Use of Default Parameters for Estimating Signalized Intersection Level of Service

RICHARD G. DOWLING

The 1985 *Highway Capacity Manual* (HCM) "operations" method for estimating the level of service of signalized intersections can require a large amount of field data: turning movement volumes, lane geometry, signal timing, approach grades, percentage heavy vehicles, number of parking maneuvers per hour, number of buses stopping per hour, peak hour factors, number of conflicting pedestrians per hour, arrival types, and right turns on red. The effects on accuracy of replacing most of these required input data with the default values recommended in Table 9-3 of the HCM are tested. The average stopped delay was calculated for six signalized intersections starting with basic volume (flow rate), lane geometry, and signal timing data. The HCM-recommended default values for grades, heavy vehicles, and such were used in place of the rest of the required input data. The calculations were then repeated several times; each time one or more of the default values were replaced with field data. The resulting delay estimates were then compared with field measurements of delay. The test results indicated that users can obtain reliable estimates of intersection level of service and delay using only field-measured turning movements, lane geometry, and signal timing plus the HCM-recommended defaults for the rest of the required input data. Field measurements of peak hour factors, grades, percentage heavy vehicles, parking maneuvers, number of stopping buses, conflicting pedestrians, and arrival type improved the accuracy of the delay estimates, but the improvements were comparatively minor and did not change the estimated intersection level of service. Delay estimates for intersections with critical volume-capacity ratios of less than 85 percent of capacity were insensitive to additional data on peaking, arrival type, and saturation flow rates.

The 1985 *Highway Capacity Manual* (HCM) recommends an "operations" method for estimating the average stopped delay at signalized intersections (*1*). This method can require a great deal of data collection. Users need to know turning movement volumes, lane geometry, signal timing, approach grades, percentage heavy vehicles, number of parking maneuvers per hour, number of buses stopping per hour, peak hour factors (PHFs), number of conflicting pedestrians per hour, arrival types, and right turns on red. Collecting all of these data would require at least 4 person-hr per intersection and possibly twice that for more complex intersections.

How much of this information is really necessary? How does the use of defaults for most of the required data affect the accuracy of the HCM method? These are the questions that this paper is designed to answer.

Two signalized intersections in Oakland, California, were videotaped for 1 peak hr each. The average stopped delay for each intersection was then calculated using the HCM method starting with basic volume (flow rate), geometric, and signal timing information combined with the default parameter values recommended in Table 9-3 of the HCM. The calculation was repeated several times, and the default values were replaced gradually with more and more field-observed values. The results were then compared with the field-measured average stopped delay to determine how additional field data-improve the accuracy of the HCM operations method.

This procedure was also performed for four more signalized intersections that were contained in the 1982 validation data set for NCHRP Project 3-28[2], "Urban Signalized Intersection Capacity," which was the precursor to the current 1985 HCM method. This older data set was not as detailed, so not all of the tests performed on the two videotaped intersections could be repeated; however, it was possible to reproduce most of the tests.

The results for all six intersections were combined and evaluated to determine how additional data collection might improve the accuracy of the stopped delay and level-of-service estimates produced by the HCM operations method for signalized intersections.

BACKGROUND

During the development of the current HCM procedure for estimating the capacity and level of service of signalized intersections, the validity and accuracy of the proposed method were tested many times.

Reilly developed the NCHRP 3-28[2] procedure using several data sets throughout the United States (*2*). He then validated the proposed procedure against 25 observations made at eight intersections in Arizona and California and found that the mean absolute error (MABS) in the estimate of average intersection stopped vehicle delay was 1.1 sec/vehicle. May later used five of these eight intersections to compare this procedure with other capacity analysis methods (*3*). The delay equation and the method for estimating saturation flow were subsequently modified before being included in Chapter 9 of the 1985 HCM.

Teodorvic tested the HCM method against 16 observations made on the approaches to five intersections in Delaware (*4*) and found that the HCM method overpredicted average stopped delay by an average of 12 sec on an approach basis. The MABS was 18 sec, with a standard deviation of 26 sec.

The actual error may have been higher since Teodorvic eliminated observations in which the calculated volume-capacity ratio (*v/c*) was greater than 1.2. He did keep two observations in which the estimated *v/c* was greater than 1.0, and these two observations accounted for most of the observed error. Since a queue cannot discharge faster than the actual capacity of the approach, one can conclude that the error may be attributed to an underestimation of actual saturation flow rates. This may have been due to a failure to measure ideal saturation flow rates in the field or to the HCM method's underestimation of actual approach capacity at these locations.

Lin compared the HCM estimated average stopped delay with field measurements for 20 approaches at seven intersections in New York State (*5*). He found the MABS to be 9.0 sec (on an approach

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HCS:  Signalized Intersection    Version 2.1                              1
=====================================================================
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Gainesville, FL   32611-2083          (904) 392-0378
=====================================================================
Streets: (E-W) Twenty-Seventh          (N-S) Harrison
Analyst: RGD                           File Name: HARRIS7C.HC9
Area Type: Other                       5-16-93 8-9
Comment: Vol+Geo+actual timing+PHF+Delay Adj+actual sat (1 lane NB LT)
=====================================================================

                    Traffic and Roadway Conditions
---------------------------------------------------------------------
              |   Eastbound    |  Westbound     |  Northbound    |  Southbound
              | L    T    R    | L    T    R    | L    T    R    | L    T    R
              |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes     | 1  > 2  <      |     > 2  <     | 1    2  <      | 1    2  <
Volumes       |  53  150  120  |  81  218  125  | 286  418   36  |  81 1411  110
PHF or PK15   |0.92 0.92 0.92|1.00 1.00 1.00|0.94 0.94 0.94|0.83 0.83 0.83
Lane Width    |12.0 12.0       |     12.0       |12.0 12.0       |12.0 12.0
Grade         |        0       |        0       |        0       |       -3
% Heavy Veh   |   1    1    1  |   1    1    1  |   2    2    2  |   0    0    0
Parking       |  (Y/N) Y     0 |  (Y/N) Y     1 |  (Y/N) Y    11 |  (Y/N) N
Bus Stops     |              0 |              0 |              7 |             4
Con. Peds     |             26 |             71 |             63 |            75
Ped Button    |(Y/N) N         |(Y/N) N         |(Y/N) Y 17.5 s|(Y/N) Y 20.5
Arr Type      |   3    3    3  |   2    2    2  |   3    3    3  |   4    4    4
RTOR Vols     |              0 |              0 |              0 |             0
---------------------------------------------------------------------

