Capacity of Signalized Intersections

EUGENE F. REILLY and JOSEPH SEIFERT,
New Jersey Department of Transportation

Three methods of estimating capacity at signalized intersections (Highway Capacity Manual, W. Bellis, and R. Dier) are analyzed and compared to a field estimate of capacity (ALE). The Highway Capacity Manual estimate of service volume at the actual load factor (for the field condition) is also compared to the actual peak-hour volume. Using 38 sample approaches, the errors in estimation have been outlined for each of the 3 methods. Overall, the Highway Capacity Manual and Dier methods have errors in excess of ±20 percent for approximately half the sampled approaches. The Bellis procedure (developed in New Jersey, where this study was made) results in errors exceeding ±20 percent for less than 15 percent of the sampled approaches.

THE HIGHWAY CAPACITY MANUAL (HCM) estimates of volume and capacity at signalized intersections are based on several factors. There are at least 2 other, less complex, methods of capacity estimation. One was devised by W. R. Bellis, Director of Research and Evaluation, New Jersey Department of Transportation (2). The other was developed by Robert Dier, Traffic Engineer for Long Beach, California (3).

The purpose of this report is to estimate the capacity of approaches using the HCM method, a modified Bellis method, and the Dier method and to compare these estimates to an empirical (ALE) method. The actual peak-hour volume is also compared to the HCM estimate of peak-hour volume.

The scope of this report includes an explanation of the HCM, Bellis, Dier, and ALE methods, an analysis of the HCM factors, and a detailed examination of the estimated capacities using the various methods.

EXPLANATION OF VARIOUS METHODS

HCM

Approach volume per hour of green, and physical, environmental, and traffic factors are used to determine service volume. A final estimate of service volume, for any level of service, is determined by multiplying the basic approach volume per hour of green by both, the adjustments for these factors, and the G/C (green time/cycle length) ratio for the approach.

Bellis

This method classifies roadways into 4 types. For this report the roads will be defined as follows:

Type I—All central business district (CBD) streets;

Type II—All streets, outside the CBD, that do not fall into the following categories;

Type III—Expressways, arterials, major highways, major streets, and through streets with only right turns at intersections; and

Type IV—Expressways, arterials, major highways, major streets, and through streets with no turns at intersections or with separate phases and turn lanes (including jughandles) provided.

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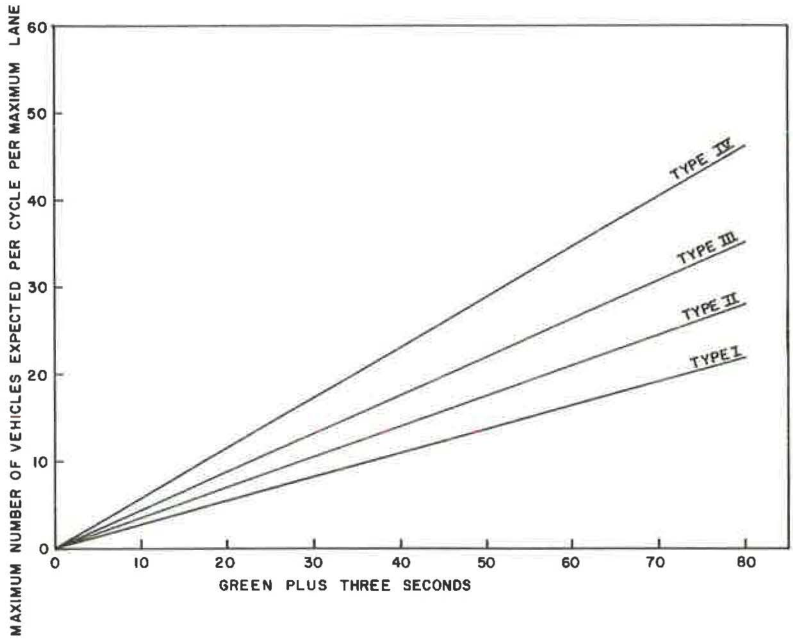
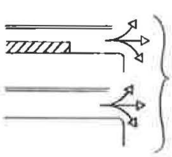
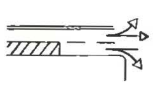


Figure 1. Bellis capacity chart—green plus 3 seconds versus maximum number of vehicles expected per cycle per maximum lane.

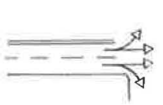
The 4 figures in Bellis' report for road Types I through IV plot 2 variables: the green light required in seconds, and the maximum number of vehicles expected per cycle per maximum lane (Fig. 1). For this study, the green light is interpreted as the green phase plus 3 seconds (for the Bellis procedure only). It is felt that the added amber time gives a more realistic value for the G/C, because a portion of the amber phase (which varies from 3.5 to 6.0 seconds for the approaches used in this study) is used by the drivers. The capacity is estimated by expanding the number of vehicles per cycle to vph and adjusting for lane distribution, turns, and trucks (using the HCM adjustments). Lane distribution is assumed as follows: 2 lanes, 55 and 45 percent; and 3 lanes, 40, 35, and 25 percent. (The maximum lane, which is not necessarily the left or right lane, is given first.) Because the Bellis method was predicated on the through movement of vehicles by lane, the authors used the following criteria to maintain uniformity.



Treated as single lane through the intersection with an adjustment for trucks, but no adjustment for turns.



Treated as a single lane, but adjusted by a factor (1 + proportion of turns).



Treated as 2 lanes, applying the adjustments for turns and trucks.

Dier

The "practical" capacity of over 40 different traffic lane configurations was developed by Robert Dier and expressed in terms of vehicles per second of green. After choosing an appropriate lane configuration from his charts, the rate of flow factor is multiplied by the total green time in the hour. Dier makes provision for grade and truck adjustments. In this study, no grade adjustments were necessary.

ALE

This name is an acronym taken from "average loaded phase expanded" to vehicles per hour. The ALE value is used as an empirical capacity to which the HCM, Bellis, and Dier values are compared. The average number of vehicles for the loaded cycles is used, rather than the maximum or the minimum, because it is felt that this is the most representative value that exists for the loaded phase conditions of trucks, turns, and pedestrian movements. As an example, if there were an average of 20 vehicles per loaded phase and 60 phases per hour, the ALE value would be 20 x 60 or 1,200 vph.

