Coefficient ± 95 percent confidence interval for coefficient.
[b]r always significantly different from zero at 0.05 level (Fisher's Z-test).

VALIDATION OF STUDY RESULTS

In presenting the results of the validation study, two different types of analyses are described. The first is a comparison of the performance measure summary statistics obtained for each of the 50 data sets (i.e., the 50 combinations of survey site, survey time, and lane configuration). The second analysis is a comparison of the frequency distribution predicted and observed for each of the performance measures.

In presenting these results, only those obtained by using the expanded survey method are shown (i.e., by using the survey form shown in Figure 2). For the study sites, there was no appreciable difference between results obtained by using either of the survey forms, mainly because each intersection was isolated from upstream intersections and hence the arrival rates in the red and green periods were approximately equal. It should also be noted that there was no difference between results obtained by using the survey method in the field and in the laboratory (see, for example, Figure 3). This implies that there was little or no observer error in recording queue lengths or signal timings in the field. Independent comparison of queue-length estimates in the field and in the laboratory confirmed this impression, although queue-length estimates in the field were marginally smaller than those in the laboratory. Signal-timing observations in the field were also quite accurate. It should be noted, however, that digital stopwatches were used in the field surveys and this eliminated many timing errors that might have occurred if normal wrist watches had been used for timing. Also, the data-entry program used in QDELAY automatically detects obvious timing errors and allows for correction of these errors. A more complete description of the comparison between survey method results obtained in the field and in the laboratory may be found elsewhere (16).

To examine the theoretical error in the survey method calculations, a comparison of summary statistics is presented both in tabular and graphical fashion. Table 1 summarizes the results of regression analyses conducted when measures of delay, stops, and vehicular volume obtained from the survey method in the laboratory were compared with the same measures obtained from the path-trace method. These regression analyses were conducted with all 50 data sets (i.e., both sites, all times of day, and all lane configurations), each contributing one data point to the analysis.

The regression equation used was of the form

$$Y = a + bX \quad (1)$$

where

Y = performance measure obtained from the survey method in the laboratory,
X = performance measure obtained from the path-trace method, and
a,b = estimated regression coefficients.

As can be seen in Table 1, most measures were predicted by the survey method with a high degree of consistency, as indicated by the high values of r^2. More importantly, the survey method and the path-trace method give nearly equal values of the performance measures, as indicated by the high value of E. This value, termed the coefficient of efficiency (19), may be used to test for bias in the regression relation. If the results from the survey method and the path-trace method are highly correlated but biased (i.e., the data points do not lie evenly around the Y = X line), then E will be much less than r^2. If there is no bias in the relation, then $E = r^2$. With the exception of the regression for the standard deviation of the number of stops per vehicle, the high values of r^2 and E indicate excellent agreement between the survey method and path-trace results.

Two other indications of the agreement between the two survey methods may be seen in the size of the intercepts and slopes of the regression lines. If there was perfect agreement between the two methods, the intercept would be equal to zero and the slope would be equal to one. It can be seen that, in most cases, the 95 percent confidence limits include the desired value of either the intercept or the slope, which indicates excellent agreement.

The conclusions that may be drawn from Table 1 may be reinforced by reference to Figures 4 through 7, which show the data points, regression lines, and confidence limits for a number of different performance measures. For each of the measures shown, which are the most important outputs of the survey method, it is obvious that there is quite good agreement between the two methods of collecting data on intersection performance.

The second type of analysis of the results is to compare the frequency distributions of the performance measures obtained from each of the survey methods. In comparing these distributions for ap-

Figure 4. Comparison of average approach delays.