                          Signal Operations
---------------------------------------------------------------------
Phase combination 1     2     3     4 |           5     6     7     8
EB  Left          *                   |NB  Left   *
    Thru          *                   |    Thru   *     *
    Right         *                   |    Right  *     *
    Peds          *                   |    Peds   *     *
                                      |
WB  Left          *                   |SB  Left         *
    Thru          *                   |    Thru         *
    Right         *                   |    Right        *
    Peds          *                   |    Peds         *
                                      |
NB  Right                             |EB  Right
SB  Right                             |WB  Right
                                      |
Green            17P                  |Green      15P   39P
Yellow/A-R        3                   |Yellow/A-R  3     3
Lost Time        3.0                  |Lost Time 3.0   3.0

Cycle Length:  80 secs  Phase combination order: #1 #5 #6
```

FIGURE 1 Harrison and 27th input data sheet.

basis). He investigated ways in which the progression adjustment factor and the second term of the delay equation contributed to this error, particularly for actuated signals. However, he did not go on to investigate ways in which the other parameters used in the HCM method to determine saturation flow would influence the result.

From these results, it appears that the current HCM method can be expected to predict average stopped delay with an average error of from 9 to 18 sec/vehicle on each approach. Data on mean error for entire intersections, however, are not available.

Several of the investigators are also unclear as to whether they used exclusively field-measured data or substituted some of the defaults recommended in Table 9-3 in their computations. There are no data on how the use of default parameters in lieu of some field data might significantly worsen the performance of the HCM method.

METHODOLOGY

Overview

The impact of default parameters on the accuracy of the HCM operations method was evaluated at six intersections in the San Francisco Bay Area of California. Four of these intersections were taken from the 1982 validation data set used by May and Reilly for testing the validity of the NCHRP 3-28[2] procedure. Another two were videotaped in Oakland in 1993 and the results combined with the results of the older data set evaluated by May.

The peak 15-min capacity and level of service were calculated for each intersection using the McTrans software, HCS2.1, released in 1990 (*6*) (Figures 1 through 6). The HCS-estimated average stopped delay for the entire intersection was compared with the field-

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HCS:  Signalized Intersection    Version 2.1                              1
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=====================================================================
Streets: (E-W) Webster                 (N-S) Grand
Analyst: RGD                           File Name: WEB7.HC9
Area Type: Other                       3-10-93 4:42PM
Comment: vol + geo + actual timing+PHF+delay adj.+ actual sat
=====================================================================

                    Traffic and Roadway Conditions
---------------------------------------------------------------------
            |  Eastbound  |  Westbound  |  Northbound  |  Southbound
            | L    T    R | L    T    R | L    T    R | L    T    R
            |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes   |             |    > 2  <   | 1    2  <    |    > 2  <
Volumes     |             | 110  280   66| 127  336   18| 25  747  256
PHF or PK15 |             |0.83 0.83 0.83|0.97 0.97 0.97|0.90 0.90 0.90
Lane Width  |             |     12.0     |12.0 12.0     |     12.0
Grade       |             |        0     |        0     |        0
% Heavy Veh |             |   0    0   0 |   2    2   2 |   0    0   0
Parking     |             | (Y/N) Y     3| (Y/N) Y     1| (Y/N) Y    4
Bus Stops   |             |             0|             4|           13
Con. Peds   |           0 |           118|            29|           68
Ped Button  |             |(Y/N) Y 17.5 s|(Y/N) Y 11.5 s|(Y/N) Y 13.0
Arr Type    |             |   2    2   2 |   4    4   4 |   4    4   4
RTOR Vols   |             |             0|             0|            0
---------------------------------------------------------------------

                          Signal Operations
---------------------------------------------------------------------
Phase combination 1     2     3     4 |            5     6     7     8
EB  Left                                |NB  Left    *
    Thru                                |    Thru    *     *
    Right                               |    Right   *     *
    Peds          *                     |    Peds          *
                                        |
WB  Left          *                     |SB  Left          *
    Thru          *                     |    Thru          *
    Right         *                     |    Right         *
    Peds          *                     |    Peds          *
                                        |
NB  Right                               |EB  Right
SB  Right                               |WB  Right
                                        |
Green            27P                    |Green      10P   34P
Yellow/A-R        3                     |Yellow/A-R  3     3
Lost Time       3.0                     |Lost Time 3.0   3.0

Cycle Length:  80 secs  Phase combination order: #1 #5 #6
```

FIGURE 2 Webster and Grand input data sheet.

measured average stopped time delay. Approach stopped delay was also evaluated in the tests.

Tests

The tests started with the minimum necessary field data needed to estimate level of service using all of the defaults suggested in Table 9-3 and Equation 9-8 of the HCM (Table 1). Each subsequent test then replaced selected default values with field-observed values, building on the field observations until all field observations had been included in the level-of-service analysis (Figure 7). Table 2 presents the parameters used in each test. The tests proceeded in the following sequence:

- *Test 1: Turning Movement and Basic Geometric Data, plus Observed Signal Timing*. Test 1 included hourly turning movement volumes (flow rates) for each approach plus basic geometric information (lanes and parking location) obtained from the field. Signal phasing sequences and minimum pedestrian times were also measured in the field and included in this test. Signal timing (cycle lengths and phase lengths) was estimated using SOAP84 (*7*). Defaults were used for all other data (grade, heavy vehicles, parking maneuvers, local buses, conflicting pedestrian volumes, arrival type, and PHF). This test was performed for only the two videotaped intersections in Oakland (Harrison and Webster).
- *Test 2: Turning Movements, Geometry, plus Observed Signal Timing*. In Test 2, the optimal signal timing used in Test 1 was replaced with observed phase and cycle lengths. Actual field-observed signal timing data were used for the two videotaped intersections (Harrison and Webster). Observed phase lengths were not reported for the four intersections evaluated by May. Consequently, estimated phase lengths (based on an equal degree of saturation solution, given the observed flow rates, cycle length, and