DATA COLLECTION

Data were collected at 38 sites. The results of the first sampling of some sites gave questionable volumes. Hence, 6 of the sites were sampled a second time. In all 6 cases, the capacities yielded by the initial sampling were verified by the second sampling.

Departure data were recorded, by cycle, for each lane. Arrival data were recorded by either minute of time or by cycle. Data were collected for approximately 90 minutes. From these data, the peak hour and the peak 15 minutes within the peak hour were determined. The total number of vehicles, trucks, turns, local buses, and loaded phases were tabulated. Loading was judged using HCM criteria (1, p. 115). To reduce the variability of determining loaded phases, only 2 field parties were used for the study. To train the field crews, the project engineer reviewed loading on a cycle-by-cycle basis under field conditions.

Information on local buses for 10 of the sites was not recorded in the field, but was taken from bus company schedules. For the additional 28 sites, these data were field-recorded.

Loaded cycles with downstream delays were rejected. However, these cycles were used in determining actual peak-hour volume.

Vehicles with over 4 wheels were classified as trucks.

ANALYSIS OF HCM FACTORS

Peak-Hour Factor

Figures 6.5 through 6.10 of the Highway Capacity Manual (1) include tables for the "adjustment for peak-hour factor and metropolitan area size." The adjustments in these tables are the result of the multiple of the 2 factors. If the adjustments are separated into individual factors, it can be seen that the HCM adjustment for peak-hour factor (PHF), not including the metropolitan area size factor, varies with the actual PHF, the type of street such as one-way or parking, and the metropolitan population. Figure 2 shows the variation of this factor with the percentage that the adjustment is greater than the actual PHF.

Figure 2 was derived by taking the HCM adjustment for PHF and metropolitan area size, at a PHF of 1.00, and using this adjustment for metropolitan size only (assuming that an adjustment of 1.00 is used for an actual PHF of 1.00). Each overall adjustment for a particular metropolitan area size is then divided by that found for PHF at 1.00 to give the adjustment for PHF only, without the influence of the metropolitan area size.

The computation of service volume, using the adjustment for the PHF alone, is not appreciably affected unless the PHF is less than 0.89. As the PHF approaches 0.70, the difference between the adjustment and the PHF approaches 20 percent (for 2-way streets, without parking). For example, if the actual PHF is 0.78 (2-way street, parking, population 250,000), the HCM adjustment for the PHF, not including the additional adjustment for metropolitan area size, is 0.813, or 4 percent greater than the actual PHF.

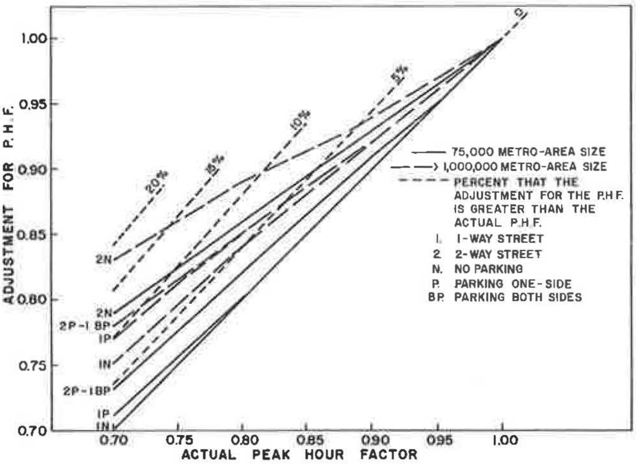


Figure 2. Actual peak-hour factor versus HCM adjustment for PHF.

The load factor at capacity is 1.00; hence, it measures the average number of vehicles departing the intersection during each cycle under the prevailing conditions (provided all cycles are loaded). If every cycle is loaded, a backup of traffic may exist for the entire hour and the "pressure" on drivers to depart the intersection may not be that reflected by the HCM adjustment for PHF.

For load factors less than 1.00, with a PHF less than 1.00, the pressure for drivers to depart the intersection at faster rates may exist to keep the queue size small.

Whatever the reasons for the adjustment factors, Figure 2 shows an increasing PHF adjustment over the actual PHF as (a) the PHF decreases, (b) the metropolitan population increases, and (c) the street goes from one-way operation (from no parking to parking both sides) to two-way operation (from parking to no parking).

Load Factor

The load factor (LF) was determined using the HCM criteria. However, traffic may delay from entering an intersection because of downstream interference during a particular cycle, and the load factor cannot include these cycles. For a precise analysis of load factor and volume, succeeding cycles, which are affected by the previous cycles, should also be eliminated from the data. But the main purpose of collecting data by cycle was to determine the number of vehicles required to load the cycle; hence, the rejected data included only those cycles when downstream delay existed.

Metropolitan Area Population

The HCM estimate of capacity is greatly influenced by the estimator's choice of metropolitan area population. For example, using HCM Figure 6.5, a peak-hour factor of 0.85, and populations of 75,000 and 250,000, the adjustment is either 0.92 or 1.00, a difference of 8.7 percent.

Choosing a realistic population may be easier in western locations where cities are specifically defined. But in northeastern locations, which are part of a megalopolis, the decision is a matter of judgment. The populations used in this study are thus subject to question.

One-Way or Two-Way Streets

A few sites are labeled one-way where the roadways are partitioned by either a median or a center barrier. In this study, where approaches are so divided and there are no left turns at the intersection, the approach is considered to be in the one-way category.

There may be some influence between the 2 opposing directions, especially on roads of minimal median width. The concrete center barrier may also have an adverse effect on drivers.

With or Without Parking

The HCM states that when vehicles are parked within 250 ft of the intersection, the approach should be considered as with parking. However, there are exceptions to this rule (1, p. 114). Parking may exist close to the intersection, and traffic can still make full use of the approach. On the other hand, parking may not be tolerated for progressive signal systems. Again, judgment was used on some of the approaches in this study.

