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TWO-LANE ROAD ANALYSIS METHODOL.OGY IN THE HIGHWAY CAPACITY MANUAL

NCHRP Project 20-7 (160)
MRI Project 110252

FINAL REPORT

September 2003

Prepared for

National Cooperative Highway Research Program
Transportation Research Board National Research Council

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ABSTRACT

Research was undertaken to address two issues raised by Highway Capacity Manual (HCM) users concerning the two-lane highway operational analysis procedure in the HCM2000. First, users noted that service volumes for two-lane highway segments tend to be lower in the HCM2000 than in the HCM1997. This can be corrected by recommended changes to the HCM2000 operational analysis procedure for directional segments on two-lane highways. Second, users were concerned that the HCM procedures do not apply to developed two-lane highways. Recommended procedures were developed concerning how existing HCM procedures can be adapted to meet this need. Further research would be needed to address situations which cannot be addressed by adapting existing procedures.

SUMMARY

Research was undertaken to address two issues raised by Highway Capacity Manual (HCM) users concerning the two-lane highway operational analysis procedures in the HCM2000.

The first concern noted by users is that service volumes for two-lane highway segments tend to be higher in the HCM2000 than in the HCM1997. The major source of this concern is overestimation of percent time spent following (PTSF) in the HCM2000 directional segment procedure. To correct this problem, revised PTSF vs. flow rate curves and a revised adjustment factor for directional split and no-passing zones were developed. Specific recommended changes to the directional segment procedure are presented.

The second concern noted by users is that the existing HCM procedures do not appear to address two-lane highways in developed areas. Three scenarios that the HCM does not explicitly address were identified: a two-lane highway through a small town; a two-lane highway in a transition area between rural and urban/suburban conditions; and a two-lane highway with continuous urban/suburban development but with no traffic signals or widely spaced traffic signals. For two-lane highways with free-flow speed of 56 krnIh (35 mi/h) or more, posted speed limit of 64 km/h (40 mi/h) or more, left-turn lanes at all public street intersections and major driveways and one or more traffic signals, a recommended method for adapting existing HCM operational analysis procedures to developed two-lane highways has been developed. It is recommended that this procedure be incorporated in HCM Chapter 15. Further research is needed for developed two-lane roads that do not meet these specified criteria.

CHAPTER 1

INTRODUCTION

An improved methodology for operational analysis of two-lane highway segments was developed in NCHRP Project 3-55(3), *Capacity and Quality of Service for Two-Lane Highways,* and published in the year 2000 edition of the HCM (1). The HCM2000 methodology is an update of the previous two-lane highway segment operational analysis methodology presented in the 1997 edition of the HCM (2), which, in turn, was identical to the operational analysis methodology developed in NCHRP Project 3-28A for the 1985 edition of the HCM (3).

The HCM2000 has now been in use for approximately two years and user feedback is beginning to be obtained. Two concerns have been called to the attention of the Transportation Research Board (TRB) Committee on Highway Capacity and Quality of Service (HCQS) by HCM users:

- Service volumes provided by the HCM2000 directional analysis procedure are lower than those provided in the HCM1997
- The HCM2000 procedures for two-lane highways do not address two-lane highways in developed areas

The issues were discussed at the meeting of the HCQS Two-Lane Highway Subcommittee in January 2002 in Washington, DC. The subcommittee discussions established that:

- It was not the intention of the HCQS committee to bring about any major reduction in service volumes, except for two-lane highway facilities with lower design speeds. A change was made to the level of service (LOS) thresholds for percent time spent following (see HCM2000 Exhibits 20-2 and 20-4) that was intended to raise service volumes, not lower them.
- The two-way analysis procedure in HCM Chapter 20 appears to function properly, but there may be an error in the directional analysis procedures in HCM Chapter 20 that results in service volumes that are lower than intended. This difference appears to be most pronounced for two-lane highways with nearly equal directional splits. This has led HCM users to note that they are getting different LOS estimates from the two-way and directional analysis procedures.
- Analysis of two-lane highways in developed areas and two-lane highways with occasional signals (signal spacing greater than 3 km or 2 mi) does not appear to be adequately addressed by either the two-lane highway analysis procedures in HCM Chapter 20 or the arterial analysis procedures in HCM Chapter 15. In the HCM2000 and its predecessors, this type of facility appears to fall through the cracks between HCM Chapters 15 and 20.

The research presented in this report was undertaken to investigate these concerns and to recommend changes to the HCM2000 to better address these issues.

CHAPTER 2

OVERESTIMA TION OF PERCENT TIME SPENT FOLLOWING FOR DIRECTIONAL SEGMENTS

Users of the HCM2000 Chapter 20 procedure have noted that the operational analysis procedure for directional segments provides results that indicate lower levels of service than the HCM1997 procedure. This anomaly has been investigated and it was found that the directional analysis procedure overestimates one of the two-lane highway segment service measures, percent time spent following (PTSF). The other two-lane highway segment service measure, average travel speed (A TS), appears to be estimated properly in the directional segment procedure, and both PTSF and ATS are estimated properly in the two-way segment procedure. The following discussion indicates the nature of the overestimation of PTSF in the directional segment procedure and recommends changes to the procedure to remove the overestimation.

HCM OPERATIONAL ANALYSIS PROCEDURES FOR TWO-LANE HIGHWAYS

The following discussion provides a comparison of three operational analysis procedures for two-lane highways:

- The HCM1997 procedure for two-way segments
- The HCM2000 procedure for two-way segments
- The HCM2000 procedure for directional segments

Each of these procedures is discussed below.

HCM1997 OPERATIONAL ANALYSIS PROCEDURE FOR TWO-WAY SEGIVIENTS

The HCM1997 operational analysis procedure for two-way highway segments is unchanged from the two-way segment operational analysis procedure in the HCM1985. The LOS for two-lane highway segments is defined in the HCM1997 procedure based on PTSF alone, except for specific upgrades for which the LOS is based on average upgrade speed. PTSF was refeITed to in the HCM1997 procedure as *percent time delay,* but this represents the same measure as PTSF in the HCM2000 procedure, defined as the percentage of their total travel time that motorists spend following in platoons behind other vehicles. The LOS thresholds for the HCM1997 procedure are shown in Table 1.

The HCM1997 procedure for two-way segments is based on the PTSF vs. flow rate relationship shown in Figure 1, based on HCM1997 Figure 8-1. Figure 1 also illustrates the speed vs. flow rate relationship used in the HCM1997. The PTSF vs. flow rate relationship shown in Figure 1 was established from computer simulation runs with the TWOP AS model (4,5) performed during development of the HCM1985 chapter in NCHRP Project 3-28A (6).

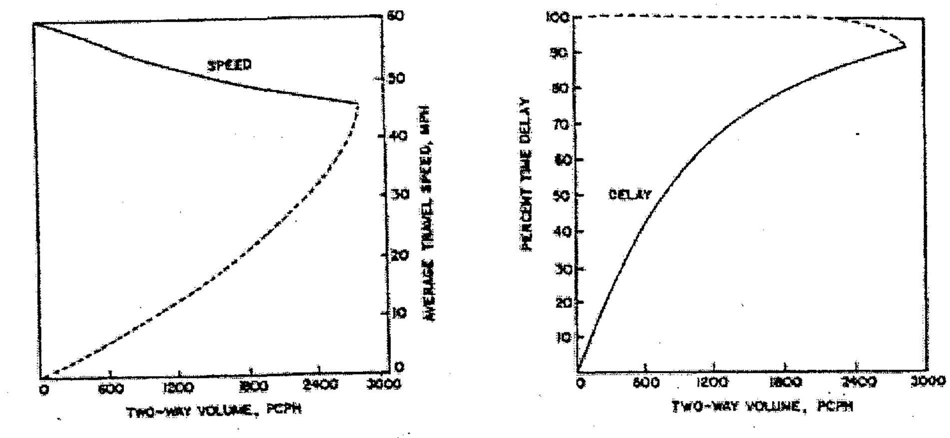

Figure 1. *Relationships of percent time delay and average travel speed to flow rate usedfor two-lane highway segments in the* 1997 *HCM(2,3).*

TABLE 1. Level of Service Criteria for General Terrain Segments on Two-Lane Highways in the 1997 HCM (*2,3*)

Level of service	Percent time delay on general terrain segments
A	≤ 30
B	≤ 45
C	≤ 60
D	≤ 75
E	> 75
F	100

The PTSF vs. flow rate relationship in Figure 1 is not represented in the HCM1997 procedure by an explicit model. Rather, volume levels based on Figure 1 are incorporated in the procedure in the form of volume-to-ideal-capacity ratios for specific LOS thresholds, as shown in Table 2, as a function of terrain and percent no-passing zones. Table 2 is presented in the HCM1997 as Table 8-1. The volume-to-ideal-capacity ratios indicate the volume level corresponding to a specific value of PTSF. The PTSF for any given volume level can be estimated by interpolating between the service flow rates determined from the tabulated values.

In the HCM1997 procedure, directional split influences the capacity of the highway under ideal conditions and, therefore, indirectly influences the service flow rates (i.e., the LOS thresholds). Table 3 shows the values of fd, the factor that represents the effect of direction split on capacity and service flow rate, based on HCM1997 Table 8-4.

Service flow rates are computed with Equation (1), based on Equation 8-1 in the HCM 1997, which incorporates values from Tables 2 and 3:

$$SF_i = 2800 \text{ x } (v/c)_i \text{ x } f_d \text{ x } f_w \text{ x } f_{HV} \qquad (1)$$

where:

- SF_i = service volume (two-way) for level of service i for prevailing roadway and traffic conditions (pc/h)
- $(v/c)_i$ = volume-to-capacity ratio for level of service i (from Table 2)
- f_d = adjustment factor for directional distribution of traffic (from Table 3)
- f_w = adjustment factor for narrow lanes and restricted lateral clearance (from HCM1997 Table 8-5)
- f_{HV} = adjustment factor for the presence of heavy vehicles in the traffic stream (from HCM1997 Equation 8-2 and HCM Table 8-6)

The HCM1997 procedure applies to two-way segments only. There is no procedure for directional segments in the HCM1997, except for the specific upgrade procedure which is applied to directional segments on upgrades that exceed 0.4 km (0.25 mi) in length and 3 percent grade.

HCM2000 Operational Analysis Procedure for Two-Way Segments

The LOS for two-way segments is defined in the HCM2000 procedure based on PTSF and A TS for Class I highways and on PTSF for Class II highways. The two-way segment procedure was developed in NCHRP Project 3-55(3) (7). Class I highways are generally arterial highways that serve long-distance trips and on which motorists expect to travel at high speeds. Class II highways are highways that serve shorter trips and on which motorists do not expect to travel at high speeds. The distinction between Class I and II highways is discussed more fully in the later section of this report in developed two-lane highways.

TABLE 2. Level of Service Criteria for Operational Analysis of General Terrain Segments on Two-Lane Highways in the 1985HCM(*2,3*)

		v/c Ratio[a]																				
		Level terrain							Rolling terrain							Mountainous terrain						
			Percent no passing zones							Percent no passing zones							Percent no passing zones					
LOS	Percent time delay	Avg[b] speed	0	20	40	60	80	100	Avg[b] speed	0	20	40	60	80	100	Avg[b] speed	0	20	40	60	80	100
A	≤ 30	≤ 58	0.15	0.12	0.09	0.07	0.05	0.04	≤ 57	0.15	0.10	0.07	0.05	0.04	0.03	≤ 56	0.14	0.09	0.07	0.04	0.02	0.01
B	≤ 45	≤ 55	0.27	0.24	0.21	0.19	0.17	0.16	≤ 54	0.26	0.23	0.19	0.17	0.15	0.13	≤ 54	0.25	0.20	0.16	0.13	0.12	0.10
C	≤ 60	≤ 52	0.43	0.39	0.36	0.34	0.33	0.32	≤ 51	0.42	0.39	0.35	0.32	0.30	0.28	≤ 49	0.39	0.33	0.28	0.23	0.20	0.16
D	≤ 75	≤ 50	0.64	0.62	0.60	0.59	0.58	0.57	≤ 49	0.62	0.57	0.52	0.48	0.46	0.43	≤ 45	0.58	0.50	0.45	0.40	0.37	0.33
E	> 75	≤ 45	1.00	1.00	1.00	1.00	1.00	1.00	≤ 40	0.97	0.94	0.92	0.91	0.90	0.90	≤ 35	0.91	0.87	0.84	0.82	0.80	0.78
F	100	< 45	–	–	–	–	–	–	< 40	–	–	–	–	–	–	< 35	–	–	–	–	–	–

[a] Ratio of flow rate to an ideal capacity of 2,800 pcph in both directions.
[b] These speeds are provided for information only and apply to roads with design speeds of 60 mph or higher.

TABLE 3. Adjustment Factors for Directional Distribution of Traffic on General Terrain Segments on Two-Lane Highways in the HCM1997(*2,3*)

Directional distribution	100/0	90/10	80/20	70/30	60/40	50/50
Adjustment factor, f_d	0.71	0.75	0.83	0.89	0.94	1.00

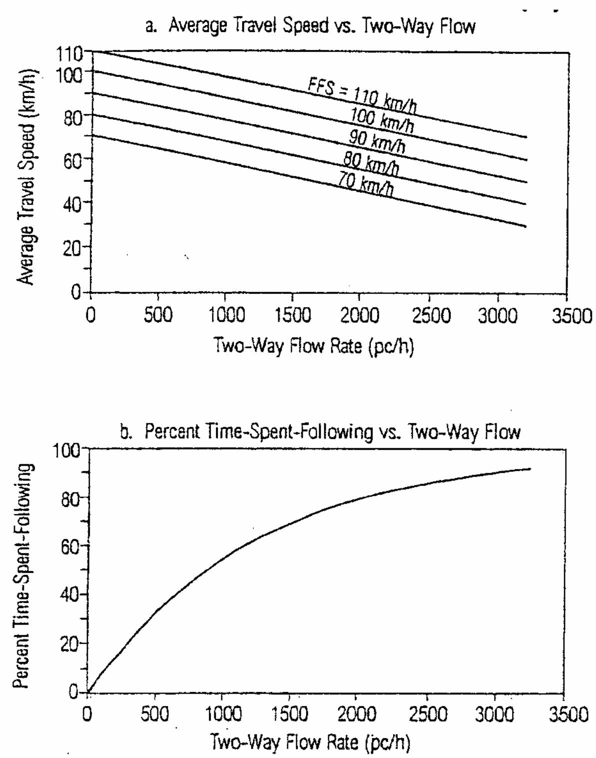

Figure 2. Speed-flow and percent time-spent-following flow relationships for two-way segments with base conditions(1).

Tables 4 and 5 present the LOS thresholds for two-lane highway segments used in the HCM2000 for Class I and II highways, respectively. These tables are equivalent to HCM Exhibits 20-2 and 20-4. An editorial correction to Tables 4 and 5 planned for implementation in the HCM is included in the versions shown here. For a segment of Class I highway, both the PTSF and A TS definitions for any LOS must be met.

The two-way segment procedure incorporates an estimation methodology for PTSF. Figure 2 illustrates the PTSF vs. flow rate relationship for two-way segments presented in HCM2000 Exhibit 12-6; this curve is very similar to the HCM1997 curve shown in Figure 1. Figure 2 also illustrates the speed vs. flow rate relationship for two-way segments used in the HCM2000. The PTSF vs. flow rate relationship shown in Figure 2 is represented by the following equation, based on HCM2000 Equation (20-7):

$$BPTSF = 100\left(1 - \exp\left(-0.000879 v_p\right)\right) \quad (2)$$

where: BPTSF = base percent time-spent-following for both directions of travel combined

v_p = two-way passenger-car equivalent flow rate, pc/h

The PTSF estimate provided by Equation (2) is known as the base PTSF value for a two-way segment. This base value is adjusted to the actual PTSF estimate using Equation (3), based on HCM2000 Equation (20-6):

$$PTSF = BPTSF + f_{d/np} \quad (3)$$

where: PTSF = percent time spent following

$f_{d/np}$ = adjustment for the combined effect of the directional distribution of traffic and of the percentage of no-passing zones on percent time-spent-following

The term, fdlnp, in Equation (3) represents the effect of directional split and percent no-passing zones on PTSF for the two-way segment. Table 6 presents the values of fdlnp, based on HCM2000 Table 20-12.