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=====================================================================
Streets: (E-W) Rose                    (N-S) Grove (MLK)
Analyst: Rgd                           File Name: GROVE7.HC9
Area Type: Other                       6-4-93
Comment: vol+geo+cycle+PHF+delay adj.+actual sat
=====================================================================

                    Traffic and Roadway Conditions
---------------------------------------------------------------------
             |   Eastbound   |  Westbound    |  Northbound   |  Southbound
             | L    T    R   | L    T    R   | L    T    R   | L    T    R
             |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes    |     > 1  <    |     > 1  <    |     > 1  <    |     > 1  <
Volumes      |  30   89   31 |  39  110   21 |  18  272   60 |  23  407   20
PHF or PK15  |0.85 0.85 0.85|0.85 0.85 0.85|0.85 0.85 0.85|0.85 0.85 0.85
Lane Width   |     12.0      |     12.0      |     12.0      |     12.0
Grade        |        0      |        0      |        0      |        0
% Heavy Veh  |   5    5    5 |   1    1    1 |   4    4    4 |   1    1    1
Parking      |  (Y/N) Y     2|  (Y/N) Y     0|  (Y/N) Y     4|  (Y/N) Y     4
Bus Stops    |              0|              0|              3|              3
Con. Peds    |              4|             79|             51|             56
Ped Button   |(Y/N) Y 11.5 s|(Y/N) Y 11.5 s|(Y/N) Y 11.5 s|(Y/N) Y 11.5
Arr Type     |   3    3    3 |   2    2    2 |   5    5    5 |   3    3    3
RTOR Vols    |              0|              0|              0|              0
---------------------------------------------------------------------

                          Signal Operations
---------------------------------------------------------------------
Phase combination 1     2     3     4 |            5     6     7     8
EB  Left          *                   |NB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds          *                   |    Peds    *
                                      |
WB  Left          *                   |SB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds          *                   |    Peds    *
                                      |
NB  Right                             |EB  Right
SB  Right                             |WB  Right
                                      |
Green            16P                  |Green      43P
Yellow/A-R        3                   |Yellow/A-R  3
Lost Time       3.0                   |Lost Time 3.0

Cycle Length:  65 secs  Phase combination order: #1 #5
```

FIGURE 3 Grove and Rose input data sheet.

phase sequence) were used for these four intersections instead of field data.

- *Test 3: Turning Movements, Geometry, Signal Timing, plus PHF.* In Test 3, the default 0.90 peak 15-min factor (PHF) was replaced with the observed PHF. A single intersectionwide PHF was used for the intersections evaluated by May because of the lack of reported data. Approach-specific PHFs were applied to the two videotaped intersections.
- *Test 4: Turning Movements, Geometry, Timing, PHF, plus Arrival Type.* In Test 4 the default Arrival Type 3 was replaced with actual approach arrival types based on field measurements of R_p (platoon ratio) for the two videotaped intersections. The reported arrival types were used for the other four intersections evaluated by May.
- *Test 5: Turning Movements, Geometry, Timing, PHF, Arrival Type, plus Saturation Adjustment Factors.* Field measurements of the percentage of heavy vehicles (F_{hv}), grade (F_g), parking maneuvers (F_p), local buses stopping per hour (F_{bb}), and conflicting pedestrians per hour were used to replace the default values used in the saturation adjustment process. The data set did not permit testing of the lane width factor and area type factor since all lanes were 12 ft wide and all intersections were located outside of central business district areas.
- *Test 6: Turning Movements, Geometry, Timing, PHF, Arrival Type, Saturation Adjustment Factors, plus Ideal Saturation Flow.* The default 1,800 ideal saturation flow rate was replaced with a field-measured 1,900 vehicles per hour green per lane at the two Oakland intersections. This test was not performed on the four intersections reported by May because the necessary data on ideal saturation flows in these areas were lacking.
- *Test 7: Turning Movements, Geometry, Timing, PHF, Arrival Type, Saturation Adjustment Factors, Ideal Saturation Flow, plus Field-Measured Saturation Flows.* Actual saturation flow rates were measured for selected approaches. These were generally the more congested movements at each intersection. The ideal saturation flow entry was modified manually in the HCS2 software for

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=====================================================================
Streets: (E-W) McDonald                (N-S) San Pablo
Analyst: Rgd                           File Name: MCDONAL7.HC9
Area Type: Other                       6-3-93
Comment: vol+geo+cycle+PHF+delay adj.+actual sat
=====================================================================
```

Traffic and Roadway Conditions

	Eastbound			Westbound			Northbound			Southbound		
	L	T	R	L	T	R	L	T	R	L	T	R
No. Lanes	1	1	1	1	1	<	1	2	1	1	2	1
Volumes	320	210	260	113	131	56	210	905	95	108	374	78
PHF or PK15	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Lane Width	12.0	12.0	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	12.0
Grade		0			0			0			0	
% Heavy Veh	1	1	1	0	0	0	2	2	2	1	1	1
Parking	(Y/N)	N		(Y/N)	N		(Y/N)	N		(Y/N)	N	
Bus Stops			4			0			0			0
Con. Peds			0			11			13			4
Ped Button	(Y/N)	Y	23.5 s	(Y/N)	Y	23.5 s	(Y/N)	Y	14.5 s	(Y/N)	Y	17.5
Arr Type	3	3	3	3	3	3	3	3	3	3	3	3
RTOR Vols			0			0			0			0

Signal Operations

Phase combination	1	2	3	4		5	6	7	8
EB Left	*				NB Left	*	*		
Thru	*				Thru		*	*	
Right	*				Right		*	*	
Peds	*				Peds		*	*	
WB Left		*			SB Left	*			
Thru		*			Thru			*	
Right		*			Right			*	
Peds		*			Peds			*	
NB Right					EB Right				
SB Right					WB Right				
Green	23A	21A			Green	7A	8A	21A	
Yellow/A-R	3	3			Yellow/A-R	3	3	3	
Lost Time	3.0	3.0			Lost Time	0.0	3.0	3.0	

Cycle Length: 95 secs Phase combination order: #1 #2 #5 #6 #7

FIGURE 4 McDonald and San Pablo input data sheet.

these approaches until the resulting HCM saturation flow calculation resulted in the field-measured saturation flow.