Approach Width

The basic approach volume was extrapolated for 5 of the study approaches, where the width of approach is less than the lowest value shown on the appropriate chart.

There is a shoulder at 3 sites, but no provision is made in the analysis for this extra width. It seems likely that the shoulder may have some effect on capacity.

Green Time/Cycle Length

The green phase alone is used for the green time/cycle length (G/C) computations of HCM service volume and capacity.

Turns and Trucks

Because ALE capacity is determined on the basis of the average number of vehicles serviced per loaded cycle, only these cycles were used to determine the percentage of turns and trucks and the corresponding adjustment factors.

The differences between the peak-hour percentages and the loaded phase percentages of turns and trucks are small, and either one could have been used with minor error.

Local Buses

The exact cycle during which local buses stopped was not field-recorded for 10 of the 38 sites.

Some error may have thus resulted from using the same bus correction for both the peak-hour data and the loaded cycle data. However, the bus correction factor is equal or very close to 1.00 for these 10 sites.

All local bus data were field-recorded for the remaining sites.

The HCM adjustments for "near-side bus stop with parking" give inflated results for the 2-lane, high-turning volume approaches. The presence of one bus per hour on a 2-lane approach with greater than 25 percent turns has the effect of increasing the service volume by 35 percent (bus adjustment factor is 1.35). If the bus stop were removed, the adjustment for local buses would be 1.00.

COMPARISON OF HCM CAPACITY AND VOLUME ESTIMATES WITH ALE AND ACTUAL VOLUME

Volume comparisons are not made for conditions when the LF = 0, because the HCM estimate of volume at LF = 0 is for a condition when one cycle is near loaded. The actual field volume for this condition could be near zero.

For the site characteristics and volumes referred to in the following text, reference should be made to Tables 1 and 2 and the appropriate sketches of the intersections in the Appendix.

One-Way Streets

Volume Comparisons at the Actual Load Factor—Of the 13 samples in this category, taken at 9 different sites, the HCM estimate of volume is either equal to (within ±1 percent) or less than the actual volume for 7 of the 9 locations.

TABLE 1
SAMPLE CHARACTERISTICS

Sample	PHF	Load Factor	Population (000's)	Metro. Location	Bellis Type	Cycle Length	G/C	Width (ft)	1-Way 2-Way	Parking	Loaded Cycle Data: Bus Location	Loaded Cycle Data: Bus No.	Loaded Cycle Data: No.	Loaded Cycle Data: Percent Right Turns	Loaded Cycle Data: Percent Left Turns	Loaded Cycle Data: Percent Trucks
1a	0.91	0.90	250	Res.	IV	120	0.618	25	1	None	—	—	27	—	—	11
1b	0.96	1.00	250	Res.	IV	120	0.618	25	1	None	—	—	30	—	—	9
2a	0.79	0.43	75	Res.	IV	90	0.396	25	1	None	—	—	17	—	—	3
2b	0.90	0.90	75	Res.	IV	120	0.364	25	1	None	—	—	27	—	—	7
3	0.92	0.85	250	Res.	IV	90	0.570	30	1	None	Near	10	34	0	—	5
4	0.85	0.00	500	CBD	I	90	0.318	23	1	None	—	—	0	—	—	—
5	0.84	0.27	250	CBD	I	70	0.339	34	1	1 side	Far	15	14	—	—	8
6	0.92	0.28	250	Res.	IV	90	0.571	29	1	1 side	—	—	11	—	0	4
7	0.90	0.76	250	Fringe	II	70	0.322	22	1	1 side	—	—	39	86	—	0
8a[a]	0.92	0.27	250	CBD	I	70	0.460	37	1	1 side	Far	20	14	22	15	2
8b	0.89	0.06	250	CBD	I	70	0.460	37	1	1 side	Far	20	3	18	14	4
9	0.85	0.00	500	CBD	I	90	0.550	40	1	2 sides	—	—	0	—	—	—
10	0.82	0.08	250	Fringe	III	70	0.400	40	1	2 sides	—	—	4	14	0	4
11a	0.80	0.04	250	Fringe	II	70	0.340	38	1	2 sides	Near	0	2	20	30	3
11b	0.85	0.14	250	Fringe	II	70	0.340	38	1	2 sides	Near	7	7	6	34	4
12	0.87	0.21	250	CBD	I	70	0.560	10	2	None	Near	15	11	2	—	3
13	0.75	0.02	250	Outly	III	70	0.600	21	2	None	Near	—	1	11	—	0
14a	0.80	0.12	100	Res.	III	90	0.344	20	2	None	Near	5	5	0	—	3
14b	0.91	0.40	100	Res.	III	90	0.344	20	2	None	Near	0	16	8	—	4
15	0.86	0.23	250	Fringe	II	70	0.514	13	2	None	—	—	12	10	—	1
16	0.89	0.35	250	Res.	III	90	0.700	9	2	None	—	—	14	7	—	0
17	0.79	0.46	250	Res.	II	70	0.450	18	2	None	—	—	24	11	10	6
18	0.87	0.12	250	Fringe	II	70	0.443	26	2	None	—	—	6	2	8	1
19	0.86	0.19	250	Fringe	II	70	0.390	22	2	None	—	—	10	6	6	1
20	0.89	0.78	250	Res.	II	90	0.611	20	2	None	Near	0	31	7	4	2
21[b]	0.87	0.10	250	Fringe	II	70	0.450	26	2	None	—	—	5	15	17	6
22[b]	0.84	0.90	250	Res.	II	70	0.378	9.5	2	None	—	—	46	3	31	2
23[b]	0.81	0.27	250	CBD	I	70	0.460	10	2	None	Far	11	14	—	16	3
24	0.90	0.00	500	Fringe	III	90	0.611	19	2	Yes	—	—	0	—	—	—
25	0.91	0.00	500	Fringe	II	90	0.604	19	2	Yes	—	—	0	—	—	—
26	0.91	0.10	250	CBD	I	120	0.390	25	2	Yes	Far	4	3	12	—	5
27	0.85	0.52	250	Fringe	II	70	0.380	17	2	Yes	Far	6	27	37	0	6
28	0.82	0.63	250	Fringe	II	70	0.490	20	2	Yes	—	—	32	70	15	1
29	0.83	0.41	250	Fringe	II	70	0.380	17	2	Yes	Far	5	21	12	4	3
30a	0.81	0.41	250	Fringe	II	70	0.450	20	2	Yes	—	—	21	17	13	4
30b	0.83	0.58	250	Fringe	II	70	0.450	20	2	Yes	—	—	30	14	16	3
31	0.82	0.41	250	Fringe	II	70	0.510	20	2	Yes	Far	0	21	10	4	4
32	0.87	0.18	250	Fringe	II	70	0.443	25	2	Yes	—	—	9	15	26	1
33	0.86	0.58	250	CBD	I	70	0.460	20	2	Yes	Near	18	30	18	0	5
34	0.86	0.75	500	Fringe	II	90	0.324	21	2	Yes	Near	0	30	25	8	1
35	0.88	0.00	500	Fringe	II	90	0.550	28	2	Yes	Near	0	0	—	—	—
36	0.81	0.18	250	Fringe	II	70	0.510	20	2	Yes	Near	6	9	7	7	1
37	0.94	0.35	250	Fringe	II	70	0.600	22	2	Yes	Near	3	18	2	7	1
38	0.85	0.88	250	Fringe	II	70	0.400	22	2	Yes	Near	6	45	9	3	5