HCM2000 Operational Analysis Procedure for Directional Segments

The two-lane highway operational analysis procedure for directional segments is similar to the two-way procedure described above, except that a modified equation is used to determine the base PTSF value and the term fdlnp is replaced by fnp, for which a table specific to directional segments is provided.

TABLE 4. LOS Criteria for Two-Lane Highway Segments in Class I(*1*)

LOS	Percent time	Average travel speed (km/h)
A	≤ 35	> 90
B	≤ 50	> 80
C	≤ 65	> 70
D	≤ 80	> 60
E	> 80	≤ 60

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

TABLE 5. LOS Criteria for Two-Lane Highway Segments in Class II(*1*)

LOS	Percent time-spent-following
A	≤ 40
B	≤ 55
C	≤ 70
D	≤ 85
E	> 85

Note: LOS F applies whenever the flow rate exceeds the segment capacity.

TABLE 6. Adjustment ($f_{d/np}$) for Combined Effect of Directional Distribution of Traffic and Percentage of No-Passing Zones on Percent Time-Spent-Following on Two-Way Segments(*1*)

Two-way flow rate, v_p (pc/h)	Increase in percent time-spent-following (%)					
	No-passing zones (%)					
	0	20	40	60	80	100
Directional split = 50/50						
≤ 200	0.0	10.1	17.2	20.2	21.0	21.8
400	0.0	12.4	19.0	22.7	23.8	24.8
600	0.0	11.2	16.0	18.7	19.7	20.5
800	0.0	9.0	12.3	14.1	14.5	15.4
1400	0.0	3.6	5.5	6.7	7.3	7.9
2000	0.0	1.8	2.9	3.7	4.1	4.4
2600	0.0	1.1	1.6	2.0	2.3	2.4
3200	0.0	0.7	0.9	1.1	1.2	1.4
Directional split = 60/40						
≤ 200	1.6	11.8	17.2	22.5	23.1	23.7
400	0.5	11.7	16.2	20.7	21.5	22.2
600	0.0	11.5	15.2	18.9	19.8	20.7
800	0.0	7.6	10.3	13.0	13.7	14.4
1400	0.0	3.7	5.4	7.1	7.6	8.1
2000	0.0	2.3	3.4	3.6	4.0	4.3
≥ 2600	0.0	0.9	1.4	1.9	2.1	2.2
Directional split = 70/30						
≤ 200	2.8	13.4	19.1	24.8	25.2	25.5
400	1.1	12.5	17.3	22.0	22.6	23.2
600	0.0	11.6	15.4	19.1	20.0	20.9
800	0.0	7.7	10.5	13.3	14.0	14.6
1400	0.0	3.8	5.6	7.4	7.9	8.3
≥ 2000	0.0	1.4	4.9	3.5	3.9	4.2
Directional split = 80/20						
≤ 200	5.1	17.5	24.3	31.0	31.3	31.6
400	2.5	15.8	21.5	27.1	27.6	28.0
600	0.0	14.0	18.6	23.2	23.9	24.5
800	0.0	9.3	12.7	16.0	16.5	17.0
1400	0.0	4.6	6.7	8.7	9.1	9.5
≥ 2000	0.0	2.4	3.4	4.5	4.7	4.9
Directional split = 90/10						
≤ 200	5.6	21.6	29.4	37.2	37.4	37.6
400	2.4	19.0	25.6	32.2	32.5	32.8
600	0.0	16.3	21.8	27.2	27.6	28.0
800	0.0	10.9	14.8	18.6	19.0	19.4
≥ 1400	0.0	5.5	7.8	10.0	10.4	10.7

The base PTSF value for directional segments is determined with the following equation, which appears as Equation 20-17 in the HCM2000:

$$BPTSF_d = 100\left(1 - \exp\left(a v_d^{\,b}\right)\right) \quad (4)$$

where: $BPTSF_d$ = base percent time-spent-following in the direction analyzed
v_d = directional passenger-car equivalent flow rate, pc/h

Equation (4) serves the same function for directional segments as Equation (2) serves for two-way segments. The values used for coefficients a and b in Equation (4) are presented in Table 7, which appears in the HCM2000 as Exhibit 20-21. Figure 3, based on HCM2000 Exhibit 12-7, illustrates these relationships.

The PTSF estimate provided by Equation (4)is known as the base PTSF value for a directional segment. This base value is adjusted to the actual PTSF estimate using Equation (5), based on HCM2000 Equation 20-16:

$$PTSF_d = BPTSF_d + f_{np} \quad (5)$$

where: $PTSF_d$ = percent time-spent-following in the direction analyzed
$BPTSF_d$ = base percent time-spent-following in the direction analyzed
f_{np} = adjustment for percentage of no-passing zones in the analysis direction (see Table 8)

The values of fop for use in Equation (5) are presented in Table 8, which appears as Exhibit 20-20 in the HCM2000.

COMPARISON OF HCM TWO-LANE HIGHWAY OPERATIONAL ANALYSIS PROCEDURES

Users have found that the HCM2000 directional procedure produces service flow rates (i.e., volumes corresponding to particular LOS thresholds) that are lower than those obtained from the HCM 1997 procedure. This is not what was intended because, as illustrated by the comparison of Tables 4 and 5 with Table 1, the LOS thresholds for PTSF were increased by 5 percent from the 1997 procedure to the 2000 procedure.

TABLE 7. Values of Coefficients Used in Estimating Percent Time-Spent-Following for Directional Segments(*1*)

Opposing demand flow rate, v_o (pc/h)	a	b
≤ 200	–0.013	0.668
400	–0.057	0.479
600	–0.100	0.413
800	–0.173	0.349
1000	–0.320	0.276
1200	–0.430	0.242
1400	–0.522	0.225
≥ 1600	–0.665	0.199

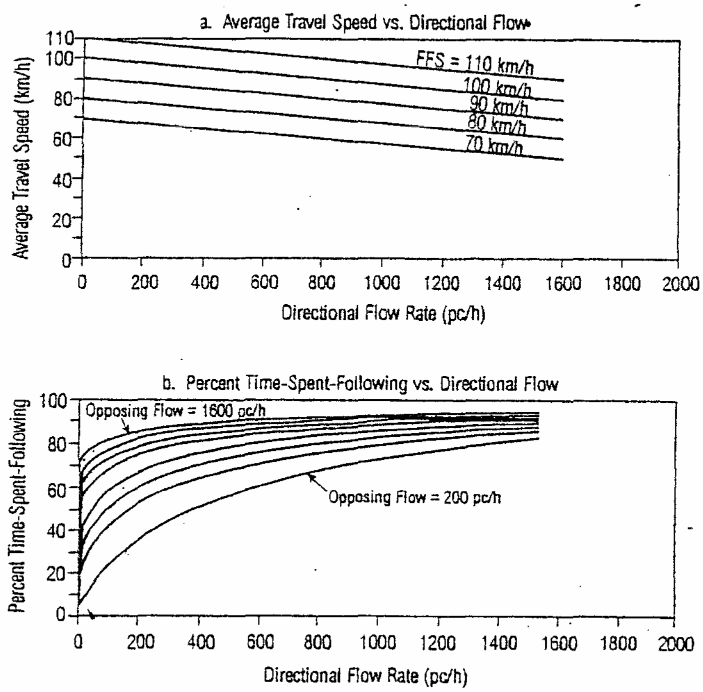

Figure 3. Speed-flow and percent time-spent-following flow relationships for directional segments with base conditions(1).

TABLE 8. Adjustment (f_{np}) to Percent Time Spent Following for Percentage of No-Passing Zones in Directional Segments(*1*)

Opposing demand flow rate, v_o (pc/h)	No-passing zones (%)				
	≤ 20	40	60	80	100
			FFS = 110 km/h		
≤ 100	10.1	17.2	20.2	21.0	21.8
200	12.4	19.0	22.7	23.8	24.8
400	9.0	12.3	14.1	14.4	15.4
600	5.3	7.7	9.2	9.7	10.4
800	3.0	4.6	5.7	6.2	6.7
1000	1.8	2.9	3.7	4.1	4.4
1200	1.3	2.0	2.6	2.9	3.1
1400	0.9	1.4	1.7	1.9	2.1
≥ 1600	0.7	0.9	1.1	1.2	1.4
			FFS = 100 km/h		
≤ 100	8.4	14.9	20.9	22.8	26.6
200	11.5	18.2	24.1	26.2	29.7
400	8.6	12.1	14.8	15.9	18.1
600	5.1	7.5	9.6	10.6	12.1
800	2.8	4.5	5.9	6.7	7.7
1000	1.6	2.8	3.7	4.3	4.9
1200	1.2	1.9	2.6	3.0	3.4
1400	0.8	1.3	1.7	2.0	2.3
≥ 1600	0.6	0.9	1.1	1.2	1.5
			FFS = 90 km/h		
≤ 100	6.7	12.7	21.7	24.5	31.3
200	10.5	17.5	25.4	28.6	34.7
400	8.3	11.8	15.5	17.5	20.7
600	4.9	7.3	10.0	11.5	13.9
800	2.7	4.3	6.1	7.2	8.8
1000	1.5	2.7	3.8	4.5	5.4
1200	1.0	1.8	2.6	3.1	3.8
1400	0.7	1.2	1.7	2.0	2.4
≥ 1600	0.6	0.9	1.2	1.3	1.5
			FFS = 80 km/h		
≤ 100	5.0	10.4	22.4	26.3	36.1
200	9.6	16.7	26.8	31.0	39.6
400	7.9	11.6	16.2	19.0	23.4
600	4.7	7.1	10.4	12.4	15.6
800	2.5	4.2	6.3	7.7	9.8
1000	1.3	2.6	3.8	4.7	5.9
1200	0.9	1.7	2.6	3.2	4.1
1400	0.5	1.1	1.7	2.1	2.6
≥ 1600	0.5	0.9	1.2	1.3	1.6
			FFS = 70 km/h		
≤ 100	3.7	8.5	23.2	28.2	41.6
200	8.7	16.0	28.2	33.6	45.2
400	7.5	11.4	16.9	20.7	26.4
600	4.5	6.9	10.8	13.4	17.6
800	2.3	4.1	6.5	8.2	11.0
1000	1.2	2.5	3.8	4.9	6.4
1200	0.8	1.6	2.6	3.3	4.5
1400	0.5	1.0	1.7	2.2	2.8
≥ 1600	0.4	0.9	1.2	1.3	1.7

Results from the *HCM2000* directional procedure cannot be directly compared to the results from the HCM1997 procedure because the HCM1997 results address both directions of travel together, while the *HCM2000* directional procedure, of course, represents only one direction of travel. There are two methods, however, by which the two-way and directional procedures can be compared. First, for cases in which there is a 50/50 directional split in traffic volume, the service flow rates from the HCM2000 procedure can be doubled and compared to those from the HCM1997 procedure. In this case, the PTSF values from the two-way and directional analyses can be compared directly. Second, for any roadway, the estimated PTSF values from separate HCM2000 analyses of the two directions of travel can be combined as a weighted average to obtain an estimate of the two-way PTSF and that value can be compared to the HCM1997 estimate of two-way PTSF. The same approach can be used to compare the two-way and directional results from the *HCM2000.* It should be recognized that, for any two-lane highway segment with a directional split of traffic volume other than 50/50, the LOS for the peak direction of travel is likely to be lower than the LOS for the two directions of travel combined.

For high-speed highways, any difference in levels of service between the *HCM2000* twoway and directional procedures must necessarily arise from differences in the computed values of PTSF, because ATS for a high-speed highway would have no impact on LOS and, because the linear nature of the speed-flow relationship shown in Figures 2 and 3 ensures that the A TS values from the two procedures will be consistent. The nonlinear nature of the PTSF vs. flow relationships for two-way and directional segments, illustrated in Figures 2 and 3, respectively, introduce the possibility of differing PTSF values from the two procedures.

Each of the three HCM procedures presented above was applied to a variety of two-lane highway conditions to compare the results obtained. The HCM procedures that have been compared are:

- HCM1997 two-way operational analysis procedure
- HCM2000 two-way operational analysis procedure
- HCM2000 directional operational analysis procedure

Specifically, the following two-lane highway conditions were evaluated:

- Two-way flow rates from 200 to 3,200 pc/h in increments of 200 pc/h
- Directional splits of 50/50, 60/40, 70/30, 80/20, and 90/10
- Percent no-passing zones from 0 to 100 percent in increments of 20 percent

There are a total of 480 unique combinations of these conditions. Only 348 of these 480 combinations were actually evaluated because combinations of two-way flow rate and directional split in which the heavier flow direction exceeds the directional capacity of 1,700 pclh indicated in *HCM2000* Chapter 20 were not considered.

The application of the *HCM2000* procedures was independent of terrain type (level vs. rolling vs. mountainous). In the application of the HCM2000 procedure, terrain type affects the passenger-car equivalents for heavy vehicles. Therefore, consideration of a passenger-car equivalent flow rate of, say, 1,000 pclh could represent many different combinations of vehicle volume and vehicle mix. A choice of terrain type was necessary in applying the HCM1997 procedure because the terrain type must be specified to use Table 2. Therefore, the HCM 1997 values were computed using level terrain.

Table A-I in Appendix A of this report presents the results of the comparison of the three HCM procedures identified above for the 384 combinations of interest. The results of this companson are:

- The PTSF results from the HCM1997 two-way segment procedure are, on the average, 3.8 percent lower than the PTSF results from the HCM2000 two-way segment procedure.

- The PTSF results from the HCM1997 two-way segment procedure are, on the average, 15.5 percent lower than the combined two-way PTSF results from the HCM2000 directional segment procedure.

- The PTSF results from the HCM2000 two-way segment procedure are, on the average, 11.3 percent lower than the combined two-way PTSF results from the HCM2000 directional segment procedure.

There is substantial variation in the differences reported above among the 384 cases considered. For example, while the average difference in computed PTSF between the HCM1997 two-way procedure and the HCM2000 two-way procedure is -3.8 percent, the individual differences range from -20.1 to +9.4 percent. It is natural that there should be some differences between the procedures because the HCM2000 procedure was developed, in part, to correct perceived difficulties with the HCM 1997 procedure.

Of greater concern is the average difference in PTSF of 11.3 percent between the HCM2000 two-way and directional procedures. A difference of this magnitude is unacceptable because the choice of one procedure or the other is likely to estimate different levels of service. Furthermore, the individual differences in PTSF between the HCM2000 two-way and directional procedures range from -29.3 percent to +0.5 percent. In other words, the directional segment procedure is likely to predict PTSF values that are consistently higher than the two-way segment procedure. The next section of the report examines changes to the HCM2000 procedures to eliminate this unacceptably large difference.

DEVELOPMENT OF MODIFICATIONS TO THE HCM2000 OPERATIONAL ANAL YSIS PROCEDURES

An initial review of the HCM2000 procedures found that the likely explanation for the observed differences in PTSF between the two-way and directional segment procedures is that PTSF vs. flow rate relationships for directional segments shown in Figure 3 and Equation (4) is inconsistent with the two-way segment procedure. The figure shows that the PTSF vs. flow rate relationships for directional segments rises much more steeply at low flow rates than would appear to be appropriate from the comparable two-way PTSF vs. flow rate relationship shown in Figure 2.

