EVALUATION OF INTERSECTION-DELAY MEASUREMENT TECHNIQUES

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The purpose of this study was to evaluate two intersection-delay measurement techniques. As a result of an extensive literature review, two methods were chosen to be the most practical for field application: the Sagi-Campbell method, which determines "aggregate" intersection delay from measurements of inflow, outflow, and length of queues at various points during each cycle, and the Berry-Van Til sampling method, which measures stopped delay counts of the number of stopped vehicles at predetermined time intervals. A two-lane intersection approach in Arlington, Virginia, was recorded on closed-circuit real-time television and filmed simultaneously on time-lapse super-8 movie film for four 1-hour periods. Traffic conditions varied from extremely low to very high saturated flow. Data were extracted while videotapes were played back. Delays computed from the time-lapse photography were used as bases for comparison of results from either of the two test methods. In addition, results by the Sagi-Campbell method were compared with delays measured by the traffic flow meter. Relations between volume and delay and queue length and delay were investigated. Neither one of the methods produced consistent trends in predicting delays as compared to the traffic flow meter or photographic methods used as bases. Even the base methods failed to give consistent, direct relations.

•SEVERAL years of widespread use of the signalized intersections section of chapter six of the Highway Capacity Manual (HCM) (1) have revealed a variety of problems ranging from difficulties with adjustment factors for some specific conditions to entire concepts such as load factor, peak-hour factor, and level of service. Also, users of the HCM indicate that it tends to predict higher volumes than are actually attainable at a given level of service, which means that underdesign may well be occurring where the HCM is used for design purposes (2, 3, 4). The HCM is also being criticized because it does not give ample weight and direct consideration to factors such as delay, effect of pedestrians, number and width of lanes in each approach, and opposing traffic volumes.

The Federal Highway Administration (FHWA) in cooperation with the Highway Research Board (HRB) is sponsoring a new nationwide data-gathering and analysis effort to update the intersections data in the HCM. It is intended that the new data will be collected and analyzed while taking into consideration all possible factors that might prove relevant in the performance, operation, and capacity of intersections.

In order to determine the state of the art and to single out for evaluation potential study methods that might lead to simpler and more accurate results, we conducted a thorough literature review on the subject of intersection capacity and performance. This review provided very limited concrete conclusions as to better methods of determining levels of service at individual intersections. The majority of the authors seemed to conclude, however, that delay was the most desirable and tangible measure.

Ideally, it was desirable to find a method whereby, given a set of easily and simply observable traffic conditions at an intersection, it would be possible to determine the delay experienced under those conditions.

A special HRB advisory subcommittee working with FHWA staff reviewed several available methods of measuring level of service for individual intersections. The subcommittee concluded that delay was potentially the best general measure of level of service at intersections and that stopped delay was the most practical measure. Two methods of study of delay, the Sagi-Campbell method (5) and the Berry-Van Til sampling method (6), appeared to be most promising so far as simplicity and ease of uniform application throughout the country are concerned. The subcommittee recommended a two-stage pilot study: the first stage to select one of these methods of observation and data-collection techniques and the second stage to determine the variance of delay and service volumes measured by the selected method of observation under different conditions.

In the first stage, in addition to observations by the Sagi-Campbell method and the Berry-Van Til sampling method, data were to be collected by the traffic flow meter method (7) and the photographic method (8). These data were to be used as a base, and results by the other two methods were to be compared to either one of the base measurements. All four methods were to be tried concurrently on one intersection approach for a period of about 4 hours under variable traffic flow conditions, i.e., from light, off-peak flows to heavy peak-hour traffic observations. The selection of the study method for nationwide application was also to take into consideration factors such as comparable manpower requirements, complexity of field measurements and data analysis, and uniformity of results under varying traffic conditions.

During the second stage, the selected method would be applied to several intersection approaches and under several traffic flow conditions. Several replications would be conducted at each intersection approach.

This report describes the findings of the first phase of the recommended study.

DATA COLLECTION AND ANALYSIS

Because of the high manpower requirements of conducting all four study methods of observation concurrently and the unreliability of the weather in the Washington, D.C., area during the winter months, it was decided to investigate the possibility of using real-time closed-circuit television photography. The data would then be extracted while playing back the video tapes for each of the study methods. The television real-time method was tested for a 1-hour study. Results from data extracted from the television playback varied by less than 5 percent from the field manual counts taken during the same period (the difference most likely being due to errors in the field manual counts); therefore, the television real-time method was accepted as a satisfactory substitute to manual field observations.

The photographic field data were collected on February 8, 1972, from 10:30 a.m. to 5:30 p.m. The southbound approach of the intersection of Jefferson Davis Highway and 23rd Street in Crystal City, Arlington, Virginia, was photographed for four 1-hour periods from the top floor of a high-rise office building. The approach is a two-lane, typical approach providing right- and left-turn movements without any special turning lanes or signal phases reserved for turning movements. The distance to the upstream signalized intersection is approximately 700 ft. The signal, although traffic-actuated, operated as fixed-time throughout the study period. There was no evidence of any signal coordination or traffic progression. The cycle length was 74 sec with a 36-sec green-and-yellow phase and a 38-sec red phase for the southbound approach. Figure 1 shows a photograph of the intersection taken from the television screen. Traffic conditions varied from extremely low volumes at about 11:00 a.m. to very heavily congested (oversaturated) conditions between 4:00 p.m. and 5:00 p.m. The weather was clear and cold. A Shibaden video camera, recorder, and monitor were used for the real-time closed-circuit television recording, and a Minolta super-8 movie camera system, operating at one frame per second, was used for the time-lapse photography.

During the last two observation periods (from 3:00 p.m. to 4:02 p.m. and from 4:15 p.m. to 5:17 p.m. when traffic conditions were changing from light to heavy and extremely heavy), short-duration manual counts were conducted at the street level by both the Sagi-Campbell method and the Berry-Van Til sampling method to identify any

difficulties that might be experienced by field personnel during periods of heavy traffic-flow conditions and evaluate comparative ease of conducting each method. Data from these short-period counts were compared with data extracted from the video tapes and the movie film as a further test.

Data from the video tapes were extracted by viewing each 1-hour tape on a 16-in. television screen for each method of analysis. Data were collected by lane and by cycle for the traffic flow meter method and for the Sagi-Campbell method and by 1-min intervals for the Berry-Van Til sampling method. Tables 1 and 2 give a summary of the data collected by the various methods.

Traffic Flow Meter Method

Basically, the traffic flow meter consists of four digital counters and one elapsed-time recorder. The digital counters record the number of vehicles entering the section of a single traffic lane under study, the number of vehicles leaving the study section, the difference between the number of entering and leaving vehicles, and the number of accumulated vehicle-seconds to pass from the "in" point to the "out" point. A vehicle was recorded in the in counter as it joined the end of a queue at the intersection approach, and it was maintained there until it cleared the intersection. If there was no queue, the vehicle was recorded in at the instant its front wheels crossed the stop line, and it was recorded in the out counter the instant it cleared the intersection. In cases where a vehicle was not delayed while going through the study section, the in and out actuations were almost simultaneous. For every second the vehicle was within the study section, 1 vehicle-sec was accumulated on the vehicle-second counter. If two vehicles were within the section, 2 vehicle-sec were accumulated every second. At the end of every cycle, the number of in and out vehicles and the accumulated vehicle-seconds were recorded. The data were summarized for intervals of eight cycles, adding up to 10 min. The average delay per vehicle in seconds, for every 10-min interval, was calculated by dividing the total vehicle-seconds accumulated during the interval by the number of the vehicles out.

Sagi-Campbell Method

The Sagi-Campbell method of calculating intersection delay requires the following measurements by lane:

1. The number of vehicles in the queue in the approach of the intersection during the whole length of the cycle or until the queue is dissipated (count includes all the vehicles waiting when the light turns green plus the vehicles joining the queue during the green phase, and vehicles are considered to be in the queue when they are noticeably slowed down as they approach the tail of the queue),
2. The number of vehicles in the queue waiting at the beginning of each red phase,
3. The number of vehicles going through the intersection during each green plus yellow phase,
4. The total cycle length, and
5. The length of the red phase.

In this study, when volumes were low, one observer per lane could make all the required measurements. During periods when traffic volumes were high and queue lengths exceeded 20 to 25 vehicles per lane, one observer counted the queue length and another the outflow per lane. The number of vehicles waiting in the queue at the beginning of each red phase was determined by subtracting the outflow from the total queue length during each oversaturated cycle. The data were summarized for intervals of eight cycles, and the total delay for each interval was calculated by the equation

$$D = \sum_{j=1}^{N} D_j = \frac{R}{2}\left(\sum_{j=1}^{M} Q_j + \sum_{j=1}^{P} V_{oj}\right) + C \sum_{j=1}^{P} A_{j-1}$$

Figure 1. Study intersection.