[a]Policeman enforcing controls in intersection. [b]Exclusive of left-turn lane.

In one of the 2 cases (site 3) where the HCM estimate is greater than the actual volume, it should be noted that the basic HCM approach volume is for a 30-ft approach (compared to 25 ft for sites 1 and 2). It would appear that the additional 5-ft width of approach, for a roadway marked for 2 lanes, should only increase the basic approach volume (over a 25-ft width) by about 200 vph of green rather than the 400 vph of green indicated by Figure 6.5 of the Highway Capacity Manual (1).

The other location, site 11 (samples 11a and 11b) where the HCM estimate was higher than the actual volume, has a near-side bus stop, with parking. Because few local buses stop, and there are greater than 25 percent turning movements, the HCM adjustment for this factor is approximately 1.25. However, if the bus stop were removed, the HCM adjustment would be reduced to 1.00, yielding HCM estimates of volume below those found in the field. This is the first indication that the HCM adjustments for near-side bus stops, with parking, could be extremely high. Sites 33 through 38 (to be discussed later in this report) give similar results.

Sample 8a shows a +3 percent difference, which may be explained by the influence of the policeman within the intersection during the study. His presence may have slowed the traffic as it came through the intersection.

Capacity Comparison—The HCM estimate of capacity ranges from -33 to +40 percent of the ALE capacity.

Site 11, which is composed of samples 11a and 11b, has the largest differences, +40 and +33 percent. This site has a near-side bus stop, but few local buses stop. The HCM adjustment for this case is 1.24. If the bus stop were removed, the HCM

TABLE 2

SAMPLE VOLUMES AND CAPACITIES

Sample	PH Vol.	HCM Vol.	Percent Diff.[a]	Capacity						
				ALE	HCM	Percent Diff.[b]	Bellis	Percent Diff.[b]	Dier	Percent Diff.[b]
1a	1,934	1,780	-8	1,950	1,820	-7	2,170	11	2,190	12
1b	1,970	1,980	1	1,970	1,980	1	2,180	11	2,200	12
2a	1,448	910	-37	1,520	1,020	-33	1,560	3	1,430	-6
2b	1,330	1,000	-25	1,340	1,020	-24	1,370	2	1,300	-3
3	1,864	2,060	11	1,930	2,100	9	2,160	12	2,070	7
4	473	550	NA	—	—	—	—	—	—	—
5	700	640	-9	880	790	-10	600	-32	1,220	39
6	1,450	1,310	-9	1,640	1,600	-2	2,160	32	2,020	23
7	413	390	-5	460	410	-11	460	0	530	15
8a[c]	1,050	1,080	3	1,190	1,380	16	1,050	-12	1,650	39
8b	1,090	940	-14	1,250	1,310	5	1,030	-18	1,650	32
9	571	980	NA	—	—	—	—	—	—	—
10	760	710	-7	1,010	1,100	9	1,220	21	1,330	32
11a	590	670	14	770	1,080	40	770	0	1,120	45
11b	620	760	23	820	1,090	33	780	-5	1,120	37
12	470	480	2	620	680	10	560	-10	1,000	61
13	690	990	43	1,390	1,480	6	1,780	28	2,140	54
14a	867	590	-32	1,140	780	-32	1,060	-7	1,220	7
14b	900	690	-23	1,110	810	-27	1,010	-9	1,220	10
15	460	820	78	600	950	58	660	10	910	52
16	904	760	-16	1,040	970	-7	1,160	12	1,240	19
17	460	690	50	520	820	58	580	12	620	19
18	640	1,060	66	1,010	1,380	37	1,020	1	1,180	17
19	510	730	43	850	1,020	20	940	11	1,000	18
20	1,070	1,360	27	1,120	1,530	37	870	-22	1,630	46
21[d]	720	1,140	58	1,020	1,320	29	1,000	-2	1,510	48
21L[e]	180	100	-44	210	100	-52	—	—	180	-14
22[d]	530	540	2	550	580	5	500	-7	690	25
22L[e]	170	100	-41	260	100	-62	—	—	150	-42
23[d]	360	400	11	450	600	33	450	0	880	95
23L[e]	80	170	113	110	170	55	—	—	30	-73
24	345	1,050	NA	—	—	—	—	—	—	—
25	506	1,180	NA	—	—	—	—	—	—	—
26	468	550	18	560	670	20	390	-30	340	-39
27	380	440	16	450	470	4	480	7	620	38
28	608	490	-19	670	550	-18	660	1	650	-3
29	355	470	32	450	490	9	500	11	500	11
30a	460	470	2	570	550	-4	590	4	590	4
30b	470	500	6	560	550	-2	600	7	590	5
31	570	710	25	700	860	23	730	4	670	-4
32	670	620	-7	900	740	-19	860	-4	890	-1
33	530	690	30	570	790	39	480	-16	410	-28
34	404	630	56	430	690	60	440	2	430	0
35	640	1,270	NA	—	—	—	—	—	—	—
36	563	800	42	680	970	43	750	10	680	0
37	880	1,040	18	950	1,280	35	890	-6	800	-16
38	540	720	33	550	750	36	600	9	530	-4

NA = not applicable.