- *Test 8: Field-Measured Average Stopped Delay.* Test 8 merely documents the average stopped delay values measured in the field for each intersection. The field-measured average total delay reported by May was converted back to average stopped delay using the same 1.3 conversion factor used by May to convert stopped delay to total delay. A volume-weighted average of the approach delay reported by May was used to obtain average stopped delay for the entire intersection.

Field measurements of average stopped delay for the two videotaped intersections in Oakland were obtained using the "point sampling" method with 15-sec sampling periods as described by Reilly in his paper on delay estimation techniques (*8*). Average stopped delay was estimated for the peak 15-min volume (flow rate) period for each intersection.

Queues due to vehicles failing to clear the previous cycle were not present at the beginning or ending of the 1-hr sample period. There were short queues of vehicles (fewer than 10 vehicles) on the intersection approaches not receiving a green indication at the start and end of the sample period.

The field-measured delay was assumed to be the true delay for the purposes of this evaluation. Note that Reilly estimated that the point sampling method appears to be a slightly biased estimator of true stopped delay, overestimating delay by about 8 percent (*6*).

ROBUSTNESS OF DATA SET

Every data set is by definition a small sample of the universe of real-world data. No sample can be expected to cover all possible conditions in the field, but by comparing the range of the parameters contained in the data set with the range of values for the parameters in

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=====================================================================
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=====================================================================
Streams: (E-W) Central                 (N-S) Carlson
Analyst: Rgd                           File Name: CARL7.HC9
Area Type: Other                       6-3-93
Comment: vol+geo+cycle+PHF+Delay Adj+ actual sat
=====================================================================

                    Traffic and Roadway Conditions
---------------------------------------------------------------------
             |   Eastbound    |  Westbound     |  Northbound    |  Southbound
             | L    T    R    | L    T    R    | L    T    R    | L    T    R
             |---- ---- ----  |---- ---- ----  |---- ---- ----  |---- ---- ----
No. Lanes    |     > 2  <     |     > 2  <     | 1    2  <      | 1    2  <
Volumes      |  78  522  200  |  16  270   74  | 210  430   40  |  59  164   37
PHF or PK15  |0.85 0.85 0.85  |0.85 0.85 0.85  |0.85 0.85 0.85  |0.85 0.85 0.85
Lane Width   |     12.0       |     12.0       |12.0 12.0       |12.0 12.0
Grade        |        0       |        0       |        0       |        0
% Heavy Veh  |   2    2    2  |   1    1    1  |   1    1    1  |   1    1    1
Parking      |  (Y/N) N       |  (Y/N) N       |  (Y/N) N       |  (Y/N) N
Bus Stops    |              7 |              0 |              0 |              1
Con. Peds    |              0 |              7 |              1 |              5
Ped Button   |(Y/N) Y 20.5 s  |(Y/N) Y 20.5 s  |(Y/N) Y 17.5 s  |(Y/N) Y 17.5
Arr Type     |   3    3    3  |   3    3    3  |   4    4    4  |   3    3    3
RTOR Vols    |              0 |              0 |              0 |              0
---------------------------------------------------------------------

                          Signal Operations
---------------------------------------------------------------------
Phase combination 1     2     3     4 |           5     6     7     8
EB  Left          *                   |NB  Left   *
    Thru          *                   |    Thru         *
    Right         *                   |    Right        *
    Peds          *                   |    Peds         *
                                      |
WB  Left          *                   |SB  Left   *
    Thru          *                   |    Thru         *
    Right         *                   |    Right        *
    Peds          *                   |    Peds         *
                                      |
NB  Right                             |EB  Right
SB  Right                             |WB  Right
                                      |
Green            36P                  |Green      16P   19P
Yellow/A-R        3                   |Yellow/A-R  3     3
Lost Time       3.0                   |Lost Time 3.0   3.0

Cycle Length:  80 secs  Phase combination order: #1 #5 #6
```

FIGURE 5 Carlson and Central input data sheet.

HCM and in the field, one can gain a sense of how completely the data set does represent the real world.

Lane Geometry

The data set consists of six intersections with 22 approaches. About a quarter of the approaches are single-lane approaches, and the rest are two-lane approaches with and without exclusive turn lanes. All single-lane approaches are opposed by single-lane approaches in this data set. One- and two-lane approaches are well-represented in this sample, but approaches of three lanes and wider are missing. The data set also does not contain an example of a single-lane approach opposed by a multilane approach.

Signal Timing and Left Turn Treatment

The intersections included in this analysis ranged from two-phase fixed-time signals up to six-phase fully actuated signals. Fixed-time signals account for 80 percent of the sample. Actuated signals are represented by only one intersection in this sample.

Cycle lengths range from 65 to 95 sec. Longer cycle lengths that might be typical of wider intersections in suburban locations are not represented in this sample data set.

About two-thirds of the approaches have permitted left-turn phasing. Half of the approaches have exclusive left-turn lanes. The only combination not represented in this data set is protected left turns from a shared turn lane.

Other Characteristics

The maximum average intersection delay observed at the sample intersections was 35 sec (Level of Service D). The highest critical *v/c* (X_c) was 96 percent. Most of the six intersections and 22 approaches in the data set tended to be uncongested (X_c less than 85 percent of capacity); however, the sample data set does include

```
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Streets: (E-W) Dwight                  (N-S) Sacramento
Analyst: Rgd                           File Name: DWIGHT7.HC9
Area Type: Other                       6-3-93
Comment: vol+geo+phf+delay Adjust+actual sats
=====================================================================