Table 1. Traffic characteristics and delays (lane 1).

Period Number	Cycle	Beginning of Period	Total Volume	Trucks and Buses (percent)	Left Turns (percent)	Average Queue Length (vehicle per cycle)	Delay per Vehicle (sec) Flow Analyzer	Sagi-Campbell	Berry-Van Til Sampling	Photo Stopped	Photo Aggregate
1	1 to 8	10:53 a.m.	35	8.6	20.0	1.8	8.4	7.2	6.5	5.3	6.3
2	9 to 16	11:03 a.m.	47	8.5	8.5	2.5	9.2	8.1	–	6.3	8.0
3	17 to 24	11:13 a.m.	37	10.8	8.1	2.1	10.9	10.3	10.8	7.1	9.2
4	25 to 32	11:23 a.m.	61	9.8	16.4	4.2	13.2	10.3	–	8.2	11.0
5	33 to 40	11:33 a.m.	51	15.7	9.8	3.8	12.7	11.2	9.4	–	–
6	41 to 48	11:43 a.m.	55	18.2	3.6	2.8	10.8	7.5	–	–	–
7	1 to 8	12:03 p.m.	65	9.3	6.2	4.6	15.3	10.7	12.1	9.6	14.8
8	9 to 16	12:13 p.m.	46	4.3	13.0	3.2	12.3	10.5	–	7.2	9.8
9	17 to 24	12:23 p.m.	46	15.2	24.0	4.1	19.7	11.9	16.2	13.5	18.2
10	25 to 32	12:33 p.m.	59	8.5	13.5	3.5	8.0	8.7	–	4.6	6.7
11	33 to 40	12:43 p.m.	44	13.6	4.5	1.6	7.4	5.9	7.5	5.1	6.9
12	41 to 48	12:53 p.m.	47	14.9	29.8	5.2	26.7	18.6	–	18.1	25.2
13	1 to 8	3:01 p.m.	52	10.9	2.2	2.8	12.1	8.2	11.3	8.7	11.7
14	9 to 16	3:11 p.m.	57	5.3	10.5	3.1	10.7	8.5	9.8	7.3	10.2
15	17 to 24	3:21 p.m.	59	18.6	11.9	3.0	10.1	7.5	8.1	6.9	9.6
16	25 to 32	3:31 p.m.	79	19.0	1.3	4.9	12.0	9.5	12.7	7.5	12.1
17	33 to 40	3:41 p.m.	68	16.2	1.5	3.5	11.9	8.1	9.0	8.3	11.3
18	41 to 48	3:51 p.m.	72	12.5	1.4	4.1	10.0	8.8	8.4	6.8	9.1
19	1 to 8	4:16 p.m.	90	4.4	1.1	9.1	22.0	19.8	18.4	12.1	–
20	9 to 16	4:26 p.m.	98	11.2	1.0	14.6	41.3	36.4	34.2	23.4	–
21	17 to 24	4:36 p.m.	103	3.9	2.9	27.0	77.9	93.4	75.7	44.4	–
22	25 to 32	4:46 p.m.	105	4.8	4.8	30.6	102.8	119.4	77.2	57.7	–
23	33 to 40	4:56 p.m.	121	5.8	3.3	26.5	70.6	87.2	50.2	36.9	–
24	41 to 48	5:06 p.m.	115	4.3	3.5	27.0	72.8	78.4	54.2	39.3	–

where

D = total delay in vehicle-seconds for the interval;
M = the number of undersaturated cycles;
P = the number of oversaturated cycles;
N = $M + P$ = the total number of cycles in the interval;
R = the length of the red phase in seconds;
j = any cycle (jth) in the interval, $j = 1$ to $j = N$ (here, 8);
Q_j = the number of vehicles in the queue (includes both stopped vehicles and those that were noticeably slowed down and applies only to undersaturated cycles where the queue is dissipated before the beginning of the red phase);
V_{oj} = the outflow per cycle (applies only to oversaturated cycles where the queue does not dissipate before the beginning of the red phase);
A_j = the number of vehicles in queue at the beginning of the red phase;
A_0 = the initial A_j at the beginning of the study period; and
C = the cycle length in seconds.

The average delay per vehicle for every 8-cycle or 10-min interval was determined by dividing the total delay for that interval by the total number of vehicles that went through the intersection.

Berry-Van Til Sampling Method

Data for the Berry-Van Til sampling method were collected during three 10-min alternate intervals for each of the first two 1-hour light traffic periods and for six 10-min intervals for each of the last two 1-hour periods. One of the two observers per lane counted and recorded the number of stopped vehicles at the approach at the end of every 20-sec interval. The other observer recorded the outflow volume during each minute and classified the vehicles as stopping and nonstopping. The total delay for each 10-min interval was determined by adding all the stopped vehicles counted in the 20-sec intervals and multiplying the total by the interval period (20 sec). The average delay per vehicle for each 10-min sample was determined by dividing the total delay by the outflow, i.e., the number of vehicles counted during the 1-min intervals.

Time-Lapse Movie Film Method

Two different types of delay were calculated from the time-lapse movie films: a pure stopped delay, where a vehicle was considered being delayed only if it was actually stopped (locked wheels), and an "aggregate" delay, where a vehicle was considered being delayed from the time its speed was affected by the intersection condition (when it slowed down to join the end of the queue) until it cleared the intersection. This aggregate delay includes deceleration time, certain travel time while the vehicle is moving slowly in a platoon, acceleration time while the vehicle leaves the intersection, and stopped time.

Stopped delay was determined by counting the number of movie film frames in which each vehicle was stopped during every cycle. The total number of frames counted for all stopped vehicles during each cycle provided the delay per cycle in vehicle-seconds because the movie was taken at one frame per second. The average stopped delay per vehicle was determined by adding the total delays per cycle for eight cycles and dividing by the number of vehicles going through the intersection during the eight-cycle period.

Similarly, the aggregate delay per cycle was determined by summing the products of the number of vehicles in the queue by the number of frames of the same queue length. For example, if there were 3 vehicles in a queue for 6 frames, 4 vehicles for 20 frames, 3 vehicles for 3 frames, 2 vehicles for 1 frame, and 1 vehicle for 1 frame before the queue was dissipated, the total aggregate delay for that cycle would be 110 vehicle-sec.

The average aggregate delay per vehicle for each 10-min interval was determined by adding the total delays for each cycle as calculated previously and dividing by the number of vehicles going through the intersection during that interval.

RELATIONS EXAMINED

Although the HRB advisory subcommittee concluded that stopped delay was the most practical measure of level of service at intersections, it was not made clear what was considered to be stopped delay. Also, the Sagi-Campbell and the traffic flow meter methods were found not to lend themselves well for "pure stopped" delay analyses. Therefore, the relations of several degrees of delay were examined. The Sagi-Campbell, the traffic flow meter, and the photographic aggregate delay methods reflect delays that include some deceleration and acceleration periods. The Berry-Van Til sampling method was thought to reflect pure stopped delay, and it is comparable to the photographic stopped delay method that is considered to represent the minimum conceivable delay at the intersection.

Six types of relations were investigated for each lane:

1. A comparison of delays computed by the various methods of analysis (the five methods described previously) for each 10-min interval of the study period (Figs. 2, 3, and 4),
2. The volume-delay relation computed by the five methods (Figs. 5 and 6),
3. The average queue length-average delay relation computed by the five methods,
4. The volume-percentage variation of delay relation (using the traffic flow meter as base),
5. The volume-percentage variation of delay relation (using the photographic aggregate delay as base), and
6. The volume-percentage variation of delay relation (using the photographic stopped delay as base).

RESULTS AND FINDINGS

The following findings reflect interpretation of the initial plots of the field data:

1. During the low traffic-volume periods, from 11:00 a.m. to about 4:00 p.m., the delays computed by any of the five methods were generally uniform, ranging from 6 sec per vehicle to 35 sec per vehicle (Figs. 2, 3, and 4). The photographic stopped delay method produced the lowest delays. The Sagi-Campbell method generally was the next higher, although in some periods it dropped below the photographic stopped delay and in some others it produced the highest calculated delay. The photographic aggregate delay method was higher than the photographic stopped delay, and its curve followed the same pattern. The Berry-Van Til sampling method produced lower delays than the photographic aggregate method; however, it was not consistent. During several periods it was higher than the photographic aggregate method although the range of its variation was narrower. The traffic flow meter method produced the highest delays, and its curve followed the general pattern of the two photographic methods.

During the high traffic-flow period of the study, the data showed neither uniformity in, nor consistent relations among, the delays computed by the various methods. Although the Sagi-Campbell method produced the highest delay for the left lane (lane 1) during this period, it was considerably lower than the traffic flow meter in the right lane (lane 2). The Berry-Van Til sampling method produced delays that did not follow a consistent pattern of variation from either of the base delay methods.