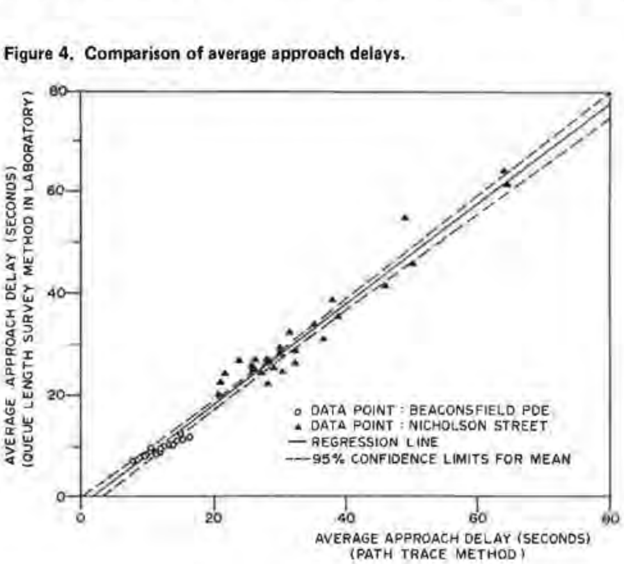


Figure 5. Comparison of standard deviations of approach delay.

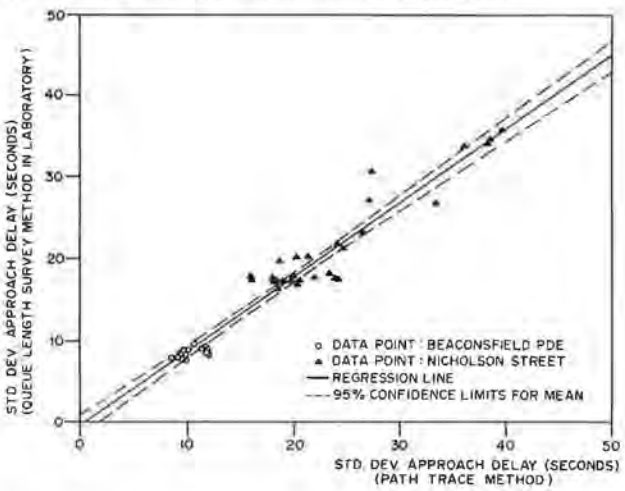


Figure 6. Comparison of average stopped delays.

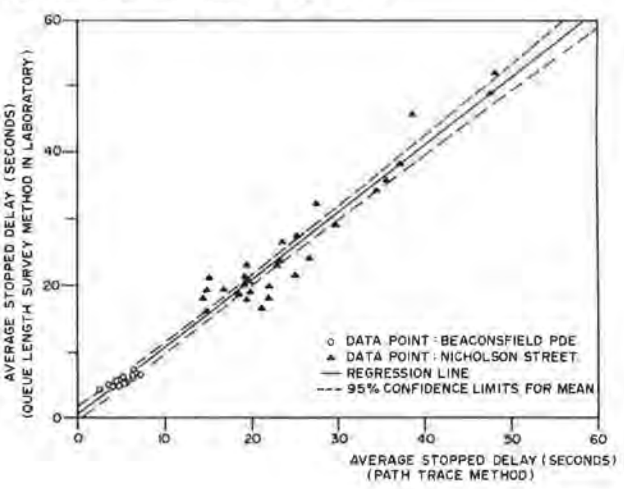


Figure 7. Comparison of number of complete stops per vehicle.

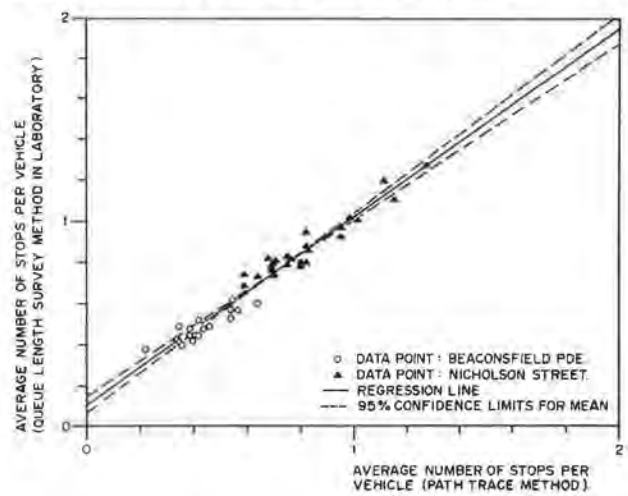


Figure 8. Comparison of approach-delay distributions (Nicholson Street).