                    Traffic and Roadway Conditions
---------------------------------------------------------------------
             |  Eastbound   |  Westbound   |  Northbound  |  Southbound
             | L    T    R  | L    T    R  | L    T    R  | L    T    R
             |---- ---- ----|---- ---- ----|---- ---- ----|---- ---- ----
No. Lanes    |    > 1  <    |    > 1  <    | 1    2  <    | 1    2  <
Volumes      |  55  335   50| 47  262   81| 84  586   50| 125  455   40
PHF or PK15  |0.85 0.85 0.85|0.85 0.85 0.85|0.85 0.85 0.85|0.85 0.85 0.85
Lane Width   |     12.0     |     12.0     |12.0 12.0     |12.0 12.0
Grade        |        0     |        0     |        0     |        0
% Heavy Veh  |   2    2    2|   2    2    2|   2    2    2|   2    2    2
Parking      |  (Y/N) Y    20| (Y/N) Y    20| (Y/N) Y    20| (Y/N) Y   20
Bus Stops    |             0|             0|             0|             0
Con. Peds    |            50|            50|            50|            50
Ped Button   |(Y/N) Y 20.5 s|(Y/N) Y 20.5 s|(Y/N) Y 11.5 s|(Y/N) Y 11.5
Arr Type     |   3    3    3|   3    3    3|   3    3    3|   3    3    3
RTOR Vols    |             0|             0|             0|             0
---------------------------------------------------------------------

                          Signal Operations
---------------------------------------------------------------------
Phase combination 1     2     3     4 |          5     6     7     8
EB  Left          *                   |NB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds          *                   |    Peds    *
                                      |
WB  Left          *                   |SB  Left    *
    Thru          *                   |    Thru    *
    Right         *                   |    Right   *
    Peds          *                   |    Peds    *
                                      |
NB  Right                             |EB  Right
SB  Right                             |WB  Right
                                      |
Green            40P                  |Green      24P
Yellow/A-R        3                   |Yellow/A-R  3
Lost Time       3.0                   |Lost Time 3.0