2. When average delays, determined by the five methods, were plotted against volumes for 10-min periods (Figs. 5 and 6), there was considerable variation in delays, not only among methods but even within each method for the same volume. The Sagi-Campbell method, for example, produced delays of 8, 12, 19, and 26 sec per vehicle at a volume range of 46 to 50 vehicles per 10-min period and delays of 13 and 16 sec per vehicle at a volume range of 61 to 66 vehicles per 10-min period. This inconsistency applies to all methods, including the base methods. The highest average delay, 120 sec per vehicle, occurred at a volume of 105 vehicles per 10-min period. Above this volume, the average delay per vehicle dropped. At 115 vehicles per 10-min period, the average delay per vehicle was 73 sec.

3. The average queue length-delay relation showed some trend, although not consistently (Tables 3 and 4). As the average queue length per 10-min period increased,

Table 2. Traffic characteristics and delays (lane 2).

Period Number	Cycle	Beginning of Period	Total Volume	Trucks and Buses (percent)	Right Turns (percent)	Average Queue Length (vehicle per cycle)	Delay per Vehicle (sec): Flow Analyzer	Sagi-Campbell	Berry-Van Til Sampling	Photo Stopped	Photo Aggregate	Comment
1	1 to 8	10:53 a.m.	74	10.8	15.0	3.2	10.7	6.8	8.6	6.8	8.4	Bus loading (cycle 3)
2	9 to 16	11:03 a.m.	71	18.3	18.3	4.9	16.5	10.8	—	10.3	14.7	
3	17 to 24	11:13 a.m.	69	18.8	21.8	5.2	17.0	15.1	15.7	11.1	15.5	
4	25 to 32	11:23 a.m.	75	14.7	21.4	5.7	20.4	12.4	—	14.5	19.1	
5	33 to 40	11:33 a.m.	80	10.0	21.2	6.9	19.4	12.4	15.8	—	—	
6	41 to 48	11:43 a.m.	69	21.2	14.5	4.9	18.1	10.7	—	—	—	
7	1 to 8	12:03 p.m.	79	13.9	21.6	9.5	34.9	16.3	29.4	19.8	32.0	Bus loading (cycle 3)
8	9 to 16	12:13 p.m.	78	12.8	14.1	7.1	19.2	20.6	—	12.1	17.2	
9	17 to 24	12:23 p.m.	82	11.0	20.8	7.5	21.0	18.2	15.4	12.0	17.8	
10	25 to 32	12:33 p.m.	87	10.3	23.0	9.4	26.8	17.4	—	14.4	21.7	
11	33 to 40	12:43 p.m.	66	13.6	18.2	5.5	18.2	11.3	17.1	13.0	18.3	
12	41 to 48	12:53 p.m.	76	13.2	14.5	8.5	25.6	22.4	—	16.6	22.4	
13	1 to 8	3:01 p.m.	90	12.2	17.8	8.4	23.0	13.7	19.3	14.9	22.7	
14	9 to 16	3:11 p.m.	76	7.9	17.1	6.1	21.4	13.2	15.7	12.2	17.8	
15	17 to 24	3:21 p.m.	75	10.6	16.0	6.2	17.5	11.8	16.4	11.2	15.5	Bus loading (cycle 21)
16	25 to 32	3:31 p.m.	83	9.6	15.7	13.0	39.0	44.2	38.7	25.5	33.2	Bus loading (cycle 27)
17	33 to 40	3:41 p.m.	89	5.6	12.4	8.0	19.4	15.4	18.4	12.8	16.3	
18	41 to 48	3:51 p.m.	80	11.2	13.7	9.2	26.5	16.2	22.6	16.5	23.8	
19	1 to 8	4:16 p.m.	92	4.3	10.9	18.4	65.3	65.5	56.0	—	—	Bus loading (cycle 4)
20	9 to 16	4:26 p.m.	77	6.5	11.7	16.9	70.8	66.6	59.3	—	—	Right turn interference
21	17 to 24	4:36 p.m.	94	7.5	7.5	25.1	115.2	105.1	97.8	—	—	(road construction
22	25 to 32	4:46 p.m.	100	3.0	14.0	26.7	119.2	107.4	76.3	—	—	equipment)
23	33 to 40	4:56 p.m.	105	3.8	14.3	22.7	102.0	78.4	75.5	—	—	
24	41 to 48	5:06 p.m.	95	2.1	12.6	26.8	112.0	109.3	83.3	—	—	Bus loading (cycle 47)

Figure 2. Delays during off-peak periods (lane 1).

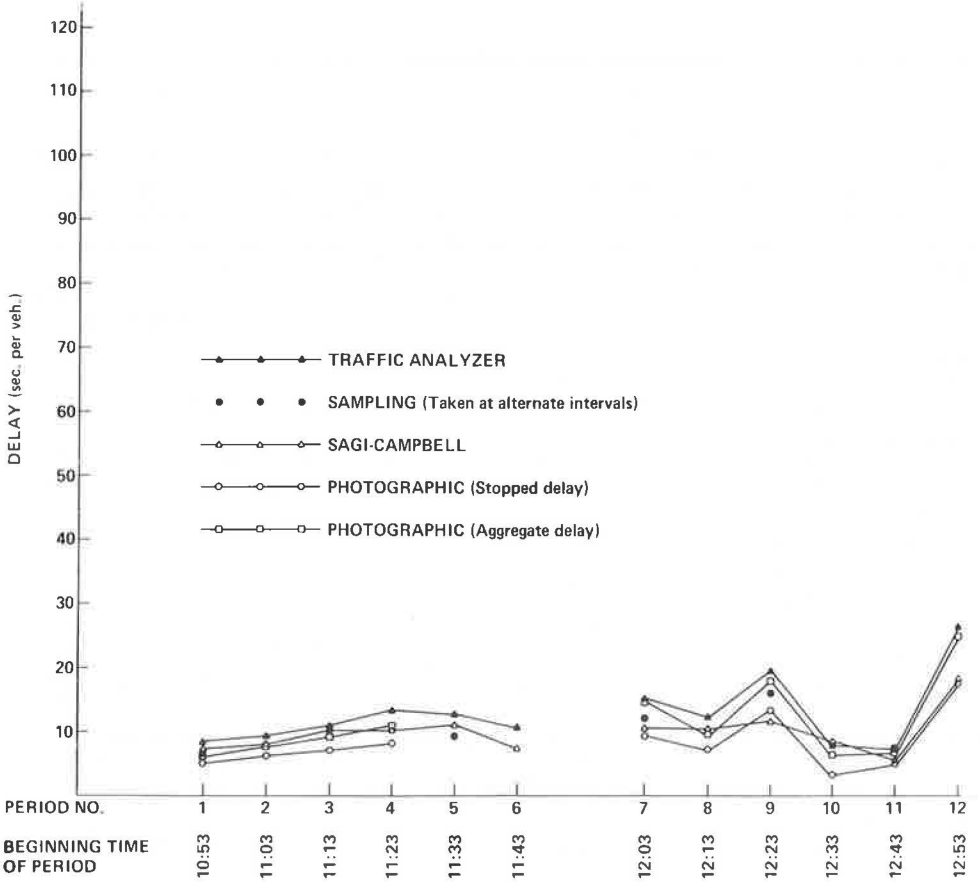

Figure 3. Delays during off-peak and peak periods (lane 1).