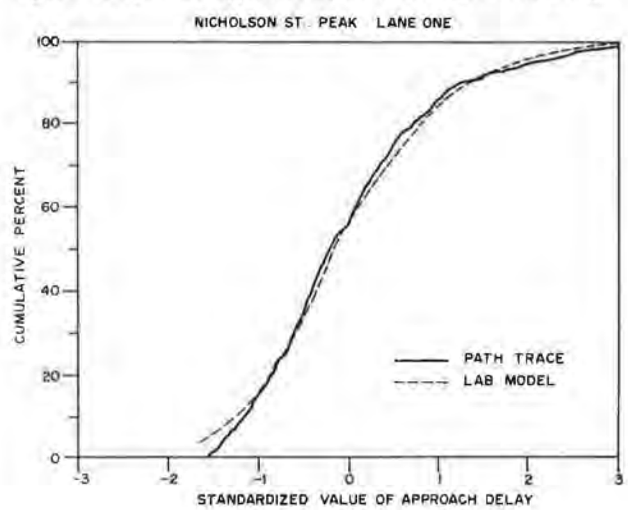


Figure 9. Comparison of approach-delay distributions (Beaconsfield Parade).

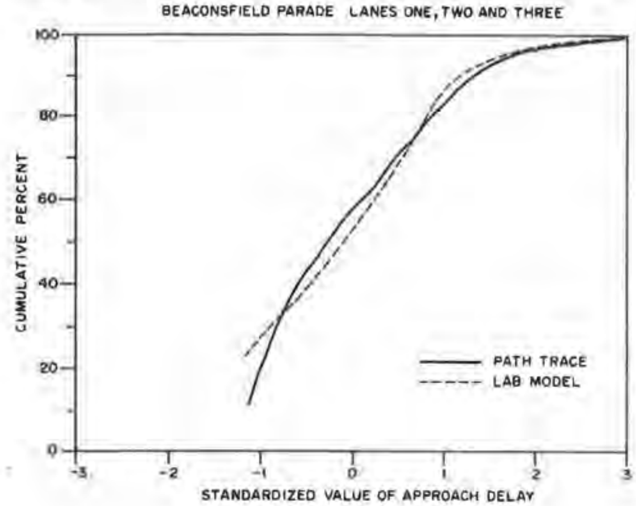


Figure 10. Comparison of stopped-delay distributions (Nicholson Street).

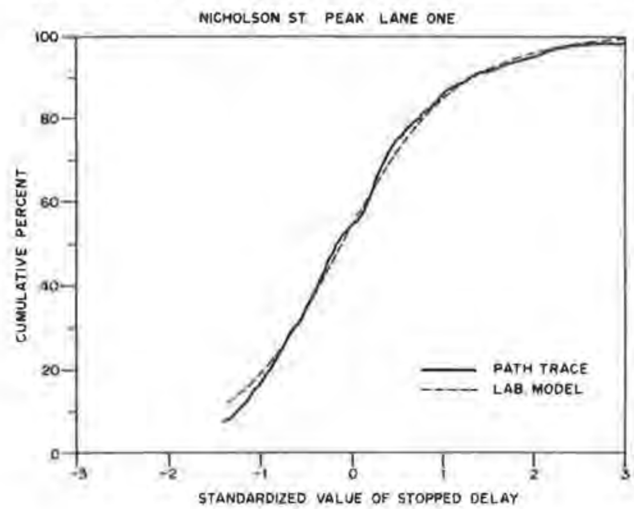
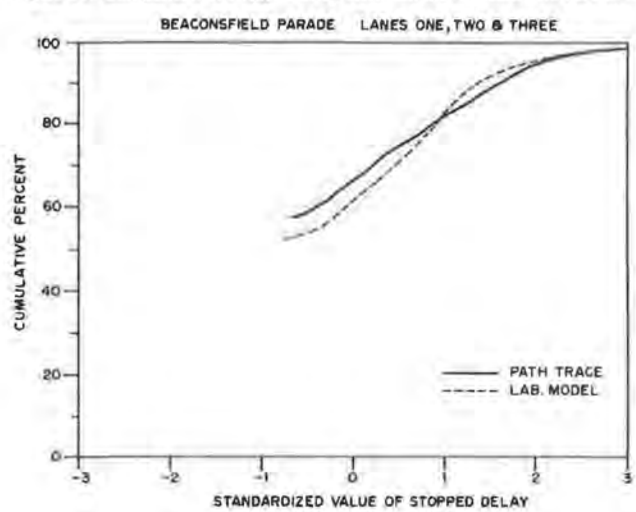