Cycle Length:  70 secs  Phase combination order: #1 #5
```

FIGURE 6 Dwight and Sacramento input data sheet.

TABLE 1 Default Values Used in Level-of-Service Analysis (*1*)

Parameter	Value
Ideal saturation flow	1,800 veh/hr/lane
Conflicting pedestrian flow	Low: 50 pedestrians/hr
Percentage heavy vehicles	2%
PHF	0.90
Grade	0%
Number of stopping buses	0 buses/hr
Number of parking manuevers	20 manuevers/hr
Arrival type	3

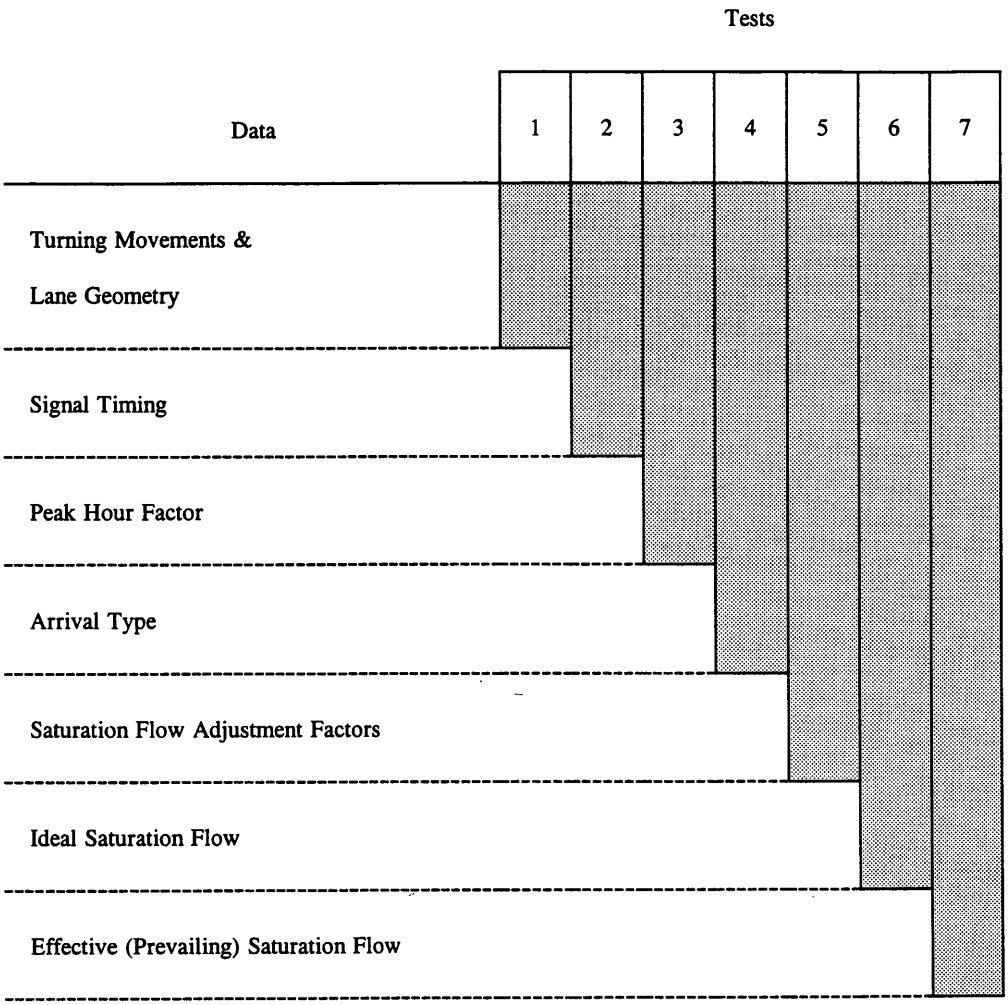

FIGURE 7 Test structure.

4 approaches with *v/c*'s greater than 85 percent of capacity and two intersections (Harrison and McDonald) with X_c's greater than 85 percent.

Variation of Field-Measured Parameters from HCM Defaults

The field-measured parameters in the data set (PHF arrival type, ideal saturation flow, grade, heavy vehicles, parking buses, and pedestrians) did vary from the default values contained in the HCM, but in most cases they fell close to the default values recommended in the HCM (Table 3).

The approach PHFs varied from 0.83 to 1.00 in the field. The maximum range for the PHF is 0.25 to 1.00. The mean PHF observed in the field was 0.87, which is close to the HCM-recommended default of 0.90. Grades were generally flat (under 3 percent) in the data set. The mean observed grade was 0 percent, which is the same as the HCM default.

Heavy vehicles ranged from 0 to 5 percent in the data set. The mean percentage heavy vehicles was 1 percent, which is close to the HCM-recommended default of 2 percent. Parking maneuvers ranged from 0 to 11 per hour—significantly lower than the HCM-recommended default of 20.

Stopping local buses ranged from 0 to 13 per hour. The mean was two buses per hour, which is close to the HCM-recommended default of 0. Pedestrian volumes ranged from 0 to 118 pedestrians per hour; the mean was 32, which is less than the HCM-recommended default of 50.

RESULTS

The results for each test are given in Tables 4 through 7. Table 4 presents the MABS in the estimated average stopped delay per vehicle aggregated for each intersection. Table 5 gives the variation in the estimated critical *v/c* (X_c) for each intersection. Table 6 gives the effect of each test on the estimated intersection level of service. Table 7 presents the estimated average stopped delay per vehicle (in seconds) by approach, sorted by *v/c*.

Results for Entire Intersections

The 1985 HCM operations method for estimating signalized intersection level of service was found to be able to estimate average

TABLE 2 Parameter Values Used in Tests

Parameter Values																							
Parameter	Harrison				Webster			Grove				McDonald				Carlson				Dwight			
	E	W	N	S	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S
Test #1 - SOAP Signal Timings																							
Cycle	70"				70"																		
Split - Thrus	20"	20"	50"	39"	21"	38"	38"																
Split - Lefts	-	-	11"	-	-	11"	-																
Test #2 - Actual Signal Timings																							
Cycle	80"				80"			65"				95"				80"				70"			
Split - Thrus	20"	20"	60"	42"	30"	37"	37"	19"	19"	46"	46"	26"	24"	35"	24"	39"	39"	22"	22"	43"	43"	27"	27"
Split - Lefts	-	-	18"	-	-	13"	-	-	-	-	-	-	-	21"	10"	-	-	19"	19"	-	-	-	-
Test #3 - Peak Hour Factor																							
	0.92	1.05	0.94	0.83	0.83	0.97	0.90	0.85															
Test #4 - Arrival Type																							
	3	2	3	4	2	4	4	3	2	5	3	3	3	3	3	3	3	4	3	3	3	3	3
Test #5 - Saturation Adjustment																							
Grade (%)	0	0	0	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heavy Veh.(%)	1	1	2	0	0	2	0	5	1	4	1	1	0	2	1	2	1	1	1	2	1	1	1
Parking	0	1	11	None	3	1	4	2	0	4	4	None				None				1	1	1	1
Buses	0	0	7	4	0	4	13	0	0	3	3	4	0	0	0	7	0	0	1	0	0	11	0
Peds	26	71	63	75	118	29	68	4	79	51	56	0	11	13	4	0	7	1	5	9	51	0	0
Test #6 - Ideal Saturation Flow per Lane																							
	1900	1900	1900	1900	1900	1900	1900																
Test #7 - Effective Saturation Flow Per Lane (measured in field)																							
Thru Sat				1912			1731	1286	1525	1104	1475			1626	1602	1386				1494	1457		
Left Sat			972											1446				1636					

TABLE 3 Parameter Ranges

Parameter	HCM Default	Range in Field Data
Pedestrians	50	0–118
Heavy vehicles	2%	0–5%
PHF	0.90	0.83–1.00
Grade	0%	0–3%
Number of stopping buses	0	0–13
Number of parking manuevers	20	0–11
Arrival type	3	2–5

TABLE 4 Average Stopped Delay by Intersection

Average Stopped Delay By Intersection (secs/veh)								
Test	Harrison(1)	Webster	Grove	McDonald	Carlson	Dwight	Mean	Mean Absolute Error
1	22.1	13.1					17.6	7.8
2	31.5	16.5	8.8	26.1	17.1	13.8	19.0	2.7
3	52.5	16.6	9.4	28.5	17.7	15.0	23.3	5.1
4	48.6	16.6	9.3	28.5	16.3	15.0	22.4	4.7
5	48.1	18.3	8.9	28.5	16.3	13.7	22.3	4.6
6	33.6	16.6					25.1	0.6
7	29.1	20.0	8.8	34.6	17.3	13.4	20.5	2.0
Field Measured	33.3	17.5	9.0	35.2	20.7	14.4	21.7	0.0

(1) Northbound, Southbound, and Westbound legs only

intersection stopped delay with a MABS of 3 sec when using all of the default parameters recommended in Table 9-3 of the HCM. Field measurements of the default parameters plus measurements of ideal and effective saturation flows on critical approaches reduced the MABS to 2 sec (Table 4).

Importance of Observing Signal Timing (Tests 1 and 2)

Field observations of signal timing were found to improve significantly the accuracy of the estimated intersection delay. The MABS dropped from 7.8 sec in Test 1 to 2.7 sec in Test 2. A more accurate comparison is obtained if only the two intersections that were included in both tests are considered (Harrison and Webster). In this case, the MABS still improves significantly, dropping from 7.8 to 1.4 sec. The MABS has dropped from approximately 30 percent to only 12 percent of the mean stopped delay at these two intersections.