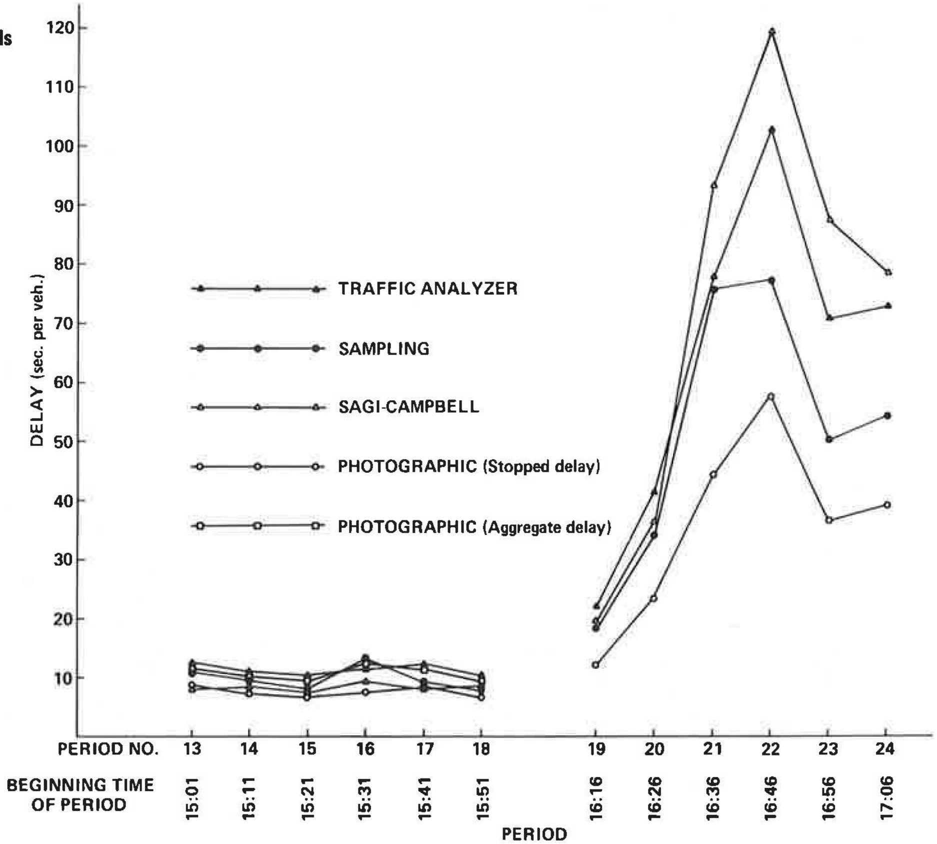

Figure 4. Delays during off-peak and peak periods (lane 2).

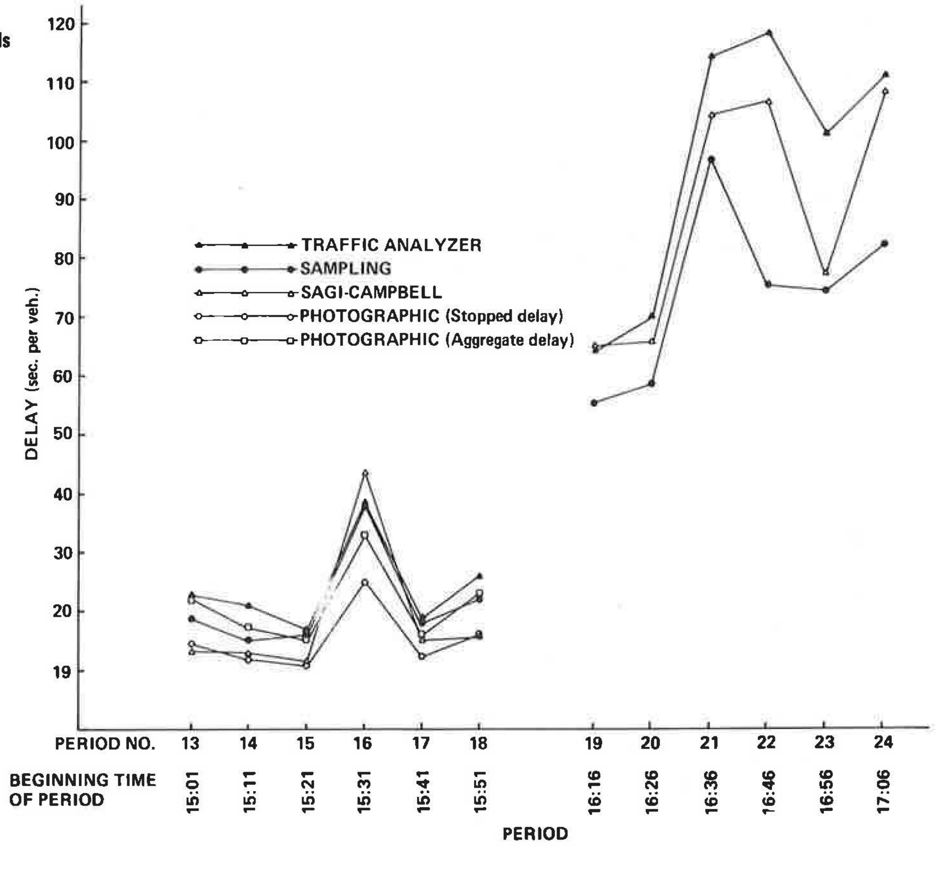

Figure 5. Volume-delay relation (lane 1).

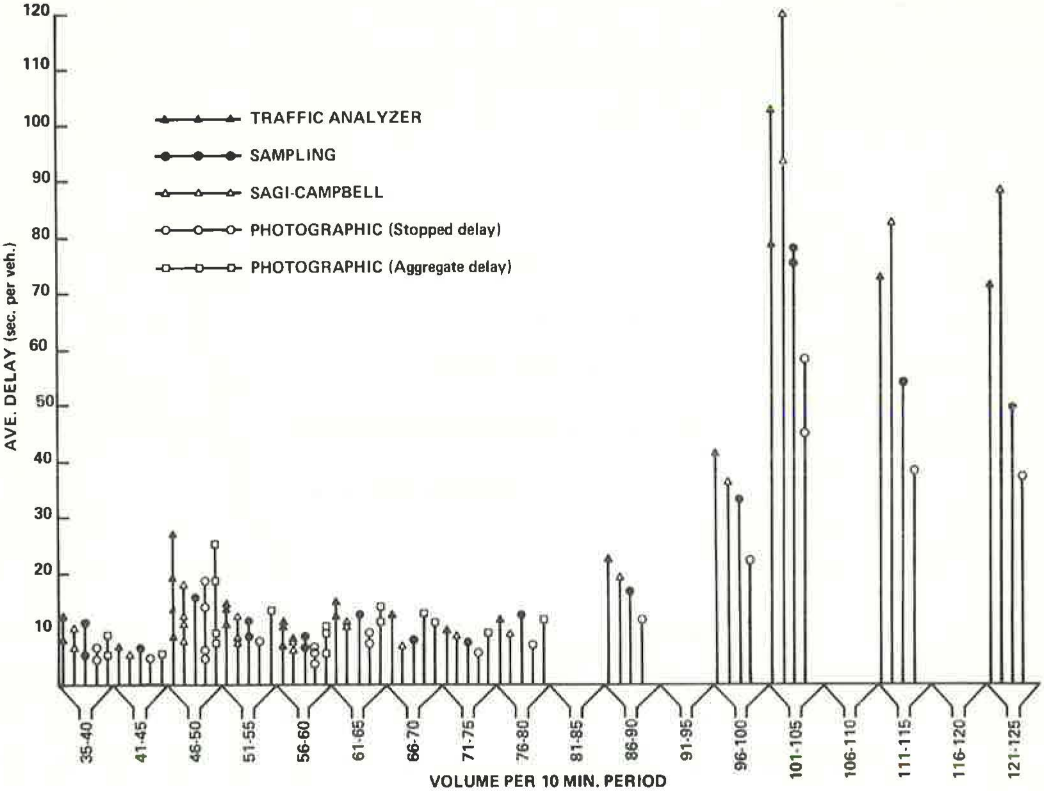

Figure 6. Volume-delay relation (lane 2).

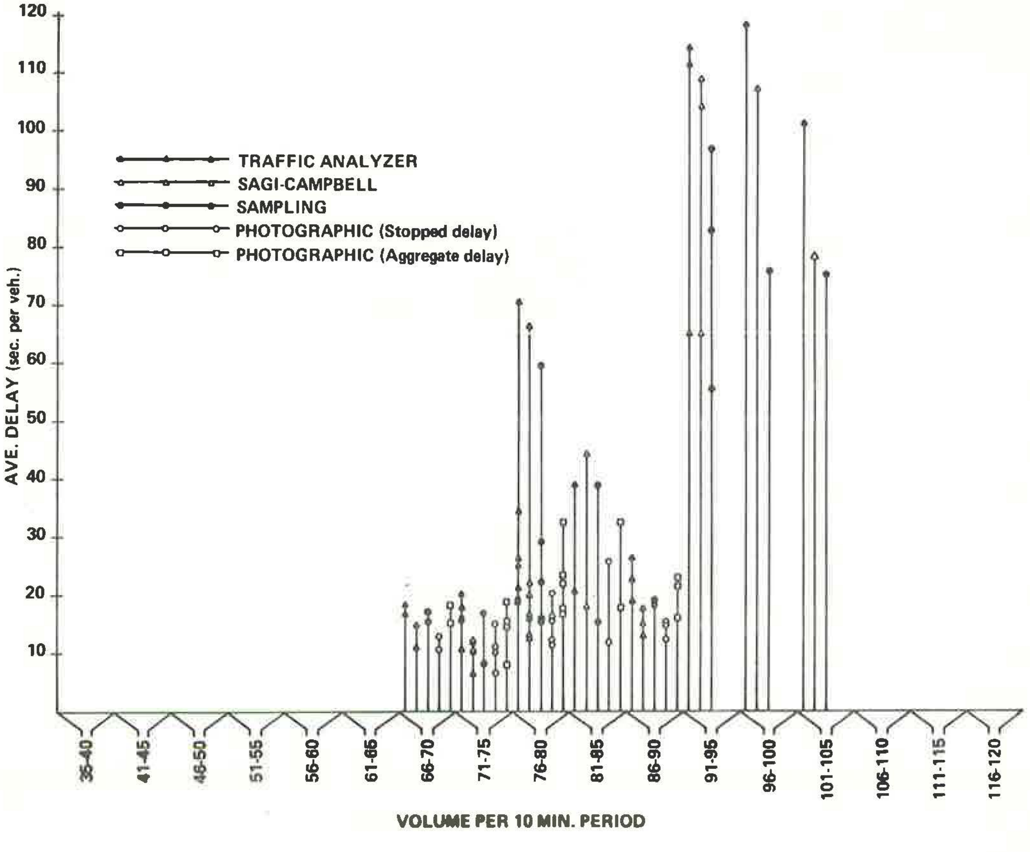

Table 3. Average queue length-delay relation (lane 1).