[a]Based on PH volume.
[b]Based on ALE.
[c]Policeman enforcing controls in intersection.
[d]Exclusive of left-turn lane.
[e]Separate left-turn lane.

adjustment would be reduced to 1.00, with a resulting difference of +12 and +9 percent with ALE.

Sample 8a has the next largest positive difference, +16 percent. However, this site had a policeman enforcing the signal controls during the period of study. Thus, his presence may have impeded the flow of vehicles to some degree.

The capacity comparison for sample 3 is similar to the volume comparison of the previous section. It would again appear that a 400 vph of green increase in basic approach volume (as indicated by the HCM) of a 30-ft wide roadway over a 25-ft wide roadway (both marked for 2 lanes) is higher than the capacity attained in the field.

Of the 6 samples where the HCM estimates of capacity are higher than ALE, 5 of the samples have parking on either one or both sides of the one-way approach.

Two-Way Streets With No Parking

Volume Comparisons at the Actual Load Factor—Thirteen samples were studied in this category using 12 different approaches. Of the 12 approaches, the HCM estimate of volume was high at 10 of them (ranging from +2 to +78 percent).

For those approaches marked for 2 lanes, the following tabulation shows how the percentage difference in HCM estimate increases with an increase in width of approach. (All samples have a metropolitan location factor of 1.25.)

Sample	Width	Multiple of Turn Adj.	Percent Diff.
14a	20	1.16	-32
14b	20	1.11	-23
20	20	1.07	+27
13	21	1.07	+43
19	22	1.00	+43
21	26	1.08	+58
18	26	1.07	+66

A similar trend is noted for the one-lane approaches. (All samples have a metropolitan location factor of 1.25, except samples 23 and 12, which have a factor of 1.00.)

Sample	Width	Multiple of Turn Adj.	Percent Diff.
16	9	1.38	-16
22	9.5	1.48	2
23	10	1.56	11
12	10	1.51	2
15	13	1.31	78
17	18	0.97	50

The only factor of importance that distinguishes samples 14a, 14b, and 16 (the sample approaches at which the HCM estimate was low) from the others is that site 14 is on the approach to a bridge entering a city, and site 16 is the departure of a bridge leaving a city. It is difficult to determine from these listings the exact cause for the HCM differences. The 2 factors, width (hence, basic approach volume) and turning movements (the break-off width in the HCM, for significant differences in turn factors, is 16 ft), are present simultaneously. For the volume comparisons, there is also a difference in load factor between the separate samples. This latter factor is removed in the capacity comparisons of the next section.

There are 3 "separate left turn lane" samples in this category. The HCM estimate of the volumes for the samples shows little similarity with the actual left-turn volumes.

Capacity Comparison—The results of the HCM estimate of capacity (LF = 1.00) are similar to those of volume. The HCM estimate of capacity is again high for 10 of the 12 sites studied, and again exhibits a tendency for this difference to get proportionately larger as the width of roadway increases (while keeping the number of marked lanes constant).

For the approaches marked for 2 lanes, all samples have a metropolitan location factor of 1.25.

Sample	Width	Multiple of Turn Adj.	Percent Diff.
14a	20	1.15	-32
14b	20	1.11	-27
20	20	1.08	+37
13	21	1.10	+6
19	22	1.06	+20
21	26	1.08	+29
18	26	1.06	+37

For the one-lane approaches, all samples have a metropolitan location factor of 1.25, except samples 23 and 12, which have a factor of 1.00.

Sample	Width	Multiple of Turn Adj.	Percent Diff.
16	9	1.38	-7
22	9.5	1.48	+5
23	10	1.56	+33
12	10	1.51	10
15	13	1.30	+58
17	18	1.00	+58

Again, the precise nature of a revised shape of the LF = 1.00 curve in the HCM cannot be determined because of the simultaneous influence of the turning movements. But even with a controlled study, the results may only be applicable to New Jersey.

Two-Way Streets With Parking

Volume Comparisons at the Actual Load Factor—The HCM estimate of volume is higher than the actual volume for 11 of the 13 samples in this category. Five of these 11 samples have a near-side bus stop. If the adjustment for the bus stop is reduced to 1.00 from a range of 1.08 to 1.35, the HCM estimate would still be higher than the actual volume by a range from +9 to 25 percent.

For the 2 samples, 28 and 32, where the HCM estimate of volume is less than the actual volume, the turning traffic is 83 and 33 percent respectively of the approach

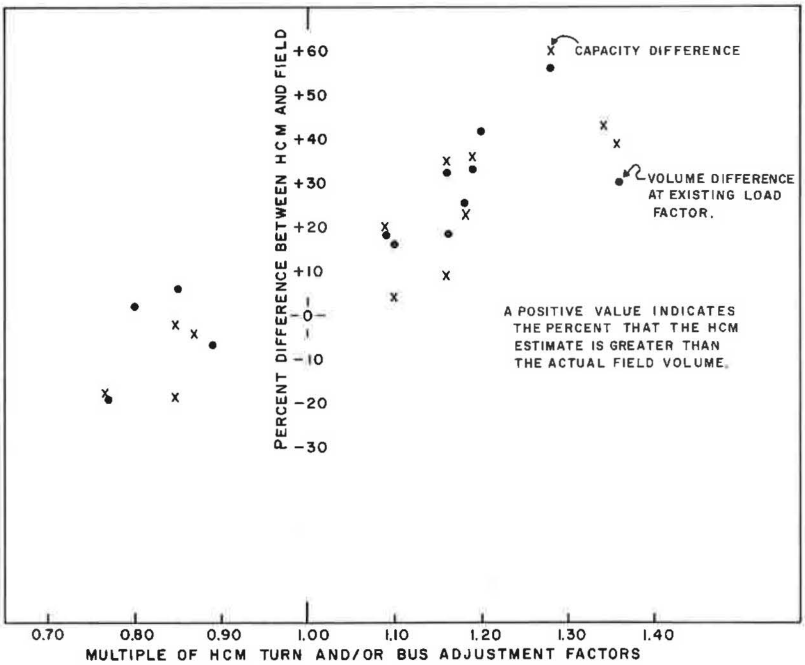


Figure 3. Multiple of HCM turn and/or bus adjustment factors versus percentage difference between HCM and field—2-way streets with parking.