The PTSF vs. flow rate relationships for directional segments shown in Figure 3b and Equation (4) were developed in NCHRP Project 3-55(3) (7). These curves, as shown in Figure 3b, rise steeply at relatively low volumes. These curves were refit to have a shape more like the shape of the two-way PTSF vs. flow relationship shown in Figure 2b. This was done by generating additional data points for the directional 200-pc/h curve with a *50/50* directional split from the 400-pc/h two-way curve. A revised set of regression relationships incorporating these additional data was developed using the SAS nonlinear regression procedure (PROC NLIN). These relationships, shown in Figure 4, correct the problem noted above, but are not a satisfactory replacement for Figure 3 because some of the curves intersect or cross. Therefore, a set of curves nearly equivalent to Figure 3 was developed with the added constraint that the curves would not intersect or cross within the range of flow rates of interest. These relationships, shown in Figure 5, constitute a potential replacement for Figure 3b. The relationships illustrated in Figure 4 are determined with Equation (4), just as those in Figure 3b are, but the relationships in Figure 4 are based on a revised set of coefficients shown in Table 9.

A second problem found in this review was incompatibility between the adjustment factors for two-way and directional segments shown in Tables 6 and 8, respectively. It was found that a suitable adjustment factor for directional segments could not be as simple as Table 8. Table 10 presents a replacement for Table 8 that is more compatible with the two-way segment adjustments shown in Table 6. The revised adjustment factor shown in Table 10 is a function of two-way volume, directional split, and no-passing zones. Table 8 included separate adjustment factors for various levels of free-flow speed. There is no comparable adjustment for free-flow speed in Table 6 in the two-way procedure; based on a review of the available data and for consistency between the two-way and directional segment procedures, it was concluded that such an adjustment was not appropriate in the directional segment procedure either and, therefore, Table 10 does not include adjustment factors for separate levels of free-flow speed.

The revised adjustment factor shown in Table 10 applies to two-way traffic and must be apportioned between the two directions of travel as follows:

$$f_{np} = f_{adj}\left(\frac{V_d}{V_d + V_0}\right) \qquad (6)$$

where: f_{adj} = adjustment factor for directional split and no-passing zones (see Table 10)

V_0 = opposing direction passenger-car equivalent flow rate (pc/h)

With this addition, Equation (5) should be revised as:

$$PTSF_d = BPTSF_d + f_{adj}\left(\frac{V_d}{V_d + V_0}\right) \qquad (7)$$

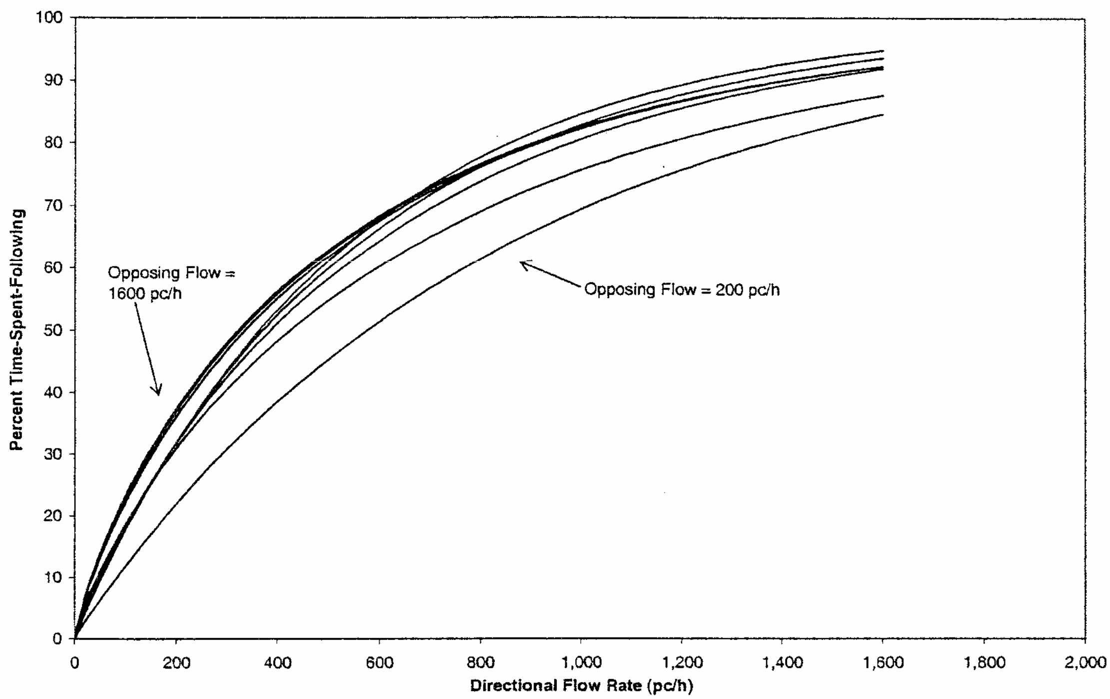

Figure 4. Initial revision of percent time-spent-following flow relationships for directional segments with base conditions.

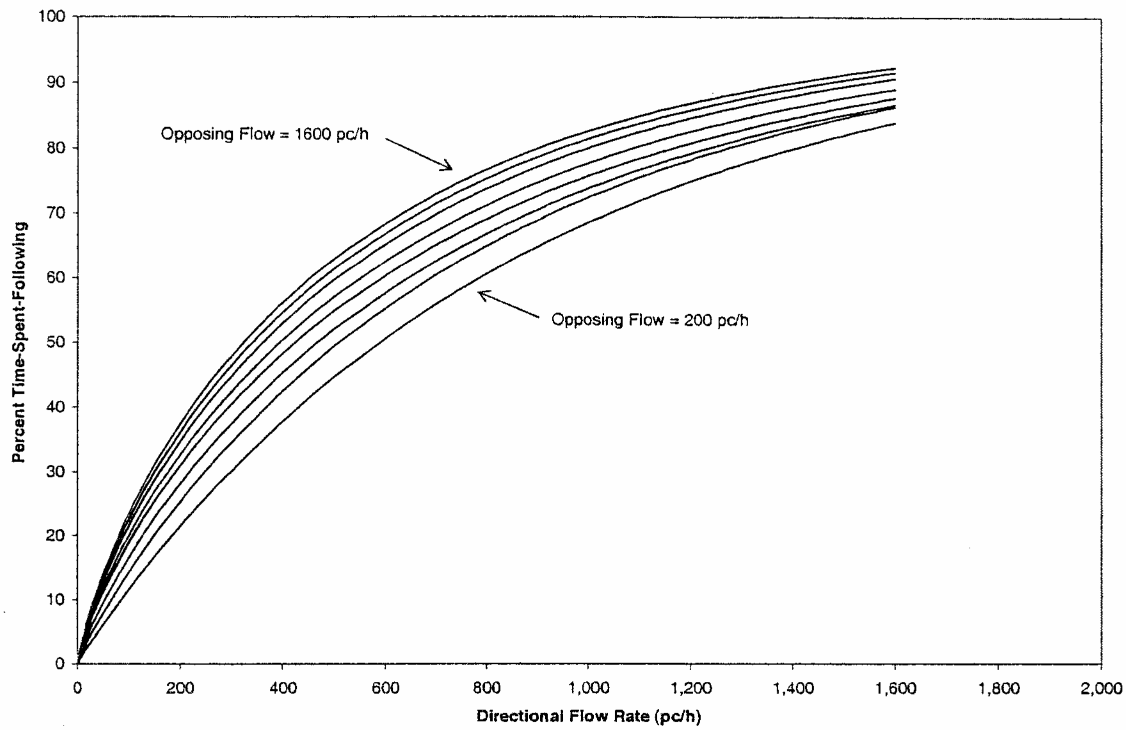

Figure 5. Recommended revision of percent-time-spent-following flow relationships for directional segments with base conditions.

TABLE 9. Revised Values of Coefficients Used in Estimating Percent Time Spent Following for Directional Segments

Opposing demand flow rate, v_o (pc/h)	a	b
≤ 200	–0.0014	0.973
400	–0.0022	0.923
600	–0.0033	0.870
800	–0.0045	0.833
1000	–0.0049	0.829
1200	–0.0054	0.825
1400	–0.0058	0.821
≥ 1600	–0.0062	0.817

TABLE 10. Revised Adjustment (f_{adj}) to Percent Time Spent Following Directional Split and Percent No-Passing Zones on Directional Segments

Two-way flow rate, v_p (pc/h)	Increase in percent time-spent-following (%)					
	No-passing zones (%)					
	0	20	40	60	80	100
Directional split = 50/50						
≤ 200	9.0	29.2	43.4	49.4	51.0	52.6
400	16.2	41.0	54.2	61.6	63.8	65.8
600	17.1	39.5	49.1	54.5	56.5	58.1
800	15.8	33.8	40.4	44.0	44.8	46.6
1400	13.7	20.9	24.7	27.1	28.3	29.5
2000	10.0	13.6	15.8	17.4	18.2	18.8
2600	5.5	7.7	8.7	9.5	10.1	10.3
3200	3.9	5.5	6.1	6.7	6.9	7.3
Directional split = 60/40						
≤ 200	11.0	30.6	41.0	51.2	52.3	53.5
400	14.3	35.9	44.5	53.2	54.7	56.1
600	14.3	35.4	43.5	50.6	52.3	54.1
800	13.8	28.4	33.6	38.8	40.1	41.5
1400	11.7	18.8	22.1	25.3	26.3	27.3
2000	8.5	13.0	15.1	15.5	16.2	16.8
2600	5.0	6.8	7.7	8.7	9.1	9.3
Directional split = 70/30						
≤ 200	9.9	28.1	38.0	47.8	48.5	49.0
400	9.3	29.0	37.2	45.4	46.4	47.4
600	7.0	27.0	33.6	39.9	41.5	43.0
800	7.1	20.4	25.2	30.1	31.3	32.3
1400	6.2	12.7	15.8	18.9	19.8	20.5
2000	4.0	6.4	12.4	10.0	10.7	11.2
Directional split = 80/20						
≤ 200	8.9	27.1	37.1	47.0	47.4	47.9
400	3.9	23.4	31.8	40.0	40.8	41.4
600	–1.6	18.9	25.7	32.5	33.5	34.4
800	–1.8	11.7	16.7	21.6	22.3	23.1
1400	–1.9	4.8	7.9	10.8	11.4	12.0
2000	–1.9	2.7	4.2	5.8	6.1	6.4
Directional split = 90/10						
≤ 200	4.6	24.1	33.6	43.1	43.4	43.6
400	–3.8	16.3	24.4	32.4	32.8	33.1
600	-9.7	10.1	16.8	23.3	23.8	24.3
800	–10.9	2.3	7.1	11.7	12.2	12.7
1400	–10.9	–3.9	–1.1	1.4	1.9	2.3

The replacement of Figure 3b by Figure 5, Table 7 by Table 9, Table 8 by Table 10, and Equation (5) by Equation (7) provides a modified operational analysis procedure for directional segments that agrees more closely with the two-way operational analysis procedure.

ASSESSMENT OF THE REVISED OPERATIONAL ANALYSIS PROCEDURE FOR DIRECTIONAL SEGMENTS

The modified operational analysis procedure for directional segments was compared with the three operational analysis procedures reviewed above and the following results were obtained:

- The PTSF results from the HCM1997 two-way segment procedure are, on the average, 3.8 percent lower than the combined two-way PTSF results from the modified HCM2000 directional segment procedure.
- The PTSF results from the HCM2000 two-way segment procedure are, on the average, less than 0.1 percent lower than the combined two-way PTSF results from the modified HCM2000 directional segment procedure.
- The PTSF results from the existing HCM2000 directional segment procedure are, on the average, 11.4 percent higher than the combined two-way PTSF results from the modified HCM2000 directional segment procedure.

To summarize, the modified directional segment procedure provides PTSF estimates that are very similar to those from current HCM2000 two-way segment procedure (i.e., the average difference is less than 0.1 percent). This accomplishes an important goal because differences between the two-way and directional segment procedures are undesirable. While the two procedures agree on the average, there are still differences; in more than 90 percent of the cases evaluated, the two procedures agree within 0.3 percent. The largest observed difference is 2.2 percent.

Appendix B summarizes the specific proposed changes to existing HCM2000 Chapters 12 and 20 to implement the modified procedure described above. These changes are expected to result in a typical difference of less than 0.1 percent and a maximum difference of 2.2 percent between the PTSFestimates from the HCM2000 two-way and directional segment procedures. This will, in turn, result in nearly identical service volumes from the two procedures.

CHAPTER 3

LEVEL-OF-SERVICE ESTIMATION FOR DEVELOPED TWO-LANE HIGHWAYS

Users of *HCM2000* Chapter 20 have noted that the operational analysis procedures do not appear to adequately address two-lane highways in developed areas. The two classes into which two-lane highways are classified appear to be appropriate for highways in undeveloped areas, but not for highways in more developed areas. The following discussion reviews the classes into which two-lane highways are currently classified in the HCM, identifies scenarios for which the current two-lane highway classes may not apply, and suggests potential modification to HCM operational analysis procedures to better address those scenarios.

Chapters 12 and 20 of the HCM2000 address two classes of two-lane highways:

- Class I—Two-lane highways on which motorists expect to travel at relatively high speeds. Two-lane highways that are major intercity routes, primary arterials connecting major traffic generators, daily commuter routes, or primary links in state or national highway networks generally are assigned to Class I. Class I facilities most often serve long-distance trips or provide connecting links between facilities that serve long-distance trips.

- Class II—Two-lane highways on which motorists do not necessarily expect to travel at high speeds. Two-lane highways that function as access routes to Class I facilities, serve as scenic or recreational routes that are not primary arterials, or pass through rugged terrain are generally assigned to Class II. Class II facilities most often serve relatively short trips, the beginning and ending portion of longer trips, or trips for which sightseeing plays a significant role.

The *HCM2000* states that the classes of two-lane highways closely relate to their functions-most arterials are considered Class I, and most collectors and local roads are considered Class II. However, the primary determinant of a highway's classification in an operational analysis is the motorist's expectation concerning the ability to travel at high speeds, which might not agree with the functional classification. For example, an intercity route that passes through rugged mountainous terrain might be described as Class II, instead of Class I, if motorists recognize that a high-speed route is not feasible in that corridor.

The class of a two-lane highway influences the selection of performance measures used in the *HCM2000* to determine its LOS. On Class I highways, for which efficient mobility is paramount, the LOS is defined in terms of both PTSF and ATS. On Class II facilities, mobility is less critical, and LOS is defined only in terms of PTSF. Drivers generally tolerate higher levels of PTSF on a Class II facility than on a Class I facility, because Class II highways usually serve shorter trips and different trip purposes.

Tables 4 and 5 present the LOS criteria used in the *HCM2000* for Class I and II highways, respectively. The LOS criteria for Class I highways were chosen to accommodate a broad range of two-lane highway design speeds. On a high-speed two-lane highway, the LOS is generally defined by PSTF alone. On a Class I highway with a lower design speed, the ATS criteria in Table 4 lead to lower levels of service. Where the HCM user's assessment is that travel speed is less important to motorists, the LOS criteria for Class II highways, presented in Table 5, are used.

SCENARIOS WHERE CURRENT TWO-LANE HIGHWAY CLASSES MAY NOT APPLY

HCM users have questioned whether the current HCM classes for two-lane highways are appropriate for two-lane highways in developed areas. The following types of two-lane highways represent situations in which motorists do not expect to travel at speeds of 89 kmIh (55 mi/h) or more, as they do on rural highways in open country:

- a two-lane highway through a small town with a reduced speed limit located along a major rural route that generally has speeds of 89 km/h (55 mi/h) or more
- a two-lane highway in a transition area between rural and urban/suburban conditions with reduced speeds and low- to medium-density development
- a two-lane highway with continuous urban/suburban development but with no traffic signals or with traffic signals spaced at intervals greater than 3 km (2 mi). Such a facility does not meet the definition of an urban street for consideration with the procedures of HCM Chapter 15.