Period	Average Queue (vehicle per cycle)	Delay per Vehicle (sec) Flow Meter	Sagi-Campbell	Berry-Van Til Sampling	Photo Stopped	Photo Aggregate
11	1.6	7.4	5.9	7.5	5.1	6.9
1	1.8	8.4	7.2	6.5	5.3	6.3
3	2.1	10.9	10.3	10.8	7.1	9.2
2	2.5	9.2	8.1	–	6.3	8.0
6	2.8	10.8	7.5	–	–	–
13	2.8	12.1	8.2	11.3	8.7	11.7
15	3.0	10.1	7.5	8.1	6.9	9.6
14	3.1	10.7	8.5	9.8	7.3	10.2
8	3.2	12.3	10.5	–	7.2	9.8
10	3.5	8.0	8.7	–	4.6	6.7
17	3.5	11.9	8.1	9.0	8.3	11.3
5	3.8	12.7	11.2	9.4	–	–
9	4.1	19.7	11.9	16.2	13.5	18.2
18	4.1	10.0	8.8	8.4	6.8	9.1
4	4.2	13.2	10.3	–	8.2	11.0
7	4.6	15.3	10.7	12.1	9.6	14.8
16	4.9	12.0	9.5	12.7	7.5	12.1
12	5.2	26.7	18.6	–	18.1	25.2
19	9.1	22.0	19.8	18.4	12.1	–
20	14.6	41.3	36.4	34.2	23.4	–
23	26.5	70.6	87.2	50.2	36.9	–
21	27.0	77.9	93.4	75.7	44.4	–
24	27.0	72.8	78.4	54.2	39.3	–
22	30.6	102.8	119.4	77.2	57.7	–

Table 4. Average queue length-delay relation (lane 2).

Period	Average Queue (vehicle per cycle)	Delay per Vehicle (sec) Flow Meter	Sagi-Campbell	Berry-Van Til Sampling	Photo Stopped	Photo Aggregate
1	3.2	10.7	6.8	8.6	6.8	8.4
2	4.8	16.5	10.8	–	10.3	14.7
6	4.9	18.1	10.7	–	–	–
3	5.2	17.0	15.1	15.7	11.1	15.5
11	5.5	18.2	11.3	17.1	13.0	18.3
4	5.7	20.4	12.4	–	14.5	19.1
14	6.1	21.4	13.2	15.7	12.2	17.8
15	6.2	17.5	11.8	16.4	11.2	15.5
5	6.9	19.4	12.4	15.8	–	–
8	7.1	19.2	20.6	–	12.1	17.2
9	7.5	21.0	18.2	15.4	12.0	17.8
17	8.0	19.4	15.4	18.4	12.8	16.3
13	8.4	23.0	13.7	19.3	14.9	22.7
12	8.5	25.6	22.4	–	16.6	22.4
18	9.2	26.5	16.2	22.6	16.5	23.8
10	9.4	26.8	17.4	–	14.4	21.7
7	9.5	34.9	16.3	29.4	19.3	32.0
16	13.0	39.0	44.2	33.7	25.5	33.2
20	16.9	70.8	66.6	59.3	–	–
19	18.4	65.3	65.5	56.0	–	–
23	22.7	102.0	78.4	75.5	–	–
21	25.1	115.2	105.1	97.8	–	–
22	26.7	119.2	107.4	76.3	–	–
24	26.8	112.0	109.3	83.3	–	–

the average delay per vehicle increased with some exceptions. At an average queue length of 5.5 vehicles in lane 2, the average delay per vehicle was 18 sec by the traffic flow meter method and 11 sec by the Sagi-Campbell method. At a queue length of 7.1 vehicles, the average delays were 19 sec by the traffic flow meter method and 20 sec by the Sagi-Campbell method. At an average queue length of 8.4 vehicles, the respective average delays were 23 and 14 sec.

In lane 1 the Sagi-Campbell method produced the highest average delay of 119 sec per vehicle at a queue length of 30.6 vehicles; in lane 2 the traffic flow meter method produced the highest average delay. Similar inconsistencies occurred in delays computed by the other methods.

4. The average delays by the Sagi-Campbell method and the Berry-Van Til sampling method were expressed as percentages of the delays determined by the traffic flow meter and were plotted against volume per 10-min periods. The points did not follow any particular trend for either of the methods. The delays by the Sagi-Campbell method varied from 60 percent of the flow meter delay at a volume of 47 vehicles per 10-min period to 123 percent at a volume of 122 vehicles. Delays by the Berry-Van Til method varied from 71 percent at the flow meter delay at a volume of 120 vehicles to 101 percent at a volume of 42 vehicles per 10-min period.

5. When the average delays by the Sagi-Campbell and the Berry-Van Til sampling methods were expressed as percentages of the photographic stopped delay and the photographic aggregate delay and were plotted against the corresponding volumes, again no trends could be detected.

Although the principal objective of the study was a practical evaluation of the field application of the two delay measurement techniques, a statistical analysis of the data was performed to investigate validity of the methods. The analysis was aimed to determine if the true mean values of any two methods differ significantly at the 5 percent level of significance under the standard analysis-of-variance assumptions. The results of this analysis indicate that in every case the two techniques under comparison do not measure the same traffic delay information.

Another objective of this phase of the study was to compare the ease of conducting the Sagi-Campbell method and the Berry-Van Til sampling method of delay study in the field.

The Sagi-Campbell method of observation is more suitable when conducted in conjunction with capacity measurements. Data are collected on a cyclic basis, the same observers can be used to collect capacity data, and some of the data can also be used for capacity analyses. This method, however, is more difficult than the sampling method to explain to field personnel, and it requires considerable subjective judgment on the part of field personnel. The summarization and analysis of the data are also more time-consuming. The ability of personnel to observe accurately when queue lengths increase to about 20 vehicles drops considerably; i.e., in saturated conditions the accuracy of the method becomes questionable.

The Berry-Van Til sampling method is easy to explain to field personnel, and it requires no subjective judgment on their part. The data summarization and analysis are simple and easy to perform. This method, however, requires more field personnel to conduct because very little of the information can be used in capacity considerations. Most of the capacity data have to be collected on a cyclic basis. This method of observation also fails to produce reliable results during saturated flow periods. When the queue lengths exceed 20 vehicles, observers have difficulty counting the number of stopped vehicles in the queue.

CONCLUSIONS AND RECOMMENDATIONS

The study failed to produce results that would identify either the Sagi-Campbell method or the Berry-Van Til sampling method of field observation as obviously better than the other. Neither of the two methods produced consistent trends in measuring delay as compared to the base methods. Neither of the methods proved to be consistently simpler or easier to conduct in the field than the other under all traffic conditions.

The study cast some serious doubts as to the suitability of using delay as a level-of-service measure for individual intersections, at least given its current development. The subject of delay, as related to intersection performance, appears to require considerable research before it can be used as an operational tool in a nationwide intersection capacity data-gathering study.

Factors that appear to require research include the following:

1. The relations between, and differing influences of, the two fundamental types of delay found on urban intersection approaches (delay caused specifically by conditions at the intersection under study and delay caused by lack of coordination with upstream signals); and
2. The influence of differing driver populations at low volumes as compared with high volumes or mixes of populations at a given time.

There is increasing evidence—in the literature, in the results of FHWA's own research findings from simulation in connection with the urban traffic control system project, and in the preliminary findings herein reported—that research would show delay to be a more accurate and suitable indicator of overall system level of service (a long section of an arterial or a complete street network) than it is of service provided by an individual intersection within that system. This would be in keeping with the caution already expressed in the HCM that level of service for an individual intersection is a rather artificial thing because by definition level of service is an "over-a-distance," not "point," phenomenon.