Figure 11. Comparison of stopped-delay distributions (Beaconsfield Parade).



proach delay and stopped delay, the analysis was conducted separately for each site, time of day, and lane across stop line. Although it is not possible to present all these results [see Richardson and Graham (16)], Figure 8 and 9 show typical results for approach delay obtained for Nicholson Street and Beaconsfield Parade, respectively. It is clear that the agreement between the shape of the distributions is better at the Nicholson Street site, although it is far from poor at Beaconsfield Parade. Note that the results shown for Beaconsfield Parade are for the case where all three lanes are combined in the one data set, thus necessitating the use of a representative end-of-queue vehicle, as described earlier. At both sites, the approach-delay distribution shows a characteristic skew to the right.

The distributions of stopped delay for typical cases at both sites are shown in Figures 10 and 11. Again it can be seen that Nicholson Street data produce better agreement than Beaconsfield Parade data, when the proportion of vehicles that suffer no stopping delay is slightly overpredicted by the queue-length survey method. However, considering that the distributions from the queue-length survey method are synthesized from the relatively simple input data whereas the path-trace distributions are constructed from measures of individual vehicle performance, the agreement between the distributions is quite satisfactory.

CONCLUSION

This paper has described the validation of a survey method for the measurement of performance at signalized intersections. The input and output of the method have been described and some features of the analysis program have been discussed. The conduct of the validation study has been described and some of the results of the study are presented. On the basis of the results presented (and those contained in other, more complete, reports), it is concluded that the survey method produces a wide array of output statistics to a high degree of accuracy (when compared to observations by using a path-trace method). Despite the comprehensive nature of the outputs, the input to the survey method is relatively simple and requires few resources in terms of personnel and equipment. It is anticipated that the survey method should find ready application in many signalized intersection survey studies.

ACKNOWLEDGMENT

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Computer-Controlled Videotape Display: An Innovation in Traffic Analysis

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Although videotape equipment has been available to traffic researchers and engineers for over a decade, its uses have been limited to routine applications. However, the recent development of microcomputers and interface equipment facilitate the use of videotape (and videodisc) in research applications. Current research under contract to the Iowa Department of Transportation is detailed where computer-videotape simulations of uncontrolled intersections elicit responses by a sample drawn from a public location. Data are presented to demonstrate (a) the efficacy of the videotape-computer research approach as well as (b) useful findings that suggest the presence of word-oriented versus symbol-oriented subgroups in the adult population, each having very different responses to various warning signs.

Television and videotape have been used as traffic engineering data-collection tools in a variety of ways within the past decade as portable camera-recorder systems became generally available (1-5). Some of these uses have included collecting data on the speed of vehicles; lane placement of vehicles; license-plate vehicle identification for monitoring vehicles through a portion of a system; accident surveillance on bridges, tunnels, and freeways; and emergency traffic operations coordination. Videotape is being commonly used in education and training activities. This use is not, however, as extensive as is commonly thought by persons outside of education. In this paper, we presume such use to be common knowledge. In a similar fashion, the general availability of small personal computers (32K-64K memory) for use in both traffic engineering and education activities is assumed to be common knowledge. What is new on the technological scene is an interface board to permit a microcomputer to control a new generation of video player-recorders. This combination provides a new analysis tool (6). This paper outlines how this new tool has been incorporated into an innovative analysis of rural road signing through some creative computer programming.

PROBLEMS IN SIGNING

Several Iowa counties were frustrated in their attempts to communicate with people driving their extensive network of low-volume gravel rural roads. When these low-volume gravel roads intersect in the rolling Iowa terrain, a variety of factors interact to create seasonal (or sometimes continuously) hidden intersections. Some examples include the following:

1. Tall corn growing, planted to the very edge of the right-of-way (or perhaps in the right-of-way);
2. Trees at farmsteads in the corner quadrants of the intersecting roads;
3. Sharp curves within narrow cuts;
4. Densely wooded areas on curves; and