Lane geometry and turning movements by themselves were not sufficient to estimate the correct level of service at the intersections of Harrison and Webster. The use of SOAP to estimate signal timings resulted in levels of service one level better than actual for both intersections (see Test 1 in Table 6).

Accuracy of Using Only Defaults (Test 2)

The MABS was found to be 2.7 sec (12 percent of the mean delay) when the HCM operations method was applied using turning movements, lane geometry, and signal timing as the only field-collected data. This accuracy was sufficient to give the correct level of service at all intersections (see Test 2 results in Table 6).

Effect of PHF and Arrival Type (Tests 3 and 4)

The addition of field measurements of the PHF and arrival type generally did not improve the average delay estimates at most intersections. The MABS actually increased to about 5 sec for both tests (Table 4).

TABLE 5 Critical *X v/c* as Estimated by HCM Method

Critical "X" Volume Capacity Ratio (As Estimated by HCM Method)						
Test	Harrison(1)	Webster	Grove	McDonald	Carlson	Dwight
1 Volumes + Geometry + SOAP Timings	0.900	0.701				
2 Volumes + Geometry + Signal Timing	0.889	0.691	0.597	0.802	0.660	0.721
3 Volumes + Geometry + Signal Timing + PHF	0.910	0.702	0.636	0.848	0.703	0.770
4 Volumes + Geometry + Signal Timing + PHF + Rp	0.910	0.702	0.636	0.848	0.703	0.770
5 Vols + Geo + Signal + PHF + Rp + Grade + HV + Pkg + Bus + Peds	0.988	0.723	0.577	0.844	0.706	0.703
6 Test 5 plus Ideal Saturation Flow	0.936	0.685				
7 Test 6 with Actual Saturation selected moves	0.907	0.729	0.562	0.879	0.757	0.663

(1) For Northbound, Southbound, Westbound legs only

TABLE 6 Intersection Level of Service

Intersection Level of Service						
Test	Harrison(1)	Webster	Grove	McDonald	Carlson	Dwight
1 Volumes + geometry + SOAP Timing	C	B				
2 Volumes + Geometry + Signal Timing	D	C	B	D	C	B
3 Volumes + Geometry + Signal Timing + PHF	E	C	B	D	C	B
4 Volumes + Geometry + Signal Timing + PHF + Rp	E	C	B	D	C	B
5 Vols + Geo + Signal + PHF + Rp + Grade + HV + Pkg + Bus + Peds	E	C	B	D	C	B
6 Test 5 with ideal saturation flows	D	C				
7 Test 6 with Actual Saturation selected moves	D	C	B	D	C	B
8 Field Measured Delay	D	C	B	D	C	B

(1) For Northbound, Southbound, Westbound legs only

TABLE 7 Average Stopped Delay per Vehicle by Approach

Average Stopped Delay Per Vehicle by Approach										
Intersection And Approach		v/c	Field Measured Delay	Test						
				1	2	3	4	5	6	7
Carlson	SB	0.30	20.0		19.3	19.4	19.4	19.4		19.4
Carlson	WB	0.36	13.0		10.9	11.1	11.1	11.1		11.1
Webster	WB	0.51	25.9	19.7	16.7	17.1	23.2	22.6	22.2	22.3
Grove	WB	0.54	15.0		19.0	20.1	24.5	24.5		23.4
Grove	SB	0.55	3.0		5.5	5.9	5.9	5.2		4.9
Grove	EB	0.56	36.0		17.7	18.4	18.4	17.4		17.9
Grove	NB	0.56	2.0		4.5	4.7	2.5	2.4		2.8
Dwight	WB	0.57	7.0		10.0	11.3	11.3	9.2		8.0
McDonald	WB	0.58	35.0		23.0	23.3	23.3	23.2		23.2
Webster	NB	0.59	12.1	10.7	12.2	11.8	9.2	9.2	8.3	8.3
Dwight	EB	0.62	8.0		11.5	13.6	13.6	10.4		8.6
Harrison	WB	0.68	24.8	21.5	31.9	26.8	32.7	30.6	29.4	29.4
Dwight	SB	0.69	30.0		15.2	16.1	16.1	15.7		16.1
McDonald	SB	0.71	25.0		24.5	25.1	25.1	25.0		25.5
Dwight	NB	0.73	22.0		16.0	16.7	16.7	16.1		16.7
Carlson	NB	0.76	19.0		23.5	24.5	20.1	20.0		20.4
Carlson	EB	0.79	26.0		13.8	14.4	14.4	14.6		16.8
Harrison	NB	0.83	28.2	17.2	10.8	10.7	10.7	28.6	23	14.7
McDonald	EB	0.91	50.0		30.5	34.0	34.0	34.0		34.0
Webster	SB	0.94	15.8	11.2	18.4	18.4	16.6	20.1	17.5	24.0
McDonald	NB	1.02	30.0		24.7	27.9	27.9	27.9		41.8
Harrison	SB	1.03	37.2	24.2	39.9	75.2	67.6	59.9	38.8	35.0
Mean		0.67	22.05	17.42	18.16	20.30	20.20	20.32	23.20	19.29
Mean Absolute Error			0.0	6.6	6.8	8.0	7.6	6.4	3.4	6.3

The delay estimate deteriorated significantly for one seriously congested intersection (Harrison). The estimation error was greatly increased at Harrison because opposite errors generated by the use of default parameters no longer canceled each other out. Harrison has one saturated approach (southbound) operating at a *v/c* of 1.00 that is extremely sensitive to the estimated saturation flow. The addition of field measurements of the PHF (without saturation flow measurements) caused the HCM method in this case to underestimate significantly the true capacity of this approach, thus causing the increased error.

These results indicate that the additional refinements provided by PHF and arrival type are not warranted in the absence of accurate field data on saturation flows. In fact, the data may worsen the result.

Effect of Measuring Some But Not All Saturation Flow Estimation Parameters (Test 5)

Precise field measurements of the percentage heavy vehicles, parking maneuvers, local buses, and pedestrians did not much improve

the accuracy of the estimated average intersection delay. The MABS remained relatively unchanged between Tests 4 and 5 (Table 4). This conclusion is still true even for intersections with high *v/c*'s (such as Harrison and McDonald, where the *v/c*'s exceed 85 percent of capacity) as well as for those with low *v/c*'s (Figure 8).

Value of Measuring Ideal Saturation Flow in the Field (Test 6)

Test 6 was performed only at the two videotaped intersections, Harrison and Webster, because of the lack of the necessary data for the other intersections.

Field measurements of ideal saturation flow were found to contribute significantly to the accuracy of the HCM method at Harrison. The estimated average delay was within 1 sec of field observations. This intersection has one critical approach that operates at a *v/c* of 1.00 during the peak 15 min. Field measurements of ideal saturation flow did not make any significant contribution to the accuracy of the delay estimate at Webster because of the lack of congestion at this location.