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DISCUSSION

Jack A. Hutter, Northwestern University

Users of chapter six of the HCM have expressed various degrees of dissatisfaction with a number of the adjustment factors utilized in the analysis technique, with specific reservations regarding the concept of level of service, load factor, and peak-hour factor. Although some of these difficulties with the application of the HCM are real, many can be resolved if the user would apply engineering judgment in the selection of factors and the application of the analysis techniques to best fit the characteristics of the intersection under study. A number of critics have maintained that other methods utilizing measures such as lane headway, saturation flow, or delay produce more accurate results than the HCM procedures; however, most of these methods are more complex and unwieldy to use. What is needed is the simplest and most accurate method to provide a

useful analysis tool for the practitioner. Furthermore, some of these techniques are only valid at capacity or saturation flow and do not provide a measure of level of service or performance.

The authors of this paper started with the premise that delay was potentially the best general measure of level of service at intersections. The first step was to select the method of observation and data-collection techniques, and four study methods were singled out for evaluation. The second step was to determine the variance of delay and service volumes under different conditions. Their conclusions would tend to indicate that the project was a failure because it produced no significant relations between volume and delay. To the contrary, I feel that their work has produced significant information that may lead to a breakthrough in refining and simplifying intersection capacity analysis techniques. The following observations are made with regard to the authors' work:

1. Sophisticated equipment and techniques and extensive manpower requirements are necessary to conduct pilot studies that will evaluate delay as a measure of level of service. It is questionable whether nationwide studies could be initiated within the limitation of the manpower and equipment available to city and state agencies throughout the country.
2. There is a need to further identify and describe what is meant by the term delay and what is the most accurate and simplest measure of delay. This paper showed poor correlation among all measurement techniques in their ability to predict or measure delay, which emphasizes the need to define delay in an accurate, reliable manner.
3. The results of this paper would cause one to question the validity of delay as a consistent measure because all techniques fail to produce a direct relation between delay at any given level of volume input or output. Logic might seem to explain why a variety of delays can be achieved for any given level-of-service volume. Not only are we dealing with driver populations in different locations, but also there is a high variability of types of drivers, habits, decisions, and characteristics exhibited during various periods of the day at the same location.
4. This paper did not fully describe the influence of the mix of straight and left-turn movements in the left lane with the interference of the opposing flow and the effect of the mix of straight and right-turn movements in the right lane. Although these factors may have been identified, it is not clear whether the statistical techniques employed or considered were successful in isolating these and other factors that can influence or produce significant variations. Seemingly, the raw data collected would provide some basis for analysis to explain, at least partially, the obvious differences.

The results of this paper point out the need for a series of carefully designed and controlled pilot studies to determine a relatively consistent measure or measures of level of service, be it load factor, delay, headway, or "green bananas." The factor of delay or other potential measures of level of service should not be discarded as a subject of research until we are able to filter out the extraneous "noise" and gain a better understanding of the variability of driver populations by location and time. It is essential that these series of pilot studies be made and that the study techniques and procedures be carefully defined prior to the initiation of extensive nationwide studies. The results of conclusive pilot studies must serve as a basis for developing the more extensive data-collection projects to ensure that these efforts will utilize consistent measuring techniques, collect compatible data, and produce a valid interpretation and evaluation of the results. Finally, the factors that are selected as a measure of level of service must lend themselves to the limitations of the equipment and manpower available to the practitioners who must collect the data and eventually to the capabilities of the users who will need to apply the analysis techniques devised.

William R. McShane, Polytechnic Institute of Brooklyn

The results of the study addressed in this paper are most interesting and most beneficial to the profession. Certainly, it was amply demonstrated that the techniques by

which delay is measured are too ambiguous in their definition. Perhaps what is needed is a single, operational definition of delay so that a base line would exist. Other types of delay could then be related to this measure, and other measurement techniques could then be evaluated on the basis of how close they came to the base line.

In discussion with the authors, they have correctly pointed out that the techniques considered defy clear and direct correlation. Moreover, they point to a significant research role to resolve questions raised by their study. This difficulty and these recommendations are in themselves a major contribution.

It is appropriate to review the data available from this study for insights that go beyond the intended and defined task of the original work. If this is done, it is discovered that the various delays are very highly correlated, the several techniques are dependent on the total volume and other parameters, but with differing sensitivities for each technique, and the various delays can be systematically interrelated. This is in conflict with the conclusion that "... the data showed neither uniformity nor consistent relations between the delays computed by the various methods," although the simple and desirable "uniformity" was certainly lacking.

These conclusions can be illustrated by first considering the following definitions:

Method	Lane 1	Lane 2
D_1 = flow analyzer delay	X_1 = 10 min, total volume	Y_1 = 10 min, total volume
D_2 = Sagi-Campbell delay	X_2 = 10 min, trucks and buses	Y_2 = 10 min, trucks and buses
D_3 = Berry-Van Til delay	X_3 = 10 min, left turns	Y_3 = 10 min, right turns
D_4 = photo stopped delay		
D_5 = photo aggregate delay		

The delays are in seconds per vehicle and the volumes in 10-min counts. Percentages for trucks and buses and for turns are not used. Queue data were not listed in the draft on which this analysis is based.

The data were considered in two groups, group 1 (periods 1 to 18) and group 2 (periods 19 to 24), that correspond to flow levels.

For the group 1, lane 1 data, typical sample correlation coefficients are D_1, D_2 = 0.92, D_1, D_4 = 0.99, D_2, D_4 = 0.90, and D_3, D_4 = 0.89. This illustrates the strong interrelations among the various delay measures. Figure 7 shows one of the stronger correlations. As indicated by the sample correlation coefficients, the correlations of the Sagi-Campbell and Berry-Van Til delays to the photo stopped delay are not as extreme but are rather strong.

Consideration was also given to relating each delay to the three available traffic variables by regression analysis: $D_i = \hat{\alpha}_{0i} + \hat{\alpha}_{1i}X_1 + \hat{\alpha}_{2i}X_2 + \hat{\alpha}_{3i}X_3$ for lane 1 and similarly for the Y_j in lane 2. Any term whose coefficient could not cause the hypothesis $\alpha_{ik} = 0$ to be rejected at a significance level of 0.05 was dropped.

Table 5 gives the results of the analysis for the group 1 data for four delay measures. Runs were not made for D_4 (photo stopped delay) in this particular analysis.

Note that, in the lane 1 data, the flow analyzer and Sagi-Campbell delays are sensitive only to the left-turn volume. This factor alone accounts for 50 percent or more of the variance. However, they have different sensitivities: Every left-turning vehicle adds 0.73-sec-per-vehicle delay to the flow analyzer measure but only 0.46-sec-per-vehicle delay to the Sagi-Campbell measure.

The Berry-Van Til measure is statistically insensitive to any traffic variable over the range of data. (Recall that all of these are per-vehicle delays, so that total delay is increasing in all cases as volume increases.) Based on the formulas developed, one would expect the Sagi-Campbell delay to be less than the Berry-Van Til delay for left-turn volumes of 6 or less per 10 min.

The photo aggregate delay is more complex, depending on both the left-turn volume and the trucks-and-buses volume.

The lane 2 situation is interesting in that not one of the four delay measures is discernibly dependent on the variables considered.

Based on this analysis, it is apparent that the several delay measures considered do indeed measure the same sort of thing (that is, delay) but that each emphasizes a different aspect of it. The situation is thus ambiguous, and the authors sensibly question this ambiguity from a practitioner's point of view. Certainly it is not safe to proceed with a major data-collection effort until a single, relevant definition of delay (and the several measures related to it) is accepted. This may require collection of supplemental data. If, for instance, photo aggregate delay were the standard and the data were collected in terms of photo stopped delay (an unrealistic but illustrative pair), the best linear conversion, $D_5 = -2.52 + 1.42D_4 + 0.04X_1$, for group 1, lane 1 would also require information on total volume (which would be collected routinely in any case, but a more subtle variable might also enter and would require additional collection for maximum precision).

It is appropriate to consider the disquieting conclusions of the authors as to current utility with the positive emphasis that their data have provided for directions in the research component they recommend: The path for this analysis of functional relations among the measures and the traffic variables is clear, and the prospect for success is heartening. The negative conclusions on existence of "consistent, direct relations" would seem to be too strongly stated.

It is important to systematically investigate all reasonable potential determining variables before proceeding with a major data-collection effort. These variables should include opposing volumes, upstream offset and cycle length, downstream queue extent (in heavy-flow situations), and component volumes and compositions. It would be most advantageous to study the basic relations in a controlled experiment—a simulator such as UTCS-1 would be appropriate—eliminate variables if possible, and return to a field validation of the type conducted by the authors.

The opportunity to present this discussion is greatly appreciated, and the authors are thanked for the discussions we have had on this subject. Robert L. Siegel is also thanked for the execution of the regression analysis programs.