Each of these types of two-lane highways is discussed below.

Two-Lane Highway Through a Small Town

There is a question about how best to treat a small-town on a major intercity two-lane highway. The rural portions of such a highway that operate at speeds of 89 *kmIh* (55 mi/h) or more under low-flow conditions would generally be analyzed as a Class I highway using the HCM Chapter 20 procedures. The LOS on a Class I highway segment defined by considering both PTSF and A TS.

Isolated small towns on such a highway generally extend along the road for distances of 0.8 to 3.2 kID (0.5 to 2 mi), have continuous development along both sides of the road, and have a reduced speed limit in the range from 32 to 72 *kmIh* (20 to 45 mi/h). The presence of the reduced speed limit, and its obvious justification by the presence of continuous development, is an indication that it is reasonable to presume that motorists do not expect to travel at high speeds. Thus, the highway through a small town would not be considered a Class I highway segment.

Under the current HCM2000 procedures, the two-lane highway through a small town would, therefore, be considered a Class II highway and its LOS would be defined by PTSF alone. This may be reasonable from the perspective of long-distance travelers, but it does not directly represent the viewpoint of motorists who live in or near the town. Local residents may be more sensitive to speed as a service measure.

Transitions Between Rural and Urban/Suburban Areas

Where a highway transitions from a rural to an urban/suburban area, or a rural highway travels along the fringe of an urban/suburban area, there may be sections of the road with reduced speed limits due to the presence of low- to medium-density development. The reduced speed limit may have been introduced by the responsible highway agency in response to the presence of traffic turning on and off the road.

As in the case of the small town, the presence of the reduced speed limit related to development and turning activity clearly indicates that motorists would not expect to travel at high speeds. Therefore, under the current HCM definitions, this transition-area roadway would be considered a Class II highway, rather than a Class I highway, and the LOS would be defined by PTSF alone. As in the case of the small town, PTSF is a good indicator of the service provided to the through motorist, but may not be a good indicator of the service provided to the motorists who live in or near the transition area and use the roadway in question for local circulation.

Two-Lane Highway with Continuous Development But Widely Spaced Signals

The final scenario of interest is a two-lane highway with continuous urban/suburban development but either no traffic signals or signals spaced at intervals greater than 3 Ian (2 mi). Typically such roadways have speeds in the range from 32 to 72 km/h (20 to 45 milh). Such roadways may be urban extensions of rural highways or may simply be arterials that serve an urban or suburban area.

If such a highway has no signals or widely spaced signals, it does not meet the definition of an urban street for analysis using the procedures of HCM Chapter 15. Such a roadway is clearly not a Class I two-lane highway, because motorists would not reasonably expect to travel at high speed. However, it does not appear to be a Class II highway either, because PTSF is a service measure that is most applicable to through traffic that expects to return to high-speed travel after a short interruption.

FIELD REVIEWS OF SPECIFIC ROADWAYS FOR WHICH CURRENT TWO-LANE ROAD CLASSES MAY NOT APPLY

As part of the current research, field reviews were conducted of two highways in Florida to which the current two-lane road classes are difficult to apply. These facilities are State Route 997 (Krome Avenue) in Miami-Dade County and US 1 in Momoe County. Each of these facilities is discussed below.

State Route 997 (Krome Avenue) in Miami-Dade County, Florida

The site of interest on Krome A venue extends for 53 Ian (33 mi) from US 27 to Avocado Drive in Miami-Dade County, Florida. This site divides itself logically into three subsections within which quite different operational conditions are present.

The northernmost 23 km (14 mi) of the site is a two-lane highway that is primarily rural in character with a speed limit of 89 km/h (55 mi/h). The current ADT is approximately 9,000 veh/day. The average running speed was recently measured as 84.5 krn/h (52.5 mi/h). There is only one signal on the entire 23-km (14-mi) roadway section. Field review found this portion of the site to be a Class I highway for which PTSF and ATS are very logical service measures.

The middle 19 km (12 mi) of the site is a two-lane highway that is generally rural with intermittent low- and medium-density development. The speed limit is generally 72 km/h (45 mph) and the current ADT is approximately 14,500 to 14,800 veh/day. The driveway density is about 8 driveways per km (5 driveways per mi) and there is a moderate level of turning activity. There is approximately one signal every 8 km (5 mi). This middle section of the site is very much a transition area between rural and suburban conditions.

The field review noted that speeds in this middle section are definitely affected by the development and turning activity. The development along this highway, even though it is low to medium density, may reduce motorists' expectations about the ability to travel at high speeds. The traffic using the highway appeared to be a mix of through traffic (e.g., relatively long work trips) and local trips with origins or destinations along the roadway. The transition nature of this site makes it difficult to decide whether it should be classified as a Class I two-lane highway, a Class IT two-lane highway, or some other type of highway altogether.

The southernmost 11 km (7 mi) of the site has continuous suburban development and a speed limit of 72 kmIh (45 milh). The current ADT is approximately 14,100 to 14,600 veh/day. The spacing between signals is approximately 1.6 km (1 mi). There is substantial turning traffic at the signals and at driveways between signals.

This southernmost section of the site, despite its rural two-lane highway cross section, is in nearly all respects a suburban arterial, rather than a two-lane highway. The field review concluded that it would not be appropriate to analyze this southernmost section of the facility as either a Class I or Class IT two-lane highway. Instead, this portion of the site should be analyzed as a two-lane suburban arterial, using the procedures of HCM Chapter 15.

On the same day as the field visit by the research team, the SR 997 (Krome Avenue) site was reviewed in the field by FDOT traffic engineers and planners from several districts in Florida. The FDOT staff who conducted the field review included a representative of the district office with responsibility for the site who travels the road on a weekly basis and representatives from other districts who were seeing the road for the first time. At a debriefing meeting following the field review, the FDOT reviewers agreed that the three portions of the site were operationally distinct, that motorist expectations on the three areas were different, and that it would be justifiable to use different service measures and LOS definitions for the three portions of the site. One member of the field review team noted that the HCM has a hard time dealing with rural roadways that have development, like the middle section of SR 997, but drivers have a hard time dealing with them as well.

US 1 **in Monroe County, Florida**

US 1 in Monroe County, Florida, is the main highway through the Florida Keys. The facility reviewed for this research includes the 164-km (l02-mi) section from Key Largo to Stock Island Gust short of the bridge to Key West), excluding limited sections of multilane highway. The two-lane portions of US 1 alternate between rural areas on uninhabited or sparsely developed keys, bridges between keys, and developed areas with medium to high development densities.

The rural areas of US 1 appear to meet the definition of a Class I two-lane highway. The traffic consists primarily of through trips, including trips to and from Miami and points north and circulation within the Keys, which, as shown above, can include trips up to 160 km (100 mi) in length. Speed limits in the rural areas were generally 89 *km/h* (55 mi/h) and motorists clearly expect to travel at those speeds, at least under low-flow conditions.

The bridges between Keys vary in length from extremely short to 11 km (7 mi). Bridges are not addressed explicitly by HCM procedures, but the bridges are in effect a special case of rural conditions with no development or turning traffic. The HCM procedures for Class I twolane highways can clearly be applied to the bridges as well as to the rural or sparsely developed areas.

Sections of US 1 with medium- to high-density development look and operate much like suburban arterials, with the exception that there are very few signals. As an example, the US 1 roadway through Big Pine Key is 5.6 km (3.5 mi) in length with continuous development and direct driveway access, but there is only one signal on the island. The speed limit is 72 kmIh (45 milh) and the current ADT is approximately 20,000 veh/day. It does not appear that either the Class I two-lane highway procedures in HCM Chapter 20, the Class n two-lane highway procedures in Chapter 20, or the procedures for urban streets in HCM Chapter 15 apply to this section of US 1. The roadway through Big Pine Key meets the criteria for application of the HCM Chapter 15 procedures in all respects other than signal spacing.

FDOT has made an assessment that traffic operations on US 1 in Monroe County are sufficiently different than other two-lane highways that the procedures of HCM Chapter 20 (and its predecessor Chapter 8 of the 1985 HCM) should not be applied. Instead, FDOT has developed and applied the following LOS criteria for US 1 based on the ATS ranges shown (8):

- LOS A 82 km/h (51 mi/h) or above
- LOS B 81.9 to 77.2 km/h (50.9 to 48 mi/h)
- LOS C 77.1 to 72.4 km/h (47.9 to 45 mi/h)
- LOS D 72.3 to 67.6 km/h (44.9 to 42 mi/h)
- LOS E 67.5 to 57.9 km/h (41.9 to 36 mi/h)
- LOS F below 57.9 km/h (36 mi/h)

These criteria have been applied to all portions of US 1 in Monroe County, including rural areas, bridges, and developed areas, regardless of the density of development or posted speed. A separate LOS procedure for speeds of individual segments has been developed. In areas of unintelTUpted flow, LOS is defined by comparison of the ATS to the posted speed limit as follows (8,9):

- LOS A 2.4 km/h (1.5 mi/h) above posted speed limit
- LOS B 2.4 km/h (1.5 mi/h) below posted speed limit
- LOS C 7.2 km/h (4.5 mi/h) below posted speed limit
- LOS D 12.1 km/h (7.5 mi/h) below posted speed limit
- LOS E 21.7 km/h (13.5 mi/h) below posted speed limit
- LOS F more than 21.7 km/h (13.5 mi/h) below posted speed limit

It raises a concern that an agency that generally uses the HCM has found it appropriate to use alternative non-HCM procedures to determine the LOS *for* one particular type of two-lane highway. It is a greater concern that some LOS criteria for this class are based on comparison of the ATS to the posted speed limit. It is not desirable to have a situation in which the LOS of roadway can be changed by changing the posted speed limit, even if actual operating conditions on the roadway remain the same. FDOT has *shown* interest in using an A TS-based LOS procedure using LOS thresholds based on percentages of free-flow speed (FFS). Such LOS definitions would be very similar to the LOS definitions used *for* urban streets in HCM Chapter 15.

CANDIDA TE PROCEDURES TO ADDRESS DEVELOPED TWO-LANE HIGHWAY FACILITIES

The preceding discussion has identified one situation which current HCM procedures do not appear to address at all (two-lane highways with continuous development with no signals or widely spaced signals) and two situations *for* which the current HCM procedures for LOS analysis seem only partially suited (small towns and transition areas). This section of the report explores candidate procedures to deal with these types of facilities.

Two-Lane Highways With Continuous Development and Widely Spaced Signals

Two-lane highways with continuous development, direct driveway access, speeds below 89 km/h (55 milh), and no signals or signal spacing greater than 3 km (2 mi) do not appear to be addressed by any procedure in the current HCM. In order *for* the HCM to be complete, a procedure should be provided *for* such facilities or, at a minimum, the HCM should provide advice *for* the user on how to evaluate the LOS for such facilities.

Service Measure

The research team reviewed the potential service measures *for* two-lane roads with continuous development including:

- PTSF
- ATS
- PTSF and ATS combined

The research team's assessment is that ATS is the most appropriate service measure for developed two-lane highways where speeds are reduced and there is a substantial local traffic component. PTSF is a more appropriate measure when a large proportion of the traffic volume is through traffic and motorist expectations are more in line with a rural facility. On a major intercity facility, such as a Class I two-lane road, it still appears that the combination of PTSF and ATS is the most appropriate service measure.

LOS Thresholds

Except for the absence or wide spacing of signals, two-lane highways with continuous development are identical to urban and suburban arterials that are addressed with the HCM Chapter 15. It seems logical that the appropriate service measure for such facilities should be ATS and that LOS thresholds be the same as those used in Chapter 15 (see Table 11). These LOS thresholds are essentially percentages of the free-flow speed, as shown in Table 12.

It is recommended that the preceding LOS criteria, which are consistent with HCM Chapter 15 be used as the LOS criteria for developed two-lane highways.

Estimation Methodology

A methodology is needed for estimating ATS on developed two-lane highways for comparison to the LOS thresholds presented above. It is recommended that this methodology be adapted from the HCM Chapter 15 methodology.

In the HCM Chapter 15 methodology, ATS for segments between signals is estimated from HCM Exhibit 15-3, presented here as Table 13. The table shows that ATS on an urban street is a function of FFS and segment length (i.e., signal spacing). When signals are at least 1600 m (1 mi) apart, the ATS between signals is equal to the FFS.

For a two-lane highway, it has been demonstrated that ATS decreases directly as flow rate increases, asshown in Equation (8) based on HCM Equation (20-15):

$$ATS_d = FFS_d - 0.0125(v_d + v_o) - f_{np} \quad (8)$$

where:

- ATS_d = average travel speed in the analysis direction (km/h)
- FFS_d = free-flow speed in the analysis direction (km/h)
- v_d = passenger-car equivalent flow rate for the peak 15-min period in the analysis direction (pc/h)
- v_o = passenger-car equivalent flow rate for the peak 15-min period in the opposing direction (pc/h), determined from Equation (20-13)
- f_{np} = adjustment for percentage of no-passing zones in the analysis direction (see Exhibit 20-19)

TABLE 11. Urban Street LOS by Class

Urban street class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average travel speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56-72	> 46-59	> 39-50	> 32-41
C	> 40-56	> 33-46	> 28-39	> 23-32
D	> 32-40	> 26-33	> 22-28	> 18-23
E	> 26-32	> 21-26	> 17-22	> 14-18
F	≤ 26	≤ 21	≤ 17	≤ 14

TABLE 12. Level-of-Service Thresholds as a Percentage of Free-Flow Speed Used in HCM Chapter 15 (*1*)

LOS boundary	Threshold value for percentage of free-flow speed
Boundary between LOS A and B	90%
Boundary between LOS B and C	70%
Boundary between LOS C and D	50%
Boundary between LOS D and E	40%
Boundary between LOS E and F	30%

TABLE 13. Segment Running Time per Kilometer for Urban Streets in HCM Chapter 15 (*1*)

Urban street class	I			II			III		IV		
FFS (km/h)	90[a]	80[a]	70[a]	70[a]	65[a]	55[a]	55[a]	50[a]	55[a]	50[a]	40[a]
Average segment length (m)	Running time per kilometer (s/km)										
100	b	b	b	b	b	b	–	–	–	129	159
200	b	b	b	b	b	b	88	91	97	99	125
400	59	63	67	66	68	75	75	78	77	81	96
600	52	55	61	60	61	67	d	d	d	d	d
800	45	49	57	56	58	65	d	d	d	d	d
1000	44	48	56	55	57	65	d	d	d	d	d
1200	43	47	54	54	57	65	d	d	d	d	d
1400	41	46	53	53	56	65	d	d	d	d	d
1600	40[c]	45[c]	51[c]	51[c]	55[c]	65[c]	d	d	d	d	d

Notes:

[a] It is best to have an estimate of FFS. If there is none, use the table above, assuming the following default values:

For Class	FFS (km/h)
I	80
II	65
III	55
IV	45

[b] If a Class I or II urban street has a segment length less than 400 m, (a) reevaluate the class and (b) if it remains a distinct segment, use the values for 400 m.

[c] For long segment lengths on Class I or II urban streets (1600 m or longer), FFS may be used to compute running time per kilometer. These times are shown in the entries for a 1600-m segment.

[d] Likewise, Class III or IV urban streets with segment lengths greater than 400 m should first be reevaluated (i.e., the classification should be confirmed). If necessary, the values above 400 m can be extrapolated.

Although this table does not show it, segment running time depends on traffic flow rates; however, the dependence of intersection delay on traffic flow rate is greater and dominates in the computation of travel speed.

The HCM Chapter 15 methodology does not incorporate an effect oftraffic flow rate on speed for urban streets similar to that shown for two-lane highways in Equation (8). Such an effect was not deemed necessary because (1) the procedure for rural and suburban multilane highways in HCM Chapter 21 shows no decrease in speed with increasing flow rate until the flow rate reaches 1,400 pc/h/lane and (2) the delay resulting from the effect of flow rate on midblock speeds is assumed to be small relative to the control delay at signals.