volume. For those samples where there is no near-side bus stop (26 through 32), the positive and negative differences between the HCM estimate and the peak-hour volume closely approximate the multiple of HCM turn factors. When the bus stop factor is included with the multiple of the turn factors (for samples 33, 34, 36, 37, and 38), a similar trend is evident.

Capacity Comparison—As with the volume comparison, the positive or negative difference in the HCM estimate of capacity with ALE is closely related to the multiple of turn and/or bus adjustment factors. Figure 3 shows the variation of the multiple of these adjustment factors with the percentage difference between the HCM estimate and the actual peak-hour volume and ALE.

COMPARISON OF BELLIS CAPACITY ESTIMATES WITH ALE

The Bellis procedure does not estimate volumes between the lowest load factor (one loaded cycle) and capacity (all cycles loaded). Because there is just one sample in the study that had one loaded cycle, only a comparison of ALE and the Bellis estimate of capacity will be made.

For the 7 Type I samples, 6 have values between 10 and 32 percent below the ALE capacity. In one case the Bellis capacity and the ALE capacity are equal. These results indicate that the Bellis method underestimates capacity for CBD locations.

For the Type II samples, the Bellis capacities range from below to above the ALE values. Six samples are below ALE by 2 through 22 percent. For 4 samples, the Bellis estimate equals the ALE value (±1 percent). For another 11 samples, Bellis overestimates capacity by 4 through 12 percent. These samples include both parking and no parking conditions, which are not differentiated by the Bellis method.

For the Type III samples, 2 underestimate capacity by 7 and 9 percent, and 3 overestimate capacity by 12 through 21 percent.

For the Type IV samples, all 6 estimates exceed capacity by 2 through 32 percent.

Perhaps these results suggest slight revisions to Figure 1. The slope of the Type I line could be raised (because Type I capacities are underestimated), and the slopes of the Types III and IV lines could be lowered. The mean differences between the Bellis estimate and ALE are as follows:

Bellis Type	No. Samples	Mean Percent Diff.	Standard Deviation
I	7	-17	±10.4
II	21	2	±7.9
III	5	9	±14.8
IV	6	11	±9.9

COMPARISON OF DIER CAPACITY ESTIMATES WITH ALE

Dier capacities were divided into groups based on various lane configurations (Table 3).

Optional Right-Turn and Through Lane

Dier overestimates capacity for 5 of the 7 samples. The 2 samples that are underestimated are located in the CBD.

Left-Turn Only Lane

Dier underestimates capacity for the 3 samples. The California streets used to determine the Dier flow rates are wider than the streets used in this study. (Left turns across a wide street may be more difficult to make and, hence, have a lower flow rate than on a narrower street.)

TABLE 3

RATE OF FLOW AND PERCENTAGE DIFFERENCE FOR DIER METHOD

Lane Configuration	Sample	Vehicles per Second[a]	Percent Diff.[b]
Optional right-turn and through lane	15	0.49	52
	16	0.49	19
	22	0.49	25
	7	0.46	15
	27	0.46	38
	26[c]	0.25	-39
	33[c]	0.25	-28
Left-turn only lane	21L	0.11	-14
	22L	0.11	-42
	23L[c]	0.02	-73
Optional left-turn, right-turn, and through lane	17	0.39	19
	28	0.37	-3
	29	0.37	11
	30a	0.37	4
	30b	0.37	5
	31	0.37	-4
	34	0.37	0
	36	0.37	0
	37	0.37	-16
	38	0.37	-4
Through lane	12[c]	0.50	61
	23[c]	0.50	95
	1a	1.02	12
	1b	1.02	12
	2a	1.02	-6
	2b	1.02	-3
	3	1.02	7
	5[c]	0.96	39
	6	0.99	23
Optional right-turn and through lane, plus through lane	10	0.93	32
	13	0.99	54
	14a	0.99	7
	14b	0.99	10
	21	1.00	48
Optional right-turn and through lane, plus optional left-turn and through lane	11a	0.92	45
	11b	0.92	37
	18	0.74	17
	19	0.71	18
	20	0.74	46
Optional left-turn and through lane, plus right-turn only lane	32	0.56	-1
Optional left-turn and through lane, through lane, plus optional right-turn and through lane	8a[c]	1.00	39
	8b[c]	1.00	32

[a]Flow rate for individual lane configurations taken from Dier (3). [b]Difference between Dier and ALE capacities. [c]CBD location.

Optional Left-Turn, Right-Turn, and Through Lane

Dier's estimate of capacity is within ±20 percent of ALE for the 10 samples in this category. The average error is 1.2 percent with a standard deviation of ±8.4 percent.

Through Lane

For the 4 sites outside the CBD, Dier overestimates the capacity of three of them and underestimates one.

The site, which is underestimated, is a high-type roadway. (However, the estimate of capacity at another high-type location, site 1, is high by 12 percent.)

For the 3 CBD samples, Dier overestimates capacity by at least 39 percent. One of these samples has an exclusive bus lane, and another has an exclusive left-turn lane.

Optional Right-Turn and Through Lane, Plus Through Lane

Dier overestimates capacity for all 5 samples. This seems reasonable, because the optional right turn and through lane estimates, discussed earlier, for non-CBD areas are greater than ALE. The capacity of the through lanes is also overestimated by Dier.