Adolf D. May, University of California, Berkeley

One of the most important contributions of the HCM was the introduction of the level-of-service concept to capacity analysis. However, the implementation of new concepts is often difficult and encounters diversity of opinion. This has been the case when the level-of-service concept was applied to signalized intersections. Load factor was selected as the measure of level of service at signalized intersections because it was available in the previous intersection capacity studies and it is relatively easy to measure. However, its use has been criticized because results at high flow-capacity ratios are not consistent, results are dependent on the arrival distribution of vehicles as well as on the intersection itself, and the driver does not consider load factor as the measure of his level of service.

As the authors of this paper have indicated, some form of delay appears to be the single most important measure of level of service from the viewpoints of the driver and those undertaking intersection capacity analysis. Therefore, the authors are to be commended for undertaking this study of evaluating various techniques for measuring intersection delay before embarking on a new nationwide data-gathering and analysis effort to update the intersections chapter of the HCM.

A summary table of all measurements obtained for the twenty-four 10-min data-collection periods including individual vehicular delays (seconds) calculated by five different methods is contained in the paper. It was unfortunate that measurements and calculations for all time intervals and for all methods were not obtained and a complete comparative analysis was possible. The use of television video tapes combined with time-lapse photography was a very excellent method of collecting data. One of its advantages is the ability of replaying the films to collect data.

My review of the paper has resulted in several questions that the authors may wish to answer in their closure:

1. The percentage of trucks and buses as well as the percentage of vehicles turning left or right was measured for each time interval and for each lane. Were these data included in the analysis?
2. In the Berry-Van Til method, the number of stopped vehicles was recorded at 20-sec intervals. How was this sampling interval selected, and how does it affect the accuracy of the method?
3. The paper reports that statistical analyses were undertaken to test for significant differences among the mean delays obtained by the various methods. Was the analysis conducted for each individual lane and for each hour of measurements? How were missing data handled in this analysis?
4. Did the authors consider combining the lane data and performing the analysis on an approach basis? In this connection, what was the capacity of this approach according to the HCM?

The paper has stimulated me to undertake some additional analyses that may be of interest and perhaps will suggest possible directions for future research. The results presented should not be considered as complete or final because this is not the intent, and the complete data base was not available to this author at this time. Perhaps the authors of the original paper, who have the original data either on film or in tabular form, may wish to extend this analysis further.

First, statistical analysis was undertaken to test for significant differences between mean delays as calculated for different hourly periods and different methodologies. Table 6 gives a summary of the results of the significant tests. Although there are differences between the significance levels, there appear to be patterns. The mean delays as calculated by one method are consistently larger (or smaller) than the corresponding mean delays as calculated by another method for the various hours of observations. For example, the stopped delay (as obtained by the photographic technique) was always numerically less than the aggregate delay (also obtained by the photographic technique). This led the author to suspect that, although there were some comparisons that showed significant differences in mean delays by the various methods, there still might be significant relations between mean delays so that one method could be used to estimate the results of another. Consequently, a series of linear regression analyses between selected mean delays was undertaken.

Table 7 gives a summary of the results of the linear regression analysis investigations. Four comparisons were made among mean delays for lanes 1 and 2 and the combined observations of lanes 1 and 2. The resulting linear equations, the correlation coefficients, and the sample size are given in the table for each investigation. The results for the most part are very encouraging and give some evidence that one method might be used in the field to estimate the mean delay of another method. The linear relations are shown in Figures 8, 9, 10, and 11.

The authors are encouraged to continue their efforts in this two-stage pilot study leading toward a nationwide data-gathering and analysis effort to update the intersections chapter of the HCM. Much has been done, but much is left to be done. Through the continued efforts of such researchers as the authors, we can look forward to improved methods for capacity analyses.

I wish to acknowledge the assistance of Maxence Orthlieb in making the analyses for this discussion paper.

Donald S. Berry, Northwestern University

Average delay per vehicle obtained by sampling the number of stopped vehicles every 20 sec was found by the authors to be approximately 40 percent higher than the corresponding stopped-time delays obtained from time-lapse photography. This is rather surprising because a similar comparison reported for two intersection approaches in 1954 (6) and 1956 (9) yielded stopped-time delays via manual sampling that were

Figure 7. Group 1, lane 1 data for two delay measures.

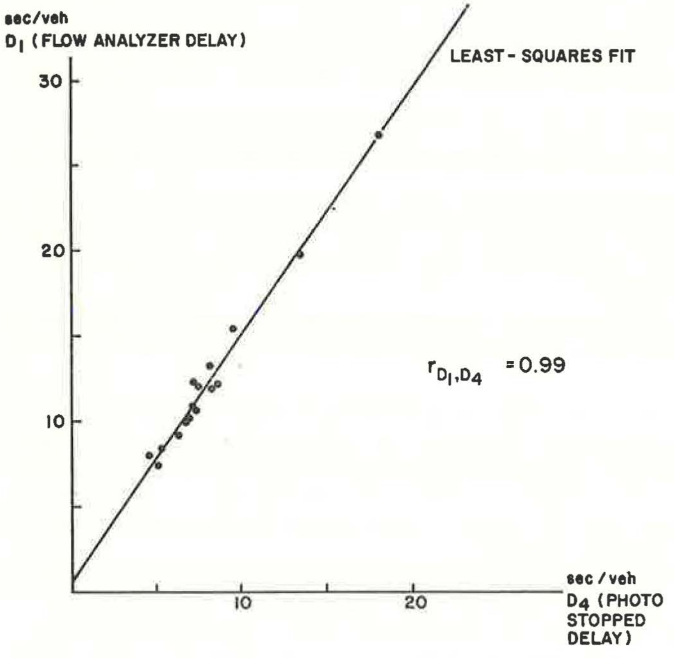

Table 5. Regression analysis for group 1 data.

Variable	Regression Line	Number of Data Points	Multiple Correlation Coefficient	Reduction of Sum of Squares (percent)
Lane 1				
D_1	$8.36 + 0.73X_3$	18	0.71	50
D_2	$7.04 + 0.46X_3$	18	0.74	55
D_3	10.1	12	—	—
D_5	$-2.52 + 0.72X_3 + 0.56X_2$	16	0.75	57
Lane 2				
D_1	21.9	18	—	—
D_2	16.0	18	—	—
D_3	19.4	12	—	—
D_5	19.8	16	—	—

Table 6. Significant differences between mean delays.

	Observation							
	First Hour		Second Hour		Third Hour		Fourth Hour	
Methods Compared	Value	Significant Difference Level	Value	Significant Difference Level	Value	Significant Difference Level	Value	Significant Difference Level
Photo stopped and photo aggregate	$X_1 < X_2$	90 percent	$X_1 < X_2$	None	$X_1 < X_2$	99 percent	—	—
Flow analyzer and photo aggregate	$X_1 > X_2$	95 percent	$X_1 > X_2$	None	$X_1 > X_2$	None	—	—
Sagi-Campbell and photo aggregate	$X_1 > X_2$	None	$X_1 < X_2$	None	$X_1 < X_2$	99 percent	—	—
Berry-Van Til and photo stopped	$X_1 > X_2$	90 percent	$X_1 > X_2$	None	$X_1 > X_2$	99 percent	$X_1 > X_2$	90 percent

Note: A one-sided test was used with the assumption that population variances are unknown.

Table 7. Linear regression analysis of mean delays.

	Observation								
	Lane 1			Lane 2			Lanes 1 and 2		
Methods Compared	Linear Equation	Correlation Coefficient	Sample Size	Linear Equation	Correlation Coefficient	Sample Size	Linear Equation	Correlation Coefficient	Sample Size
Photo stopped (y) and photo aggregate (x)	$y = 0.693x + 0.355$	$r^2 = 0.989$	16	$y = 0.663x + 0.874$	$r^2 = 0.967$	16	$y = 0.678x + 0.553$	$r^2 = 0.985$	32
Flow analyzer (y) and photo aggregate (x)	$y = 0.999x + 1.119$	$r^2 = 0.988$	16	$y = 1.107x + 0.419$	$r^2 = 0.981$	16	$y = 1.106x + 0.184$	$r^2 = 0.989$	32
Sagi-Campbell (y) and photo aggregate (x)	$y = 0.535x + 3.530$	$r^2 = 0.900$	16	$y = 0.296x + 9.005$	$r^2 = 0.476$	16	$y = 0.477x + 4.813$	$r^2 = 0.773$	32
Berry-Van Til (y) and photo stopped (x)	$y = 1.455x - 0.817$	$r^2 = 0.988$	17	$y = 1.606x - 2.997$	$r^2 = 0.992$	11	$y = 1.463x - 0.964$	$r^2 = 0.989$	28

Figure 8. Relation of stopped delay and aggregate delay.