It is recommended that, for developed two-lane arterials, a speed prediction methodology be based on a combination of Table 13 and Equation (8). Specifically:

- If the developed two-lane highway has no signals, segment length is not meaningful, so Table 13 is not necessary and Equation (8) should be applied directly to determine the ATS.

- If the developed two-lane highway has signals spaced more than 1600 m (1 mi) apart, Table 13 is not needed because the running speed between signals equal to the FFS and is not affected by segment length. In this case, Table 13 is not needed, Equation (8) should be applied directly, and the HCM Chapter 15 methodology should be used to combine the average running speed between signals computed with Equation (8) and the control delay at the signals computed with the HCM Chapter 16 procedure.

- If the developed two-lane highway has signals spaced less than 1600 m (1 mi) apart, then determine the average running speed between signals based on Table 13 and the average running speed between signals based on Equation (8), and use the lower of the two speeds as the average running speed between signals. Then, combine the average running speed between signals and the control delay at the signals in the same manner as the current HCM Chapter 15 procedure.

Incorporation of the Revised Methodology in the HCM

The preceding discussion indicates that the HCM lacks procedures to address developed two-lane highways. The incorporation in the HCM of procedures for such developed highways is desirable.

HCM procedures generally address three types of analysis units: point locations, highway segments, and highway facilities. The LOS for point locations such as signalized and unsignalized intersections can be addressed with the procedures in HCM Chapters 16 and 17, respectively. Driveways are another type of point locations that influences traffic operations. There are no explicit HCM procedures to address driveways, although an unsignalized driveway could be evaluated as an unsignalized intersection. Highway segments are sections of roadway without signals, that are generally treated as having uninterrupted flow. However, on highway types other than freeways, there are usually interruptions between signals (such as at driveways and unsignalized intersections) that delay traffic, slowing vehicle speeds and promoting the fonnation of platoons. Highway facilities are extended sections of highway that combine point locations and segments. The only complete facilities procedure in the HCM is the freeway facilities procedure in HCM Chapter 22, which combines consideration of basic freeway segments, ramps, ramp junctions, and weaving areas. The urban streets procedure in HCM Chapter 15 can assess the LOS for an arterial facility that includes an urban/suburban arterial highway segment less than or equal to 3 Ian (2 mi) in length and a signalized intersection at the end of the segment. However, the HCM Chapter 15 procedure is not a complete facilities procedure because it does not address the effects of development or unsignalized intersections between signals.

The challenges in addressing developed two-lane highways in the HCM are (1) which chapter should incorporate such a procedure and (2) whether such a procedure can be developed with existing concepts and knowledge or whether new concepts and new knowledge are required. A procedure for evaluating developed two-lane highways can be incorporated in the HCM in one of three ways:

- a new class of two-lane highways (e.g., Class III) could be added to HCM Chapter 20 representing developed two-lane highways and the procedures for estimating the free-flow speed and ATS and evaluating the LOS could be provided

- HCM Chapter 15 could be expanded to include procedures for all developed arterial highways whether or not they have signals

- a new chapter could be added to the HCM for developed arterials with no signals or with widely spaced signals

This research has developed a procedure for analysis of developed two-lane highways that combines concepts from HCM Chapters 15 and 20 and can assess the LOS for some, but not all, developed two-lane highways. The service measure for this procedure is ATS and the LOS thresholds are defined in as percentages of the FFS. Because the service measure and LOS thresholds are defined in the same manner as in HCM Chapter 15, it is our recommendation that this combined procedure would fit most naturally into HCM Chapter 15. Furthermore, since the interaction between through vehicles on a developed two-lane highway and vehicles turning onto or off the highway may be substantial (especially at intersections) an operational analysis procedure for developed two-lane highways most naturally fits in an interrupted flow chapter.

We do not recommend that a procedure be incorporated in the HCM as a Class ill facility in HCM Chapter 20 because the service measure, LOS thresholds, and analysis procedures are unlike anything in the current HCM Chapter 20. Ultimately, a choice among these alternatives will need to be made by the TRB Committee on Highway Capacity and Quality of Service (HCQS).

General Approach to Analysis of Developed Two-Lane Highways

The research has developed an approach to traffic operational analysis of developed twolane highways that combines concepts from HCM Chapters 15 and 20. This approach has potential for analysis of some, but not all types of developed two-lane highways. The general approach used in this combined procedure is presented in this section of the report. Subsequent sections present the more detailed procedures and discuss potential alternatives to those procedures.

The research has considered how the existing HCM Chapter 15 methodology might be applied to developed two-lane highways. This review began with consideration of three HCM exhibits (HCM Exhibit 10-3, presented here as Table 14; HCM Exhibit 10-4, presented here as Table 15; and HCM Exhibit 15-3, presented above as Table 13). The review concluded that the current HCM Chapter 15 methodology may be directly applicable to two-lane arterials that are in the "high speed" and "suburban" design categories defined in Table 15. Several criteria for the "intermediate" and "urban" design categories may not be applicable to developed two-lane roads. These include:

- access density
- arterial type (shoulders)
- parking
- signal density
- pedestrian activity

The limited range of running times in Table 13 for urban streets in Classes ill and IV (which Table 14 indicates apply to the "intermediate" and "urban" categories) also suggest that these classes may not be applicable to developed two-lane highways.

In summary, the review suggests that the existing HCM Chapter 15 procedures may be applicable only to developed two-lane highways that meet the following criteria:

- FFS of 56 km/h (35 mi/h) or more
- left-turn lanes (or bays) at all public street intersections and "active" driveways (i.e., no substantial delays due to turning traffic)
- one or more traffic signals (where the traffic signal is located at the **end** of the segment in question

Under these conditions, it is plausible to use Table 13 to estimate running time (and, from this, running speed, travel speed, and LOS) for a developed two-lane highway, even if it does not satisfy the maximum signal spacing criteria stated in Table 15 [i.e., 3 kmIsignal (2 mi/signal) for "high-speed" segments and 1.6 kmIsignal (1 mi/signal) for "suburban" segments].

It is a potential weakness of both HCM Chapters 15 and 20 that they do not incorporate delays to through vehicles due to turning traffic at unsignalized intersections. The HCM Chapter 15 procedure could be extended to incorporate the HCM Chapter 17 procedures for unsignalized intersections, much as it now incorporates the HCM Chapter 16 procedures for signalized intersections, but this would require a substantial development effort.

TABLE 14. Urban Street Class Based on Functional and Design Categories (*1*)

Design category	Functional category: Principal arterial	Functional category: Minor arterial
High-Speed	I	N/A
Suburban	II	II
Intermediate	II	III or IV
Urban	III or IV	IV

TABLE 15. Functional and Design Categories or Urban Streets (*1*)

Criterion	Functional category: Principal arterial	Functional category: Minor arterial
Mobility function	Very important	Important
Access function	Very minor	Substantial
Points connected	Freeways, important activity centers, major traffic generators	Principal arterials
Predominant trips served	Relatively long trips between major points and through-trips entering, leaving, and passing through the city	Trips of moderate length within relatively small geographical areas

Criterion	Design category: High-speed	Suburban	Intermediate	Urban
Driveway/access density	Very low density	Low density	Moderate density	High density
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided; undivided or two-lane with shoulders	Multilane divided or undivided; one-way, two-lane	Undivided one-way, two-way, two or more lanes
Parking	No	No	Some	Significant
Separate left-turn lanes	Yes	Yes	Usually	Some
Signals/km	0.3-1.2	0.6-3.0	2-6	4-8
Speed limit	75-90 km/h	65-75 km/h	50-65 km/h	40-55 km/h
Pedestrian activity	Very little	Little	Some	Usually
Roadside development	Low density	Low to medium density	Medium to moderate density	High density

Detailed Procedures for Analysis of Developed Two-Lane Highways

The following specific existing procedures are recommended for analysis of developed two-lane roads:

- Developed two-lane highway segment not terminated by a signal:
  - use Equation (8) to determine ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

- Developed two-lane highway segment terminated by a signal and having a signal spacing in excess of 1.6 km (1 mi):
  - use Equation (8) to determine ATS and convert ATS to a running time, TR
  - use the HCM Chapter 15 methodology to determine signal delay
  - combine the signal delay and the running time
  - reconvert the combined running time to an ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

- Developed two-lane highway segment terminated by a signal and having a length of 1.6 km (1 mi) or less:
  - use Equation (8) to determine ATS and convert to a running time, TR
  - if the FFS is 56 km/h (35 mi/h) or more and left-turn lanes (or bays) are provided for all public street intersections and "active" driveways, then use Table 13 to determine a running time, TR′. If not, then TR′ is not available.
  - use the HCM Chapter 15 methodology to determine signal delay
  - combine the signal delay with the larger running time, TR or TR′
  - reconvert the combined running time to an ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

The following caveats and assumptions should be noted in applying the procedures defined above:

- All applications of HCM Chapter 20 procedures should use the directional segment methodology, not the two-way segment methodology.

- Equation (8) is intended primarily for segments with FFS of 72 km/h (45 mi/h) or more; however, it can be applied to facilities with a lower FFS with caution and provided that values in HCM2000 Exhibit 20-19 are extrapolated. In no case, should the segment FFS be less than 56 km/h (35 mi/h).

- If the percentage of no-passing zones is not known for the developed two-lane highway segment, it should be assumed to be 100 percent.

While it is recommended that the procedure presented above be incorporated in HCM Chapter 15, it should be noted that the use of Equation (8) requires the use of HCM Exhibit 20-19 and may require HCM Equation (20-2), Exhibit 20-5, and Exhibit 20-6, as well.

Hence, the user of this new material in HCM Chapter 15 will have to refer to HCM Chapter 20 for portions of the methodology. However, this is not unlike the current need to refer to the HCM Chapter 16 methodology when using HCM Chapter 15.

Alternative Approaches to Analysis of Developed Two-Lane Highways

This section discusses approaches to analysis of developed two-lane highways that may be considered as alternatives to the approaches presented above.

The preceding section recommended the LOS thresholds shown in Table 12 for application to developed two-lane highways. These are the same LOS thresholds currently used for urban streets in HCM Chapter 15. An alternative set of LOS thresholds for developed twolane highways without signals recommended by Washburn et al. *(10)* are shown in Table 16. The proposed LOS thresholds in Table 16 are higher than those shown in Table 12 on the grounds that motorists expect less delay on a developed two-lane highway without signals than they would on an urban street with signals. It could also be that motorists would accept a lower speed on an urban street because they realize that the signals that slow them are necessary for effective traffic control. The reason that the use of Table 16 was not recommended in this research is that it would create a situation in which a highway agency could improve the LOS of a developed two-lane highway by installing signals and, then, analyzing it with HCM Chapter 15 (including the LOS criteria in Table 12) to get a better LOS. The notion that the LOS can be improved by installing a signal seems counterintuitive and is a key concern that led to the recommendation of the LOS thresholds shown in Table 12 for application to developed two-lane highways. Nevertheless, the alternative approach of using Table 16, or some alternative set of LOS thresholds between those shown in Tables 12 and 16, should receive due consideration.

Another alternative to the procedures recommended above that should be considered is the development of better speed prediction models for developed two-lane highways. Research on the HCM Chapter 15 procedures for urban arterials by Prassas (11) has concluded that the HCM procedures predict speeds that are approximately 10 percent lower than those predicted by nominally comparable simulation models. The Prassas work also found a relationship between A TS and flow rate; such a relationship is potentially needed for analysis of both urban streets and developed two-lane highways. Research to improve speed prediction for urban arterials is planned in the upcoming NCHRP Project 3-79, *Estimating and Measuring Urban Street Traffic Speed and Level of Service.* It would be desirable to address two-lane urban streets in this research.

Another alternative would be to create a new facility chapter in the HCM to address developed two-lane highways, or arterial highways with development in general, rather than incorporating a new procedure in HCM Chapter 15 as recommended in this research. We would envision such a chapter as a replacement for, or a supplement to, HCM Chapter 15. Such a chapter would need to account for (1) running speeds between intersections, as affected by both traffic volume and development, (2) delays to major-road through traffic at two-way stop controlled intersections, and (3) control delay at signalized intersections. It is further envisioned that this procedure would consider facilities that were more extensive than a single segment and a single downstream intersection. The development of such a facility procedure would require a

TABLE 16. Level-of-Service Thresholds as a Percentage of Free-Flow Speed Recommended for Developed Two-Lane Highways by Washburn et al. (*10*)

LOS boundary	Threshold value for percentage of free-flow speed
Boundary between LOS A and B	91.7%
Boundary between LOS B and C	83.3%
Boundary between LOS C and D	75.0%
Boundary between LOS D and E	66.7%
Boundary between LOS E and F	58.3%

major research effort. It is recommended that this facility procedure be capable of addressing any developed urban or suburban nonfreeway facility. The improved facilities procedure should address developed two-lane and multilane facilities and should consider facilities with signal spacing less than 3 kIn (2 mi), facilities with more widely spaced signals, and facilities with no signals.

Two-Lane Highways in Small Towns and Transition Areas

Two-lane highways in small towns and transition areas share some of the characteristics of two-lane highways with continuous development. The presence of reduced speeds and continuous development may change motorists' expectations about the feasibility or desirability of traveling at high speeds.

There are two factors that make these situations different from the continuously developed two-lane highways discussed above. First, if the developed area extends for only a short distance, as in the case of a small town or a highway that touches a fringe area and then departs, motorists on a Class I two-lane highway may have a reasonable expectation of being able to return to Class I conditions in a short distance along the road. In this situation, the analysis of the small town or transition area as a Class IT highway makes sense. However, when the developed area is extended in length or the transition area leads shortly to an urban or suburban arterial, it may be most appropriate to analyze the segment using the procedure presented above for a two-lane highway with continuous development.

Second, if there is, within the small town or transition area, a substantial proportion of local traffic that is circulating within the developed area or generated within a few iniles outside of that area, motorists expectations may be more appropriately evaluated like an urban street (with ATS) than like a two-lane highway (with PTSF).

For these reasons, it is recommended that the HCM present the following recommendations:

- a two-lane highway in an undeveloped area should be evaluated with the procedures of HCM Chapter 20; the highway should be analyzed as either a Class I or Class II highway based on the existing criteria in HCM Chapter 20

- a two-lane highway in a small town or a transition area with reduced speeds should be evaluated as a Class II highway if the developed conditions with reduced speeds extend for a distance of 3 km (2 mi) or less and if the vast majority of the traffic is through traffic that will soon depart the developed area and return to a Class I highway. However, if the developed area extends for more than 3 km (2 mi) or if there is a substantial proportion of local circulating traffic within the developed area, then the modified HCM Chapter 15 procedures described above for two-lane highways with continuous development should be applied.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The findings, conclusions, and recommendations of the research are presented below.

1. The PTSF results from the HCM1997 procedure are, on the average, 3.9 percent lower than PTSF results from the HCM2000 two-way procedure. This difference results from revision to the HCM2000 procedures that appear to make it fit field data better than in the HCM1997 procedure.

2. The LOS thresholds in the HCM2000 procedure were increased by 5 percent for Class I highways and 10 percent for Class II highways in comparison to the comparable thresholds in the HCM1997 procedure.

3. The HCM2000 has introduced a two-lane highway directional segment procedure in the HCM for the first time. Caution should be exercised in comparing the results of the HCM2000 directional segment procedure to results obtained with previous or current two-way segment procedures. It should be recognized that, for any two-lane highway with a directional split of traffic volume other than 50/50, the LOS in the peak direction of travel is likely to be lower than the LOS for the two directions of travel combined.

4. The PTSF results from the HCM1997 two-way segment procedure are, on the average, 15.6 percent lower than the combined two-way PTSF results from the HCM2000 directional segment procedure.