Measuring Effective Saturation Flow in the Field (Test 7)

Field measurements of ideal and effective saturation flow greatly improved the accuracy of the delay estimates for the two intersections with *v/c*'s of more than 85 percent (compare Tests 5 and 7 in Figure 8). The difficulty of accurately measuring and applying effective or prevailing saturation flows in the HCM method, however, made the results less satisfactory than simply measuring ideal saturation flow (compare Tests 6 and 7 in Figure 8). Field observations of saturation flow made no significant improvement in the accuracy of the delay estimates at less congested intersections. The MABS for all intersections were cut in half (from 4.6 under Test 5 to 2.0 under Test 7).

It is much more difficult to measure accurately effective or prevailing saturation flow since many more observations are required over a longer period to adequately represent the average conditions affecting saturation flow over an entire hour. Effective saturation flow measurements consequently tend to be less accurate than ideal saturation flow measurements. This effect is demonstrated in the worsening of the delay estimates for a couple of key approaches when effective saturation flow rate is used rather than ideal saturation flow rate. The MABS, however, remains among the best of the tests.

Results for Individual Intersection Approaches

The previous results are examined briefly at the more detailed approach level to determine if aggregating approach delay to intersection delay may have masked some of the effects of the tests. The results by approach are given in Table 7.

The MABS by approach is generally higher but shows less variation among the tests than for the individual intersections. The error varied relatively little for Tests 1, 2, 3, and 4 (between 7 and 8 sec). Maximum data collection (PHF, arrival type, saturation flow parameters, ideal saturation flow, and prevailing saturation flows) reduced the MABS to 6 sec (about 33 percent of the mean approach delay) (see Test 7 in Table 7).

Test 6 (using field-measured ideal saturation flows) showed a significantly improved MABS of 4 sec, but this was for a smaller sample size of 6 of the total 22 approaches. The results did vary significantly among approaches with high and low *v/c*'s (Figure 9).

The four approaches where *v/c*'s exceeded 85 percent of capacity were extremely sensitive to the lack of field data for all of the parameters used to estimate saturation flow and delay. Tests using partial field data for the parameters (Tests 3, 4, and 5) provided worse delay estimates than Test 2, which relied on only turning movment, geometry, and signal timing data collected in the field.

The remaining 18 approaches, for which *v/c*'s were less than 85 percent, were relatively insensitive to field-collected data on PHFs, arrival type, and saturation flow parameters.

Again, the difficulty of measuring effective saturation flows in the field caused the results of Test 7 to be less satisfactory than those of Test 6.

CONCLUSIONS

The test results for the six intersections suggest the following:

1. The estimate of intersection average stopped delay is insensitive to precise estimates of PHF, arrival type, and saturation flow if the *v/c*'s on all the approaches are less than 85 percent of capacity. There is no value to gathering additional field data beyond traffic counts, lane geometry, and signal timing in order to estimate

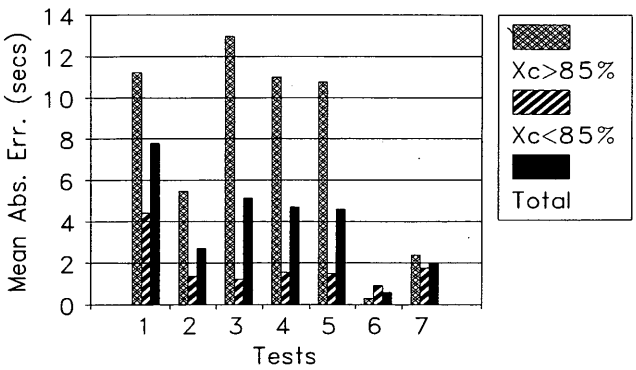

FIGURE 8 Intersection delay results.

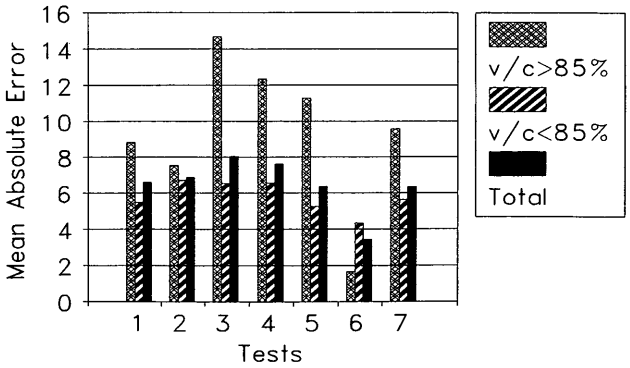

FIGURE 9 Approach delay results.

accurately the intersection level of service when there is little congestion.

2. There is some value to gathering additional field data to more precisely determine the intersection and approach delay if one or more of the approaches has a *v/c* in excess of 85 percent of capacity. However, the analyst must make a full data collection effort covering PHF, arrival type, saturation flow adjustment factors, and ideal saturation flow. Partial data collection efforts that measure only some of these parameters may result in less accurate results.

3. The basic data collection effort of counts, lanes, and signal timing should yield the correct letter grade level of service for most all situations. The MABS will be about 7 sec for the approaches and about 3 to 5 sec for the intersection as a whole.

4. The precision with which the saturation flow adjustment parameters are presented in the HCM may not be warranted in terms of their effect on the estimate of intersection delay. For example, the grade saturation flow adjustment factor might be reported for "low," "medium," and "high" grades rather than by specific grade percentage.

These conclusions apply for situations in which the PHF, arrival type, and ideal saturation flow do not vary significantly (±10 percent) from the default parameter values in the HCM; this was the approximate range of the data set analyzed in this paper. Extrapolations of the results to more extreme situations would require a more extensive data set.

Other investigators (Lin and Teodorvic) have measured higher MABS for approach delay (9 to 18 sec) for data sets where the ideal saturation flow rate is significantly higher (Teodorvic) than the HCM default or the signal control type is predominantly traffic-actuated (Lin). In these and other situations in which conditions vary significantly from the default conditions, additional field data should be collected to determine the intersection level of service with accuracy.

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