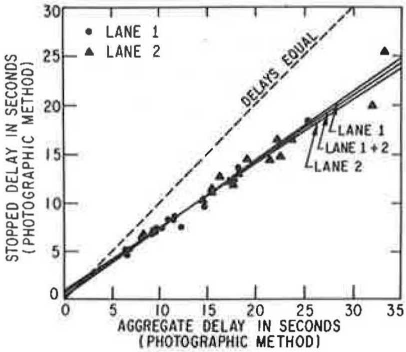

Figure 9. Relation of flow analyzer delay and and photo aggregate delay.

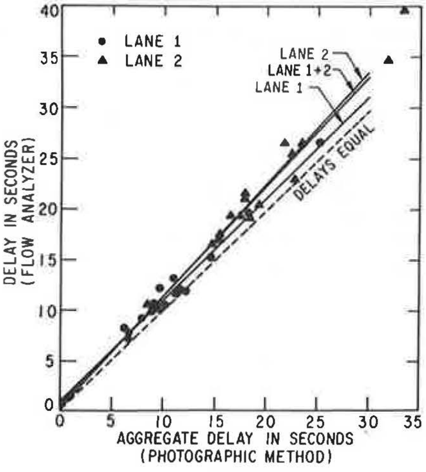

Figure 10. Relation of Sagi-Campbell delay and photo aggregate delay.

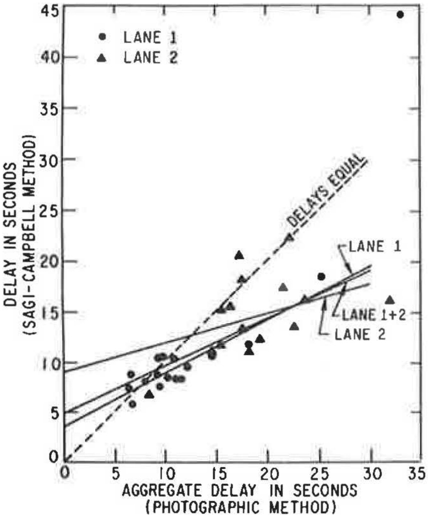

Figure 11. Relation of Berry-Van Til delay and photo stopped delay.

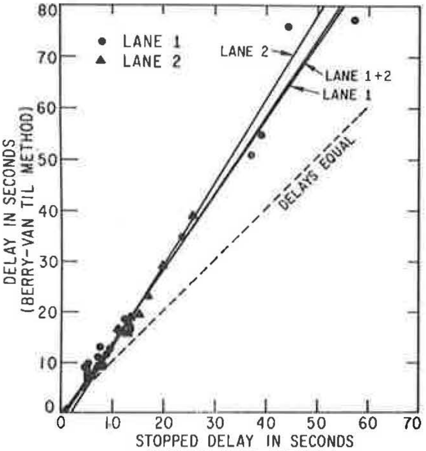

Figure 12. Intersection performance (75 percent stopping for signal).

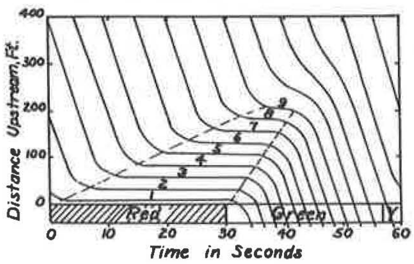

Figure 13. Intersection performance (100 percent stopping for signal).

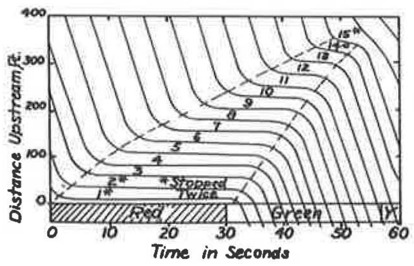

Figure 14. Intersection performance (platooned arrivals).

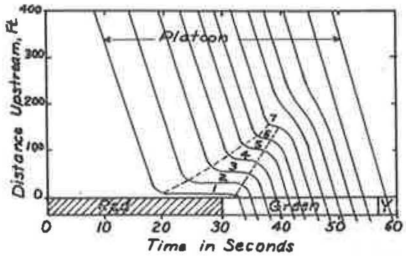

Table 8. Delay as scaled from Figures 12, 13, and 14.

Delay Method	Delay in Seconds per Cycle: 75 Percent Stopping	100 Percent Stopping	Platooned Arrivals
Travel-time delay (scaled)	210	315	41
Stopped-time delay (scaled)	157	261	35
Stopped delay (10-sec sampling)	170	260	40
Sagi-Campbell	135	315	105
Flow meter (scaled)	199	365	62

usually within 10 percent of values obtained by camera. Further study should be made to determine whether these differences are due to differences in procedures used in gathering the data for the two studies.

Some of the reasons for differences in results from the different methods can be identified by applying the methods to time-space diagrams of intersection performance (Figs. 12, 13, and 14). Stopped-time delays (between broken lines) were scaled for vehicles discharged during the cycles that are shown and are compared with other delay measures given in Table 8. Sampling of stopped-time delay was done at 10-sec intervals for all vehicles stopped during these cycles. Travel-time delay, used as the base method in earlier studies (6, 9), was also scaled from the diagrams.

Although results are not strictly comparable because the sampling method also includes delay for vehicles discharged in the following cycle, the study reveals the following:

1. The flow meter method includes in its delay values the travel times for vehicles after they leave the queue. For example, delay values scaled for vehicle 13 in Figure 13 are as follows: 16.5 sec via flow meter, 7.5 sec for stopped-time delay, and 10.0 sec for travel-time delay.
2. When a vehicle must stop for two red intervals (vehicles 1 and 2 in Fig. 13), the travel time between stops would normally not be included in stopped-time delay but is included in the other methods.
3. When vehicle arrivals are platooned as in Figure 14, the Sagi-Campbell method will overestimate delays (Table 8). Sagi and Campbell, in their original paper (5), suggest a method for correcting for such platooning.

If stopped-time delay is to be sampled in conjunction with studies of intersection capacity, effects of sampling rates should be investigated. A short sampling interval is needed for short cycle lengths and when distributions of vehicle arrivals are affected by upstream signals. Trials of sampling at 10-sec intervals are suggested, starting the sampling for each cycle at the beginning of the red.

If films for the Virginia intersection are still available, such sampling intervals can be tried along with investigating variations in instructions on how to sample stopped-time delay.

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AUTHORS' CLOSURE

The authors would like to thank Hutter, McShane, May, and Berry for taking the time to comment on our paper. We agree in general with the discussions and have a few comments to offer.

In answer to May's four questions, we have the following remarks:

1. Neither the Berry-Van Til method nor the Sagi-Campbell method, at their present stages of development, provides any distinction or special treatment for trucks and buses and right- and left-turning vehicles. These data were included in our measurements to see if some of the variation in the computed delays could be due to high turning movements or high rates of commercial vehicles in the traffic stream. From simple observations, we could not detect any such relations that were consistent. McShane's statistical analysis indicates that there are such relations.
2. The 20-sec sampling interval in the Berry-Van Til method was selected so that repetitive sampling in the same parts of the signal cycle could be avoided. With a 75-sec cycle, the 20-sec interval appeared to be the most practical choice. (Berry and Van Til recommended an interval of 15 to 20 sec in their paper.) A shorter sampling

interval (10 sec), as Berry recommends in his discussion, might have produced more accurate results under normal traffic conditions. During congestion periods, however, where long queues develop, the accuracy of the method would become questionable as observers would be hard pressed to count and record the stopped vehicles in such short intervals.

3. The statistical analyses to test for significant differences among the mean delays obtained by the various methods were conducted for each individual lane for each set of hourly measurements.

4. We did not combine the lane data on an approach basis because we considered that that would not be in keeping with the committee's recommendation that, for any future revision of the HCM, intersection capacity and delay be expressed on a "by-lane" basis. Furthermore, combining the data might have a diluting effect on the influence of turns and commercial vehicles.

McShane grouped the data into two categories: group 1 consisting of the three off-peak periods and group 2 of the 1-hour peak period. His discussion is limited to the first group. He has found that the various delays are highly correlated, but each method has differing sensitivities to traffic parameters. We agree with him, and we so indicated in our report that "during the low traffic volume periods the delays computed by any of the five methods were generally uniform. . . ." It was during the high traffic-flow period that the data showed inconsistent relations among the delays computed by the various methods. We do not doubt that the methods tested "do measure the same sort of thing (that is, delay)." But they measure delay with varying sensitivities to volume, turns, and trucks and buses. Until these degrees of sensitivities are evaluated and factored, neither of the methods is ready for nationwide application. Even more important than this is the need, as Hutter points out, to describe what is meant by intersection delay so that we will all be talking in the same terms.