5. The PTSF results from the HCM2002 two-way segment procedure are, on the average, 11.4 percent lower than the combined two-way PTSF results from the HCM2000 directional segment procedure.

6. Conclusions 4 and 5 suggest that the HCM2000 directional segment procedure overestimates PTSF. Investigations in this research have confirmed that this is the case.

7. Revised figures, tables, and equations have been developed for use in the HCM2000 direction segment procedure.

8. The revised directional segment procedure agrees with the HCM2000 two-way segment procedure within 0.1 percent, on the average. In 90 percent of cases, the two procedures differ by less than 0.3 percent. The maximum difference found was 2.2 percent. Thus, the revised directional segment procedure will provide PTSF and service volume estimates that are in close agreement with those from the HCM2000 two-way segment procedure. The revised directional segment procedure will still provide PTSF estimates that are, on the average, 3.8 percent

1. Existing HCM procedures for directional segments on two-lane highways should be revised as discussed in Chapter 2 and as summarized in Appendix B.

2. In situations where a two-lane highway has continuous development to the point that PTSF is no longer an appropriate service measure, it is recommended that the site be considered an urban street rather than a two-lane highway. Analysis procedures for developed two-lane highways fall more naturally in HCM Chapter 15 or in a new arterial facilities chapter than in HCM Chapter 20.

3. The addition to HCM Chapter 15 of a procedure to address two-lane highways with continuous development but widely spaced signals or no signals is recommended. Recommendations for a portion of this procedure that can be based on existing HCM procedures are discussed in Chapter 3 and summarized in Appendix C. The remainder of this procedure will require further research.

4. As an alternative to Recommendation 3, the analysis of developed two-lane highways with and without signals and the development of developed multilane arterials could be addressed in a new arterial facilities chapter in the HCM. Such a chapter should be capable of addressing traffic operations for facilities composed of highway segments between intersections (including the operational effects of driveways), unsignalized intersections, and signalized intersections.

5. A two-lane highway segment in a small town or a transition area with reduced speeds should be evaluated as a Class II highway if the developed conditions with reduced speeds extend for a distance of 3 km (2 mi) or less and if the vast majority of the traffic is through traffic that will soon depart the developed area and return to a Class I highway. However, if the developed area extends for more than 3 km (2 mi) or if there is a substantial proportion of local circulating traffic within the developed area, then the modified HCM Chapter 15 procedures

described in Recommendation 3 for two-lane highways with continuous development or a new arterial facilities procedure described in Recommendation 4 should be applied.

6. As noted in Recommendation 5, there are situations in small towns and transition areas where the perception of LOS by through motorists and local circulating motorists may differ. Most analysts assume that on a major intercity highway the viewpoint of the through motorist should take precedence; but, where the through highway is also a major local thoroughfare, the local perspective has merit as well. This issue of differing viewpoints toward LOS, and the possibility of assessing the LOS of a given facility from more than one viewpoint, should be considered.

7. Research to develop a comprehensive operational analysis procedure for developed two-lane highways is recommended. Such a procedure could be based on either Recommendation 3 or 4 presented above, or some combination of both concepts. NCHRP Project 3-79, *Estimating and Measuring Urban Traffic Speed and Level of Service*, is about to begin, and this research may contribute to a better understanding of speeds on two-lane urban streets. A major research effort that specifically addresses operational analysis procedures for developed two-lane highways is also recommended.

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APPEND IX A

COMPARISON OF EXISTING AND REVISED HCM PROCEDURE

Table A-1 presents a comparison of the PTSF values for existing and revised procedures including:

- the two-way segment operational analysis procedure from the HCM1997 (*2,3*)
- the two-way segment operational analysis procedure from the HCM2000 (*1*)
- the combined two-way results of the directional segment operational analysis procedure in the HCM2000 (*1*)
- the combined two-way results of the revised directional segment operational analysis procedure developed for this report

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h) Direction 1	PTSF (d2)	HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional) PTSF Direction 1	PTSF Direction 2	PTSF Combined	Revised HCM2000 (Directional) PTSF Direction 1	PTSF Direction 2	PTSF Combined	Differences in PTSF for both directions of travel combined: HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
200	50	0	100	100	14.3	16.1	33.0	33.0	33.0	16.1	16.1	16.1	1.8	18.7	1.8	16.9	0.0	-16.9
200	60	0	120	80	15.2	17.7	35.7	30.6	33.7	20.3	13.9	17.7	2.5	18.5	2.5	16.0	0.0	-15.9
200	70	0	140	60	16.1	18.9	38.1	27.8	35.0	22.7	10.2	18.9	2.8	18.9	2.8	16.1	0.0	-16.1
200	80	0	160	40	17.2	21.2	40.4	24.4	37.2	24.9	6.7	21.2	4.0	20.0	4.0	16.0	0.0	-16.0
200	90	0	180	20	19.0	21.7	42.5	20.0	40.3	23.8	3.0	21.7	2.7	21.3	2.7	18.6	0.0	-18.5
400	50	0	200	200	28.6	29.6	47.6	47.6	47.6	29.6	29.6	29.6	1.0	19.0	1.0	18.0	0.0	-18.0
400	60	0	240	160	30.2	30.1	50.0	52.3	50.9	34.6	23.5	30.1	-0.1	20.7	−0.1	20.8	0.0	−20.8
400	70	0	280	120	31.3	30.7	51.9	51.0	51.6	36.8	16.5	30.7	−0.6	20.3	−0.6	20.9	0.0	−20.9
400	80	0	320	80	32.8	32.1	54.2	45.8	52.5	37.7	10.3	32.2	−0.7	19.7	−0.6	20.4	0.1	−20.3
400	90	0	360	40	35.1	32.0	56.9	36.9	54.9	35.2	4.6	32.1	−3.1	19.8	−3.0	22.9	0.1	−22.8
600	50	0	300	300	38.0	41.0	70.3	70.3	70.3	41.0	41.0	41.0	3.0	32.3	3.0	29.3	0.0	−29.3
600	60	0	360	240	39.7	41.0	69.9	65.1	68.0	47.2	31.7	41.0	1.3	28.3	1.3	27.0	0.0	−27.0
600	70	0	420	180	41.3	41.0	62.9	59.2	61.8	49.2	21.8	41.0	−0.3	20.5	−0.3	20.8	0.0	−20.8
600	80	0	480	120	43.5	41.0	64.2	54.9	62.3	47.9	13.4	41.0	−2.5	18.8	−2.5	21.3	0.0	−21.3
600	90	0	540	60	46.5	41.0	66.5	46.2	64.5	45.0	6.3	41.1	−5.5	18.0	−5.4	23.5	0.1	−23.4
800	50	0	400	400	46.5	50.5	72.0	72.0	72.0	50.5	50.5	50.5	4.0	25.5	4.0	21.5	0.0	−21.5
800	60	0	480	320	48.2	50.5	79.9	70.8	76.3	57.5	40.1	50.5	2.3	28.1	2.3	25.8	0.0	−25.7
800	70	0	560	240	49.8	50.5	80.1	66.9	76.1	60.1	28.1	50.5	0.7	26.3	0.7	25.6	0.0	−25.7
800	80	0	640	160	52.0	50.5	72.5	62.9	70.6	58.9	17.4	50.6	−1.5	18.6	−1.4	20.1	0.1	−20.0
800	90	0	720	80	55.4	50.5	73.5	56.1	71.8	55.2	8.4	50.6	−4.9	16.4	−4.8	21.3	0.1	−21.2
1000	50	0	500	500	53.2	58.5	78.3	78.3	78.3	58.3	58.3	58.3	5.3	25.1	5.1	19.8	−0.2	−20.0
1000	60	0	600	400	55.3	58.5	79.1	74.6	77.3	65.6	47.8	58.5	3.2	22.0	3.2	18.8	0.0	−18.8
1000	70	0	700	300	57.3	58.5	87.7	73.8	83.5	68.7	34.5	58.4	1.2	26.2	1.1	25.0	−0.1	−25.1
1000	80	0	800	200	60.0	58.5	79.2	69.5	77.3	67.8	21.2	58.5	−1.5	17.3	−1.5	18.8	0.0	−18.8
1000	90	0	900	100	63.3	58.5	79.0	66.8	77.8	64.0	10.5	58.6	−4.8	14.5	−4.7	19.3	0.1	−19.2
1200	50	0	600	600	59.9	65.2	80.5	80.5	80.5	65.0	65.0	65.0	5.3	20.6	5.1	15.3	−0.2	−15.5
1200	60	0	720	480	61.9	65.2	83.9	80.3	82.5	72.5	54.2	65.2	3.3	20.6	3.3	17.3	0.0	−17.3
1200	70	0	840	360	63.7	65.2	88.3	79.1	85.5	75.7	40.6	65.1	1.5	21.8	1.4	20.3	−0.1	−20.4
1200	80	0	960	240	66.2	65.2	91.7	77.9	88.9	74.7	25.6	64.9	−1.0	22.7	−1.3	23.7	−0.3	−24.0
1200	90	0	1080	120	70.1	65.2	83.9	73.6	82.9	70.9	14.7	65.3	−4.9	12.8	−4.8	17.7	0.1	−17.6
1400	50	0	700	700	65.0	70.8	84.9	84.9	84.9	70.8	70.8	70.8	5.8	19.9	5.8	14.1	0.0	−14.1
1400	60	0	840	560	67.3	70.8	85.8	83.9	85.0	78.1	59.8	70.8	3.5	17.7	3.5	14.2	0.0	−14.2
1400	70	0	980	420	69.4	70.8	87.8	83.3	86.5	81.4	46.2	70.8	1.4	17.1	1.4	15.7	0.0	−15.7

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h) Direction 1	PTSF (d2)	HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional) PTSF Direction 1	HCM2000 (Directional) PTSF Direction 2	HCM2000 (Directional) PTSF Combined	Revised HCM2000 (Directional) PTSF Direction 1	Revised HCM2000 (Directional) PTSF Direction 2	Revised HCM2000 (Directional) PTSF Combined	Differences in PTSF for both directions of travel combined: HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs revised)
1400	80	0	1120	280	72.3	70.8	96.2	81.8	93.3	80.6	31.9	70.9	−1.5	21.0	−1.4	22.5	0.1	−22.5
1400	90	0	1260	140	76.9	70.8	88.0	78.2	87.0	76.3	19.7	70.7	−6.1	10.1	−6.2	16.2	−0.1	−16.4
1600	50	0	800	800	70.1	75.5	86.0	86.0	86.0	75.5	75.5	75.5	5.4	15.9	5.4	10.5	0.0	−10.5
1600	60	0	960	640	72.7	75.5	87.9	86.9	87.5	82.6	64.6	75.4	2.8	14.8	2.7	12.0	−0.1	−12.1
1600	70	0	1120	480	75.1	75.5	90.3	86.0	89.0	86.0	50.7	75.4	0.4	13.9	0.3	13.5	−0.1	−13.6
1600	80	0	1280	320	78.4	75.5	97.3	84.7	94.8	85.1	39.1	75.9	−2.9	16.4	−2.5	19.3	0.4	−18.9
1600	90	0	1440	160	83.5	75.5	91.5	82.1	90.6	80.1	22.6	74.3	−8.0	7.1	−9.2	15.1	−1.2	−16.3
1800	50	0	900	900	75.2	79.4	89.5	89.5	89.5	79.4	79.4	79.4	4.2	14.3	4.2	10.1	0.0	−10.1
1800	60	0	1080	720	78.0	79.4	89.7	88.5	89.2	86.5	68.4	79.3	1.4	11.2	1.3	9.8	−0.1	−9.9
1800	70	0	1260	540	80.7	79.4	91.4	88.0	90.4	89.4	57.9	80.0	−1.3	9.7	−0.7	11.0	0.6	−10.4
1800	80	0	1440	360	84.3	79.4	96.5	87.3	94.7	88.3	43.4	79.4	−4.9	10.4	−4.9	15.3	0.0	−15.3
2000	50	0	1000	1000	80.2	82.8	90.0	90.0	90.0	82.8	82.8	82.8	2.6	9.8	2.6	7.2	0.0	−7.2
2000	60	0	1200	800	83.3	82.8	90.0	89.8	89.9	89.7	72.2	82.7	−0.5	6.6	−0.6	7.1	−0.1	−7.2
2000	70	0	1400	600	86.3	82.8	91.5	89.7	91.0	91.9	61.4	82.8	−3.5	4.7	−3.5	8.2	0.0	−8.2
2000	80	0	1600	400	90.3	82.8	94.4	89.4	93.4	90.8	46.7	82.0	−7.5	3.1	−8.3	10.6	−0.8	−11.4
2200	50	0	1100	1100	85.1	85.5	91.4	91.4	91.4	85.7	85.7	85.7	0.4	6.3	0.6	5.9	0.2	−5.7
2200	60	0	1320	880	88.6	85.5	92.4	91.3	92.0	91.9	77.1	86.0	−3.1	3.4	−2.6	6.5	0.5	−6.0
2200	70	0	1540	660	91.9	85.5	93.3	91.4	92.7	94.3	65.6	85.7	−6.4	0.8	−6.2	7.2	0.2	−7.1
2400	50	0	1200	1200	90.1	87.9	92.0	92.0	92.0	88.1	88.1	88.1	−2.2	1.9	−2.0	4.1	0.2	−3.9
2400	60	0	1440	960	93.9	87.9	92.8	92.5	92.7	93.6	80.1	88.2	−6.0	−1.2	−5.7	4.8	0.3	−4.5
2600	50	0	1300	1300	95.0	89.8	93.1	93.1	93.1	89.8	89.8	89.8	−5.2	−1.9	−5.2	3.3	0.0	−3.3
2600	60	0	1560	1040	99.2	89.8	93.1	93.4	93.2	94.8	82.3	89.8	−9.4	−6.0	−9.4	3.4	0.0	−3.4
2800	50	0	1400	1400	100.0	91.5	93.8	93.8	93.8	91.6	91.6	91.6	−8.5	−6.2	−8.4	2.3	0.1	−2.2
3000	50	0	1500	1500		92.8	94.6	94.6	94.6	93.1	93.1	93.1				1.8	0.3	−1.5
3200	50	0	1600	1600		94.0	95.0	95.0	95.0	94.0	94.0	94.0				1.0	0.0	−1.0
200	50	20	100	100	17.9	26.2	33.0	33.0	33.0	26.2	26.2	26.2	8.3	15.1	8.3	6.8	0.0	−6.8
200	60	20	120	80	19.0	27.9	35.7	30.6	33.7	32.1	21.7	27.9	8.9	14.7	8.9	5.8	0.0	−5.7
200	70	20	140	60	20.1	29.5	38.1	27.8	35.0	35.4	15.7	29.5	9.4	14.9	9.4	5.5	0.0	−5.5
200	80	20	160	40	21.5	33.6	40.4	24.4	37.2	39.4	10.4	33.6	12.1	15.7	12.1	3.6	0.0	−3.6
200	90	20	180	20	23.8	37.7	42.5	20.0	40.3	41.4	5.0	37.7	13.9	16.5	13.9	2.6	0.0	−2.5
400	50	20	200	200	32.9	42.0	47.6	47.6	47.6	42.0	42.0	42.0	9.1	14.7	9.1	5.6	0.0	−5.6
400	60	20	240	160	34.0	41.3	50.0	52.3	50.9	47.5	32.1	41.4	7.3	16.9	7.4	9.6	0.1	−9.6
400	70	20	280	120	35.1	42.1	51.9	51.0	51.6	50.6	22.4	42.2	7.0	16.5	7.1	9.5	0.1	−9.5
400	80	20	320	80	36.5	45.4	54.2	45.8	52.5	53.3	14.2	45.4	8.9	16.0	8.9	7.1	0.0	−7.1