Optional Right-Turn and Through Lane, Plus Optional Left-Turn and Through Lane

Dier overestimates capacity for all 5 samples. Consistent with the optional right turn and through lanes, discussed earlier, the right turn and through lanes of this category were also overestimated by Dier. Hence, his estimation of the capacity of these approaches is high.

Optional Left-Turn and Through Lane, Plus Right-Turn Only Lane

In this single case, the Dier estimate of capacity is equal to ALE.

Optional Left-Turn and Through Lane, Through Lane, Plus Optional Right-Turn and Through Lane

Both samples overestimate capacity for this CBD location. When individual lanes are examined, Dier's estimate of capacity for the through lane exceeds ALE by approximately 70 percent. For through lanes, discussed earlier, the Dier estimate of capacity exceeded ALE by 39, 61, and 95 percent (for CBD locations).

CONCLUSIONS

Most of the sampled data for this study were collected in or near Trenton, New Jersey. An overall comparison of the accuracy of capacity estimation for the 3 methods studied in this report is evident from the data shown in Figure 4.

Regional differences in driver characteristics may be inferred from the positions of the 3 curves. As may be expected, the Bellis method of capacity estimation is the most accurate, probably because this method was developed in the state of New Jersey.

Because of the uniqueness of each of the methods, an individual analysis is made of their effectiveness.

HCM

For approximately half the study samples, the HCM method yields estimates in excess of ±20 percent of the peak-hour volume and ALE values.

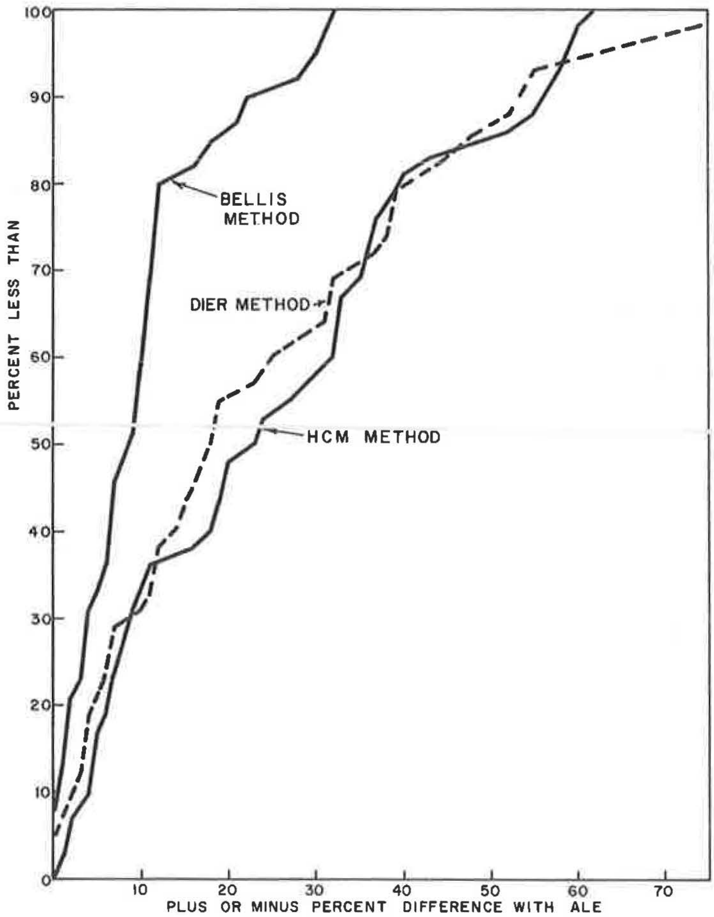


Figure 4. Cumulative frequency curves of percentage differences of methods of capacity estimation with ALE.

With the limitations of 38 sites (42 samples), the main reasons for the inaccuracy of this method appear to be the following:

1. The adjustment factor for near-side bus stops on 2- and 3-lane streets, with parking, gives inflated values for volume and capacity estimates.
2. The basic approach volume is based on width of approach, rather than number of lanes. The fact that this procedure may lead to erroneous results is evident on 2-way streets, without parking.
3. To some extent the turn adjustment factors for narrow approaches (between 10 and 15 ft) may be too extreme.
4. The computation of volume for the exclusive left-turn lane, while rational, is far from accurate for the 3 samples studied in this report.

Bellis

Of the 4 types of streets that are estimated under the Bellis procedure, the most variation is found in Type III (the standard deviation of the estimate for the sampled data is ±14.8 percent).

For consistency in the estimate, the Type I streets are estimated low, and the Type IV streets are estimated high.

The estimate of capacity for Type II streets is the most accurate, with over 95 percent of the samples (20 of 21) within ±12 percent of ALE.

Dier

As with the Bellis method, the Dier procedure uses a rate of flow by lane.

The errors of the estimate of capacity by this method can be tentatively reduced to 3 primary lane configurations.

1. The estimate of capacity for the optional right turn and through lane (outside the CBD) is consistently high.
2. The left-turn only lane estimate has been developed by Dier using wide streets and, hence, is low for the samples of this study.
3. The estimate of capacity for the through lane in the CBD locations is consistently high.

ACKNOWLEDGMENT

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3. Dier, R. A New Concept for the Determination of Roadway Capacity and Traffic Signal Timing.

Appendix

The various kinds of intersections are shown in Figures 5 through 9.

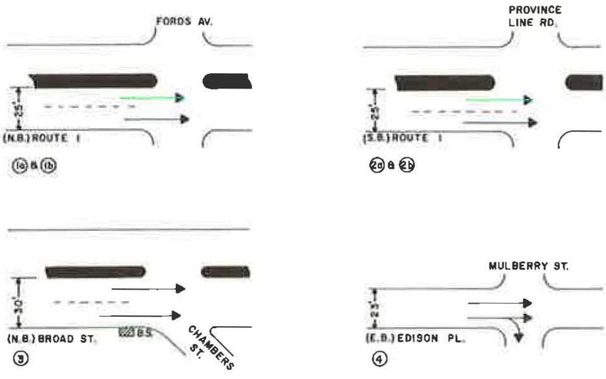

Figure 5. One-way, no parking.