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
400	90	20	360	40	38.8	48.6	56.9	36.9	54.9	53.3	6.6	48.6	9.8	16.1	9.8	6.3	0.0	−6.3
600	50	20	300	300	41.8	52.2	70.3	70.3	70.3	52.2	52.2	52.2	10.4	28.5	10.4	18.1	0.0	−18.1
600	60	20	360	240	43.5	52.5	69.9	65.1	68.0	60.5	40.5	52.5	9.0	24.5	9.0	15.5	0.0	−15.5
600	70	20	420	180	45.1	52.6	62.9	59.2	61.8	63.2	27.8	52.6	7.5	16.7	7.5	9.2	0.0	−9.2
600	80	20	480	120	46.8	55.0	64.2	54.9	62.3	64.3	17.5	55.0	8.2	15.5	8.2	7.3	0.0	−7.4
600	90	20	540	60	49.6	57.3	66.5	46.2	64.5	62.8	8.3	57.3	7.7	14.9	7.7	7.2	0.0	−7.1
800	50	20	400	400	49.6	59.5	72.0	72.0	72.0	59.5	59.5	59.5	9.9	22.4	9.9	12.5	0.0	−12.5
800	60	20	480	320	51.4	58.1	79.9	70.8	76.3	66.3	45.9	58.1	6.7	24.9	6.7	18.2	0.0	−18.1
800	70	20	560	240	53.1	58.2	80.1	66.9	76.1	69.4	32.1	58.2	5.1	23.0	5.1	17.9	0.0	−18.0
800	80	20	640	160	55.4	59.8	72.5	62.9	70.6	69.7	20.1	59.8	4.4	15.2	4.4	10.8	0.0	−10.8
800	90	20	720	80	59.1	61.4	73.5	56.1	71.8	67.1	9.7	61.4	2.3	12.7	2.3	10.4	0.0	−10.4
1000	50	20	500	500	56.7	65.7	78.3	78.3	78.3	65.5	65.5	65.5	9.0	21.6	8.8	12.6	−0.2	−12.8
1000	60	20	600	400	59.0	64.8	79.1	74.6	77.3	72.9	52.7	64.8	5.8	18.3	5.8	12.5	0.0	−12.5
1000	70	20	700	300	60.7	64.9	87.7	73.8	83.5	76.4	37.8	64.8	4.2	22.8	4.1	18.6	−0.1	−18.7
1000	80	20	800	200	62.6	66.2	79.2	69.5	77.3	76.8	23.4	66.1	3.6	14.7	3.5	11.1	−0.1	−11.2
1000	90	20	900	100	65.6	67.6	79.0	66.8	77.8	74.0	11.6	67.7	2.0	12.2	2.1	10.2	0.1	−10.1
1200	50	20	600	600	62.5	70.0	80.5	80.5	80.5	70.4	70.4	70.4	7.5	18.0	7.9	10.5	0.4	−10.1
1200	60	20	720	480	64.3	70.2	83.9	80.3	82.5	78.3	58.0	70.2	5.9	18.2	5.9	12.3	0.0	−12.3
1200	70	20	840	360	66.0	70.3	88.3	79.1	85.5	81.8	43.2	70.2	4.3	19.5	4.2	15.2	−0.1	−15.3
1200	80	20	960	240	68.2	71.4	91.7	77.9	88.9	81.9	27.4	71.0	3.2	20.7	2.8	17.5	−0.4	−17.9
1200	90	20	1080	120	71.8	72.5	83.9	73.6	82.9	79.0	15.6	72.7	0.7	11.1	0.9	10.4	0.2	−10.2
1400	50	20	700	700	67.2	74.4	84.9	84.9	84.9	74.4	74.4	74.4	7.2	17.7	7.2	10.5	0.0	−10.5
1400	60	20	840	560	69.3	74.5	85.8	83.9	85.0	82.4	62.6	74.5	5.2	15.7	5.2	10.5	0.0	−10.6
1400	70	20	980	420	71.2	74.6	87.8	83.3	86.5	85.9	48.1	74.6	3.4	15.3	3.4	11.9	0.0	−11.9
1400	80	20	1120	280	73.9	75.4	96.2	81.8	93.3	86.0	33.2	75.4	1.5	19.4	1.5	17.9	0.0	−17.9
1400	90	20	1260	140	78.1	76.3	88.0	78.2	87.0	82.6	20.4	76.4	−1.8	8.9	−1.7	10.7	0.1	−10.6
1600	50	20	800	800	71.8	78.5	86.0	86.0	86.0	78.5	78.5	78.5	6.7	14.2	6.7	7.5	0.0	−7.5
1600	60	20	960	640	74.2	78.7	87.9	86.9	87.5	86.4	67.1	78.7	4.5	13.3	4.5	8.8	0.0	−8.8
1600	70	20	1120	480	76.5	78.5	90.3	86.0	89.0	89.5	52.2	78.3	2.0	12.5	1.8	10.5	−0.2	−10.7
1600	80	20	1280	320	79.5	79.4	97.3	84.7	94.8	89.9	40.3	80.0	−0.1	15.3	0.5	15.4	0.6	−14.8
1600	90	20	1440	160	84.3	81.0	91.5	82.1	90.6	86.4	23.3	80.0	−3.3	6.3	−4.3	9.6	−1.0	−10.5
1800	50	20	900	900	76.5	81.8	89.5	89.5	89.5	81.8	81.8	81.8	5.3	13.0	5.3	7.7	0.0	−7.7
1800	60	20	1080	720	79.2	82.2	89.7	88.5	89.2	89.7	70.6	82.0	3.0	10.0	2.8	7.0	−0.2	−7.2
1800	70	20	1260	540	81.7	81.6	91.4	88.0	90.4	92.1	59.0	82.2	−0.1	8.7	0.5	8.8	0.6	−8.2

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
1600	80	20	1440	360	85.2	82.5	96.5	87.3	94.7	92.6	44.5	83.0	−2.7	9.5	−2.2	12.2	0.5	−11.7
2000	50	20	1000	1000	81.2	84.6	90.0	90.0	90.0	84.6	84.6	84.6	3.4	8.8	3.4	5.4	0.0	−5.4
2000	60	20	1200	800	84.2	85.1	90.0	89.8	89.9	92.4	74.0	85.1	0.9	5.7	0.9	4.8	0.0	−4.8
2000	70	20	1400	600	87.0	84.2	91.5	89.7	91.0	93.6	62.1	84.2	−2.8	4.0	−2.8	6.8	0.0	−6.8
2000	80	20	1600	400	90.8	85.2	94.4	89.4	93.4	94.5	47.6	85.1	−5.6	2.6	−5.7	8.2	−0.1	−8.3
2200	50	20	1100	1100	85.9	87.1	91.4	91.4	91.4	87.2	87.2	87.2	1.2	5.5	1.3	4.3	0.1	−4.2
2200	60	20	1320	880	89.2	87.3	92.4	91.3	92.0	94.0	78.5	87.8	−1.9	2.8	−1.4	4.7	0.5	−4.1
2200	70	20	1540	660	92.3	86.9	93.3	91.4	92.7	96.0	66.3	87.1	−5.4	0.4	−5.2	5.8	0.2	−5.7
2400	50	20	1200	1200	90.6	89.2	92.0	92.0	92.0	89.5	89.5	89.5	−1.4	1.4	−1.1	2.8	0.3	−2.5
2400	60	20	1440	960	94.2	89.3	92.8	92.5	92.7	95.2	81.2	89.6	−4.9	−1.5	−4.6	3.4	0.3	−3.1
2600	50	20	1300	1300	95.3	90.9	93.1	93.1	93.1	90.9	90.9	90.9	−4.4	−2.2	−4.4	2.2	0.0	−2.2
2600	60	20	1560	1040	99.2	90.7	93.1	93.4	93.2	95.9	83.1	90.7	−8.5	−6.0	−8.5	2.5	0.0	−2.5
2800	50	20	1400	1400	100.0	92.5	93.8	93.8	93.8	92.6	92.6	92.6	−7.5	−6.2	−7.4	1.3	0.1	−1.2
3000	50	20	1500	1500		93.6	94.6	94.6	94.6	94.0	94.0	94.0				1.0	0.4	−0.6
3200	50	20	1600	1600		94.7	95.0	95.0	95.0	94.7	94.7	94.7				0.3	0.0	−0.3
200	50	40	100	100	23.8	33.3	39.5	39.5	39.5	33.3	33.3	33.3	9.5	15.7	9.5	6.2	0.0	−6.2
200	60	40	120	80	25.3	33.3	42.2	37.1	40.2	38.3	25.9	33.3	8.0	14.9	8.0	6.9	0.0	−6.8
200	70	40	140	60	26.8	35.2	44.6	34.4	41.5	42.4	18.6	35.2	8.4	14.7	8.4	6.3	0.0	−6.3
200	80	40	160	40	28.7	40.4	46.9	31.0	43.7	47.4	12.4	40.4	11.7	15.0	11.7	3.3	0.0	−3.3
200	90	40	180	20	30.7	45.5	49.0	26.7	46.8	49.9	5.9	45.5	14.8	16.1	14.8	1.3	0.0	−1.3
400	50	40	200	200	36.6	48.6	54.3	54.3	54.3	48.6	48.6	48.6	12.0	17.7	12.0	5.7	0.0	−5.7
400	60	40	240	160	37.7	45.8	56.6	58.4	57.3	52.7	35.5	45.8	8.1	19.6	8.1	11.5	0.0	−11.5
400	70	40	280	120	38.8	46.9	58.5	56.4	57.9	56.4	24.9	46.9	8.1	19.1	8.1	11.0	0.0	−11.0
400	80	40	320	80	40.3	51.1	60.7	50.6	58.7	60.0	15.8	51.1	10.8	18.4	10.8	7.6	0.0	−7.5
400	90	40	360	40	42.6	55.2	63.4	41.0	61.2	60.6	7.4	55.3	12.6	18.6	12.7	6.0	0.1	−5.9
600	50	40	300	300	45.4	57.0	75.4	75.4	75.4	57.0	57.0	57.0	11.6	30.0	11.6	18.4	0.0	−18.4
600	60	40	360	240	46.8	56.2	75.9	69.2	73.2	64.7	43.4	56.2	9.4	26.4	9.4	17.0	0.0	−17.0
600	70	40	420	180	48.1	56.4	69.6	62.6	67.5	67.8	29.8	56.4	8.3	19.4	8.3	11.1	0.0	−11.1
600	80	40	480	120	49.8	59.6	70.8	57.9	68.2	69.8	18.9	59.6	9.8	18.4	9.8	8.6	0.0	−8.6
600	90	40	540	60	52.6	62.8	73.0	49.0	70.6	68.8	8.9	62.8	10.2	18.0	10.2	7.8	0.0	−7.8
800	50	40	400	400	52.6	62.8	75.5	75.5	75.5	62.8	62.8	62.8	10.2	22.9	10.2	12.7	0.0	−12.7
800	60	40	480	320	54.4	60.8	84.7	73.8	80.3	69.4	48.0	60.8	6.4	25.9	6.4	19.5	0.0	−19.5
800	70	40	560	240	56.1	61.0	86.1	69.5	81.1	72.7	33.5	61.0	4.9	25.0	4.9	20.1	0.0	−20.1
800	80	40	640	160	58.4	63.2	79.1	65.2	76.3	73.7	21.1	63.2	4.8	17.9	4.8	13.1	0.0	−13.1

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
800	90	40	720	80	61.3	65.3	80.0	58.1	77.8	71.4	10.2	65.3	4.0	16.5	4.0	12.5	0.0	−12.5
1000	50	40	500	500	59.7	68.5	81.3	81.3	81.3	68.3	68.3	68.3	8.8	21.6	8.6	12.8	−0.2	−13.0
1000	60	40	600	400	61.2	67.2	82.6	77.0	80.4	75.6	54.5	67.2	6.0	19.2	6.0	13.2	0.0	−13.2
1000	70	40	700	300	62.6	67.4	92.8	75.9	87.7	79.4	39.1	67.3	4.8	25.1	4.7	20.3	−0.1	−20.4
1000	80	40	800	200	64.4	69.2	85.9	71.2	83.0	80.3	24.3	69.1	4.8	18.6	4.7	13.8	−0.1	−13.9
1000	90	40	900	100	67.3	71.0	85.5	68.3	83.8	77.7	12.1	71.2	3.7	16.5	3.9	12.8	0.2	−12.6
1200	50	40	600	600	64.3	73.0	82.9	82.9	82.9	72.7	72.7	72.7	8.7	18.6	8.4	9.9	−0.3	−10.2
1200	60	40	720	480	66.0	72.2	87.0	82.3	85.1	80.6	59.6	72.2	6.2	19.1	6.2	12.9	0.0	−12.9
1200	70	40	840	360	67.6	72.4	92.4	80.7	88.9	84.4	44.3	72.3	4.8	21.3	4.7	16.5	−0.1	−16.6
1200	80	40	960	240	69.8	73.9	97.8	79.2	94.1	84.9	28.1	73.5	4.1	24.3	3.7	20.2	−0.4	−20.6
1200	90	40	1080	120	73.2	75.3	90.4	74.6	88.6	82.2	15.9	75.6	2.1	15.6	2.4	13.5	0.3	−13.3
1400	50	40	700	700	68.8	76.3	86.9	86.9	86.9	76.3	76.3	76.3	7.5	18.1	7.5	10.6	0.0	−10.6
1400	60	40	840	560	70.7	76.2	88.5	85.5	87.3	84.4	63.9	76.2	5.5	16.6	5.5	11.1	0.0	−11.1
1400	70	40	980	420	72.6	76.4	91.2	84.5	89.2	88.1	49.1	76.4	3.8	16.6	3.8	12.8	0.0	−12.8
1400	80	40	1120	280	75.2	77.5	100.0	62.7	96.5	88.4	33.9	77.5	2.3	21.3	2.3	19.0	0.0	−19.0
1400	90	40	1260	140	79.2	78.6	94.6	78.9	93.0	85.1	20.7	78.7	−0.6	13.8	−0.5	14.4	0.1	−14.3
1600	50	40	800	800	73.2	80.1	87.7	87.7	87.7	80.1	80.1	80.1	6.9	14.5	6.9	7.6	0.0	−7.6
1600	60	40	960	640	75.5	80.2	90.2	88.2	89.4	88.1	68.3	80.2	4.7	13.9	4.7	9.2	0.0	−9.2
1600	70	40	1120	480	77.6	80.9	93.4	86.9	91.5	92.4	53.5	80.7	3.3	13.9	3.1	10.6	−0.2	−10.7
1600	80	40	1280	320	80.5	81.1	100.0	85.3	97.1	92.0	40.9	81.7	0.6	16.6	1.2	16.0	0.6	−15.3
1600	90	40	1440	160	85.1	83.3	98.1	82.6	96.6	88.9	23.6	82.3	−1.8	11.5	−2.8	13.3	−1.0	−14.2
1800	50	40	900	900	77.7	83.2	91.0	91.0	91.0	83.6	83.6	83.6	5.5	13.3	5.9	7.8	0.4	−7.4
1800	60	40	1080	720	80.2	83.4	91.7	89.5	90.8	91.2	71.6	83.3	3.2	10.6	3.1	7.4	−0.1	−7.5
1800	70	40	1260	540	82.6	84.5	94.1	88.6	92.5	95.6	60.5	85.1	1.9	9.9	2.5	8.0	0.6	−7.4
1800	80	40	1440	360	85.9	83.9	100.0	87.8	97.6	94.2	44.9	84.4	−2.0	11.7	−1.5	13.7	0.5	−13.2
2000	50	40	1000	1000	82.1	85.7	91.2	91.2	91.2	85.7	85.7	85.7	3.6	9.1	3.6	5.5	0.0	−5.5
2000	60	40	1200	800	85.0	86.2	91.7	90.5	91.2	93.7	74.9	86.2	1.2	6.2	1.2	5.0	0.0	−5.0
2000	70	40	1400	600	87.7	87.7	93.9	90.2	92.8	97.8	63.9	87.7	0.0	5.1	0.0	5.1	0.0	−5.1
2000	80	40	1600	400	91.3	86.2	97.9	89.7	96.3	95.7	47.9	86.2	−5.1	5.0	−5.1	10.1	0.0	−10.1
2200	50	40	1100	1100	86.6	88.0	92.3	92.3	92.3	88.1	88.1	88.1	1.4	5.7	1.5	4.3	0.1	−4.2
2200	60	40	1320	880	89.7	88.2	93.9	91.9	93.1	95.1	79.2	88.7	−1.5	3.4	−1.0	4.9	0.5	−4.4
2200	70	40	1540	660	92.7	90.4	95.5	91.8	94.4	100.2	68.1	90.5	−2.3	1.7	−2.2	4.0	0.1	−3.8
2400	50	40	1200	1200	91.1	89.9	92.7	92.7	92.7	90.2	90.2	90.2	−1.2	1.6	−0.9	2.8	0.3	−2.5
2400	60	40	1440	960	94.5	89.9	94.1	92.9	93.6	96.0	81.7	90.3	−4.6	−0.9	−4.2	3.7	0.4	−3.3