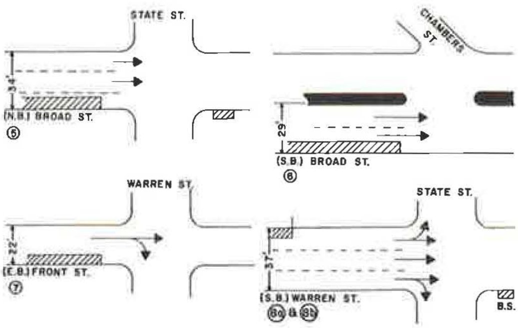

Figure 6. One-way, one side parking.

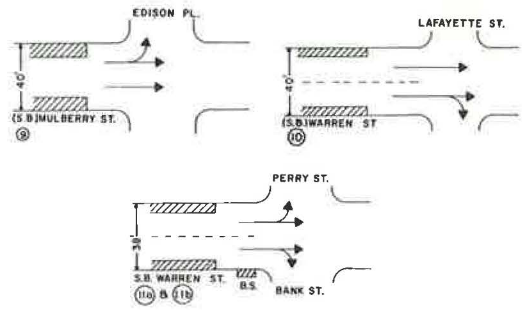

Figure 7. One-way, two side parking.

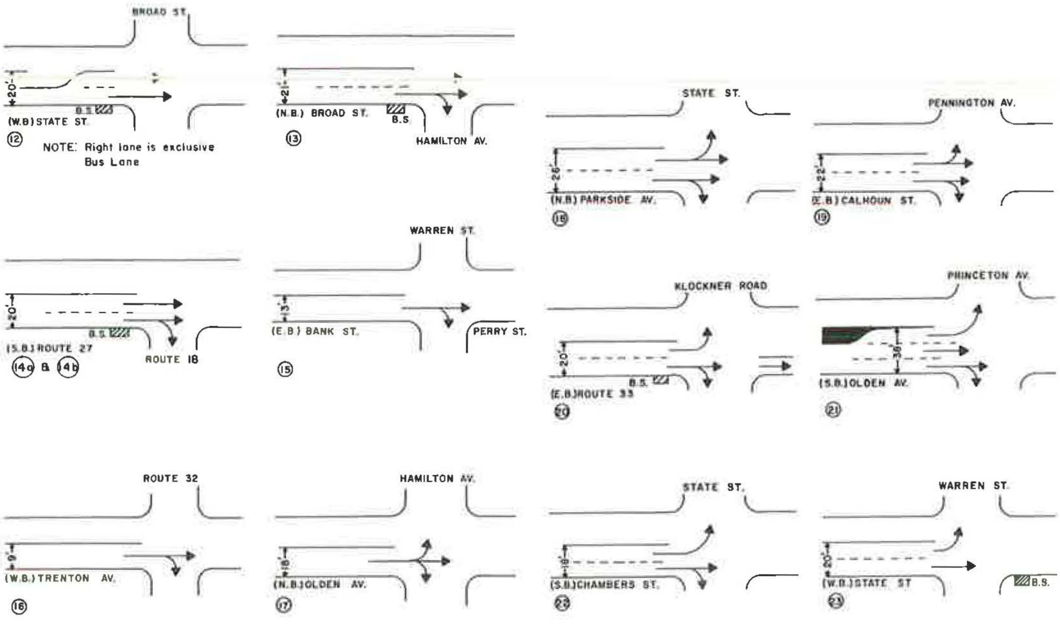

Figure 8. Two-way, no parking.

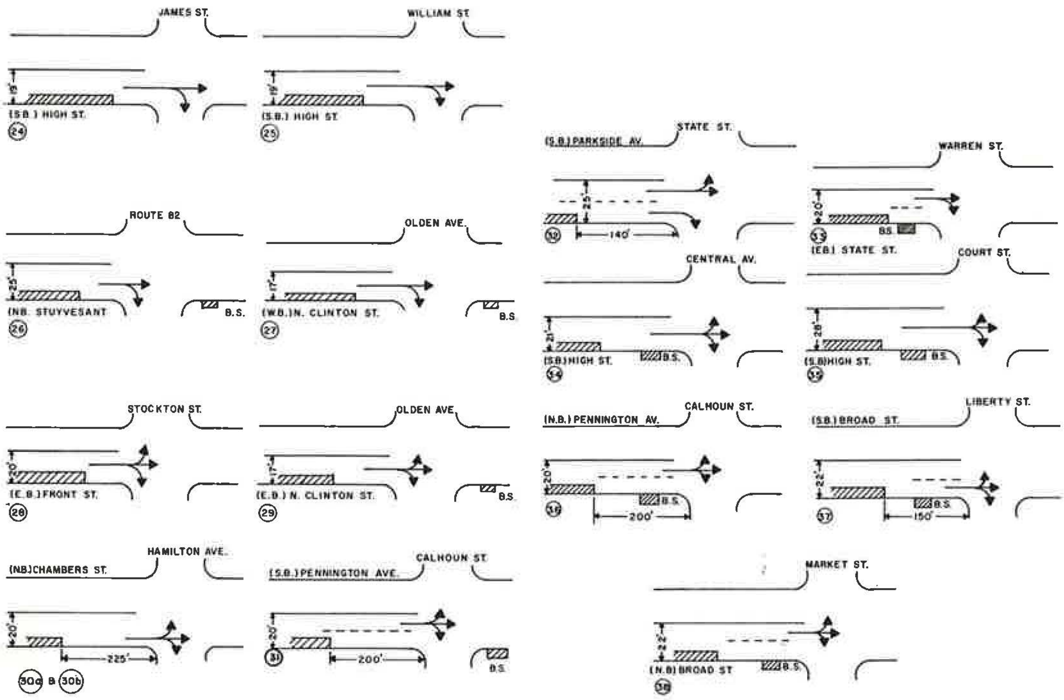

Figure 9. Two-way, parking.