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h) Direction 1	Directional flow rate (pc/h) PTSF (d2)	HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional) PTSF Direction 1	HCM2000 (Directional) PTSF Direction 2	HCM2000 (Directional) PTSF Combined	Revised HCM2000 (Directional) PTSF Direction 1	Revised HCM2000 (Directional) PTSF Direction 2	Revised HCM2000 (Directional) PTSF Combined	Differences in PTSF for both directions of travel combined: HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs revised)
2600	50	40	1300	1300	95.5	91.4	93.7	93.7	93.7	91.4	91.4	91.4	−4.1	−1.8	−4.1	2.3	0.0	−2.3
2600	60	40	1560	1040	99.2	91.2	94.2	93.8	94.0	96.4	83.4	91.2	−8.0	−5.2	−8.0	2.8	0.0	−2.8
2800	50	40	1400	1400	100.0	92.9	94.3	94.3	94.3	93.0	93.0	93.0	−7.1	−5.7	−7.0	1.4	0.1	−1.3
3000	50	40	1500	1500		93.9	95.0	95.0	95.0	94.4	94.4	94.4				1.1	0.5	−0.6
3200	50	40	1600	1600		94.9	95.3	95.3	95.3	94.9	94.9	94.9				0.4	0.0	−0.4
200	50	60	100	100	30.2	36.3	45.5	45.5	45.5	36.3	36.3	36.3	6.1	15.3	6.1	9.2	0.0	−9.2
200	60	60	120	80	30.7	38.6	48.2	43.1	46.2	44.4	30.0	38.6	7.9	15.5	7.9	7.6	0.0	−7.5
200	70	60	140	60	31.3	40.9	50.6	40.3	47.5	49.2	21.6	40.9	9.6	16.2	9.6	6.6	0.0	−6.6
200	80	60	160	40	32.0	47.1	52.9	37.0	49.7	55.3	14.3	47.1	15.1	17.7	15.1	2.6	0.0	−2.6
200	90	60	180	20	33.2	53.3	55.0	32.6	52.8	58.5	6.9	53.3	20.1	19.6	20.1	−0.5	0.0	0.5
400	50	60	200	200	39.1	52.3	60.2	60.2	60.2	52.3	52.3	52.3	13.2	21.1	13.2	7.9	0.0	−7.9
400	60	60	240	160	40.2	50.3	62.5	63.6	62.9	57.9	39.0	50.3	10.1	22.7	10.1	12.6	0.0	−12.6
400	70	60	280	120	41.3	51.6	64.5	61.0	63.5	62.1	27.3	51.7	10.3	22.2	10.4	11.9	0.1	−11.8
400	80	60	320	80	42.8	56.7	66.7	54.6	64.3	66.5	17.5	56.7	13.9	21.5	13.9	7.6	0.0	−7.6
400	90	60	360	40	45.0	61.8	69.4	44.4	66.9	67.8	8.2	61.8	16.8	21.9	16.8	5.1	0.0	−5.1
600	50	60	300	300	47.4	59.7	79.7	79.7	79.7	59.7	59.7	59.7	12.3	32.3	12.3	20.0	0.0	−20.0
600	60	60	360	240	48.8	59.9	81.2	72.6	77.8	69.0	46.2	59.9	11.1	29.0	11.1	17.9	0.0	−17.9
600	70	60	420	180	50.1	60.1	75.5	65.2	72.4	72.2	31.6	60.1	10.0	22.3	10.0	12.3	0.0	−12.3
600	80	60	480	120	51.8	64.2	76.8	60.4	73.5	75.2	20.2	64.2	12.4	21.7	12.4	9.3	0.0	−9.3
600	90	60	540	60	54.6	68.2	74.2	11.3	67.9	74.7	9.6	68.2	13.6	13.3	13.6	−0.3	0.0	0.3
800	50	60	400	400	54.6	64.6	78.2	78.2	78.2	64.6	64.6	64.6	10.0	23.6	10.0	13.6	0.0	−13.6
800	60	60	480	320	56.4	63.5	88.7	76.3	83.7	72.5	50.1	63.5	7.1	27.3	7.1	20.2	0.0	−20.2
800	70	60	560	240	58.1	63.8	91.4	71.6	85.5	76.2	35.0	63.8	5.7	27.4	5.7	21.7	0.0	−21.7
800	80	60	640	160	60.3	66.5	85.1	67.1	81.5	77.6	22.1	66.5	6.2	21.2	6.2	15.0	0.0	−15.0
800	90	60	720	80	62.5	69.1	86.0	59.8	83.4	75.6	10.6	69.1	6.6	20.9	6.6	14.3	0.0	−14.3
1000	50	60	500	500	61.0	70.1	83.7	83.7	83.7	67.9	67.9	67.9	9.1	22.7	6.9	13.6	−2.2	−15.8
1000	60	60	600	400	62.4	69.5	85.3	79.1	82.8	78.3	56.3	69.5	7.1	20.4	7.1	13.3	0.0	−13.3
1000	70	60	700	300	63.7	69.8	97.1	77.6	91.3	82.4	40.4	69.8	6.1	27.6	6.1	21.5	0.0	−21.5
1000	80	60	800	200	65.4	72.1	91.8	72.6	88.0	83.6	25.1	71.9	6.7	22.6	6.5	15.9	−0.2	−16.0
1000	90	60	900	100	68.2	74.2	91.5	69.4	89.3	81.2	12.5	74.4	6.0	21.1	6.2	15.1	0.2	−14.9
1200	50	60	600	600	65.3	74.4	85.0	85.0	85.0	74.1	74.1	74.1	9.1	19.7	8.8	10.6	−0.3	−10.9
1200	60	60	720	480	67.0	74.3	89.4	84.0	87.2	82.9	61.1	74.2	7.3	20.2	7.2	12.9	−0.1	−13.0
1200	70	60	840	360	68.5	74.6	95.7	82.0	91.6	86.9	45.4	74.5	6.1	23.1	6.0	17.0	−0.1	−17.1
1200	80	60	960	240	70.6	76.3	100.0	80.2	96.0	87.8	28.9	76.0	5.7	25.4	5.4	19.7	−0.3	−20.1

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h) Direction 1	Directional flow rate (pc/h) PTSF (d2)	HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional) PTSF Direction 1	HCM2000 (Directional) PTSF Direction 2	HCM2000 (Directional) PTSF Combined	Revised HCM2000 (Directional) PTSF Direction 1	Revised HCM2000 (Directional) PTSF Direction 2	Revised HCM2000 (Directional) PTSF Combined	Differences in PTSF for both directions of travel combined: HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
1200	90	60	1080	120	73.9	78.1	96.4	75.4	94.3	85.1	16.3	78.2	4.2	20.4	4.3	16.2	0.1	−16.1
1400	50	60	700	700	69.6	77.5	88.7	88.7	88.7	77.5	77.5	77.5	7.9	19.1	7.9	11.2	0.0	−11.2
1400	60	60	840	560	71.5	77.9	90.7	86.8	89.1	86.3	65.2	77.9	6.4	17.6	6.4	11.2	0.0	−11.3
1400	70	60	980	420	73.3	78.2	93.8	85.5	91.3	90.2	50.0	78.2	4.9	18.0	4.9	13.1	0.0	−13.1
1400	80	60	1120	280	75.8	79.5	100.0	83.4	96.7	90.8	34.4	79.5	3.7	20.9	3.7	17.2	0.0	−17.2
1400	90	60	1260	140	79.7	80.8	100.0	79.5	98.0	87.4	21.0	80.7	1.1	18.3	1.0	17.2	−0.1	−17.2
1600	50	60	800	800	73.9	81.2	89.1	89.1	89.1	81.2	81.2	81.2	7.3	15.2	7.3	7.9	0.0	−7.9
1600	60	60	960	640	76.1	81.4	92.2	89.2	91.0	89.4	69.1	81.3	5.3	14.9	5.2	9.6	−0.1	−9.7
1600	70	60	1120	480	78.2	81.6	95.9	87.6	93.4	93.2	53.8	81.4	3.4	15.2	3.2	11.8	−0.2	−12.0
1600	80	60	1280	320	81.0	82.8	100.0	85.9	97.2	93.9	41.3	83.4	1.8	16.2	2.4	14.4	0.6	−13.8
1600	90	60	1440	160	85.5	85.5	100.0	82.9	98.3	91.1	23.8	84.4	0.0	12.8	−1.1	12.8	−1.1	−13.9
1800	50	60	900	900	78.2	84.1	92.1	92.1	92.1	84.1	84.1	84.1	5.9	13.9	5.9	8.0	0.0	−8.0
1800	60	60	1080	720	80.7	84.2	93.4	90.3	92.2	92.0	72.1	84.1	3.5	11.5	3.4	8.0	−0.1	−8.1
1800	70	60	1260	540	83.1	84.2	96.4	89.2	94.2	95.2	60.4	84.8	1.1	11.1	1.7	10.0	0.6	−9.5
1800	80	60	1440	360	86.3	85.3	100.0	88.2	97.6	95.9	45.3	85.7	−1.0	11.3	−0.6	12.3	0.4	−11.9
2000	50	60	1000	1000	82.6	86.5	92.1	92.1	92.1	86.5	86.5	86.5	3.9	9.5	3.9	5.6	0.0	−5.6
2000	60	60	1200	800	85.4	86.4	93.1	91.2	92.3	93.9	76.0	86.4	1.0	6.9	1.0	5.9	0.0	−6.0
2000	70	60	1400	600	88.0	86.3	96.0	90.6	94.4	96.1	63.2	86.3	−1.7	6.4	−1.7	8.1	0.0	−8.1
2000	80	60	1600	400	91.5	87.3	100.0	89.9	98.0	97.0	48.2	87.2	−4.2	6.5	−4.3	10.7	−0.1	−10.7
2200	50	60	1100	1100	86.9	88.6	93.1	93.1	93.1	88.8	88.8	88.8	1.7	6.2	1.9	4.5	0.2	−4.3
2200	60	60	1320	880	90.0	88.5	95.1	92.4	94.0	95.4	79.5	89.0	−1.5	4.0	−1.0	5.5	0.5	−5.0
2200	70	60	1540	660	92.9	89.0	97.3	92.0	95.7	98.5	67.4	89.2	−3.9	2.8	−3.7	6.7	0.2	−6.6
2400	50	60	1200	1200	91.3	90.5	93.4	93.4	93.4	90.7	90.7	90.7	−0.8	2.1	−0.6	2.9	0.2	−2.7
2400	60	60	1440	960	94.6	90.4	95.1	93.3	94.4	96.6	82.1	90.8	−4.2	−0.2	−3.8	4.0	0.4	−3.6
2600	50	60	1300	1300	95.6	91.8	94.3	94.3	94.3	91.8	91.8	91.8	−3.8	−1.3	−3.8	2.5	0.0	−2.5
2600	60	60	1560	1040	99.3	91.7	95.1	94.0	94.7	97.0	83.8	91.7	−7.6	−4.6	−7.6	3.0	0.0	−2.9
2800	50	60	1400	1400	100.0	93.2	94.7	94.7	94.7	93.4	93.4	93.4	−6.8	−5.3	−6.6	1.5	0.2	−1.3
3000	50	60	1500	1500		94.2	95.3	95.3	95.3	94.7	94.7	94.7				1.1	0.5	−0.6
3200	50	60	1600	1600		95.1	95.5	95.5	95.5	95.1	95.1	95.1				0.4	0.0	−0.4
200	50	80	100	100	32.7	37.1	47.4	47.4	47.4	37.1	37.1	37.1	4.4	14.7	4.4	10.3	0.0	−10.3
200	60	80	120	80	33.2	39.2	50.1	45.0	48.1	45.1	30.4	39.2	6.0	14.9	6.0	8.9	0.0	−8.8
200	70	80	140	60	33.8	41.3	52.5	42.3	49.4	49.7	21.8	41.3	7.5	15.6	7.5	8.1	0.0	−8.1
200	80	80	160	40	34.5	47.4	54.8	39.0	51.6	55.7	14.4	47.4	12.9	17.1	12.9	4.2	0.0	−4.2
200	90	80	180	20	35.7	53.5	56.9	34.7	54.7	58.7	6.9	53.5	17.8	19.0	17.8	1.2	0.0	−1.1

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h) Direction 1	Directional flow rate (pc/h) PTSF (d2)	HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional) PTSF Direction 1	HCM2000 (Directional) PTSF Direction 2	HCM2000 (Directional) PTSF Combined	Revised HCM2000 (Directional) PTSF Direction 1	Revised HCM2000 (Directional) PTSF Direction 2	Revised HCM2000 (Directional) PTSF Combined	Differences in PTSF for both directions of travel combined: HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
400	50	80	200	200	41.6	53.4	62.3	62.3	62.3	53.4	53.4	53.4	11.8	20.7	11.8	8.9	0.0	−8.9
400	60	80	240	160	42.7	51.1	64.5	65.5	64.9	58.8	39.6	51.1	8.4	22.2	8.4	13.8	0.0	−13.8
400	70	80	280	120	43.8	52.2	66.4	62.7	65.3	62.8	27.6	52.3	8.4	21.5	8.5	13.1	0.1	−13.0
400	80	80	320	80	45.2	57.2	68.6	56.1	66.1	67.2	17.6	57.3	12.0	20.9	12.1	8.9	0.1	−8.8
400	90	80	360	40	46.9	62.1	71.3	45.7	68.7	68.2	8.2	62.2	15.2	21.8	15.3	6.6	0.1	−6.6
600	50	80	300	300	49.2	60.7	81.3	81.3	81.3	60.7	60.7	60.7	11.5	32.1	11.5	20.6	0.0	−20.6
600	60	80	360	240	50.4	60.8	83.1	73.9	79.4	70.0	46.9	60.8	10.4	29.0	10.4	18.6	0.0	−18.7
600	70	80	420	180	51.6	61.0	77.6	66.3	74.2	73.4	32.1	61.0	9.4	22.6	9.4	13.2	0.0	−13.2
600	80	80	480	120	53.3	64.9	78.7	61.5	75.3	76.0	20.4	64.9	11.6	22.0	11.6	10.4	0.0	−10.4
600	90	80	540	60	55.8	68.6	80.9	52.3	78.0	75.1	9.6	68.6	12.8	22.2	12.8	9.4	0.0	−9.5
800	50	80	400	400	55.8	65.0	79.3	79.3	79.3	65.0	65.0	65.0	9.2	23.5	9.2	14.3	0.0	−14.3
800	60	80	480	320	57.6	64.2	90.2	77.4	85.1	73.3	50.6	64.2	6.6	27.5	6.6	20.9	0.0	−20.9
800	70	80	560	240	59.2	64.5	93.3	72.8	87.2	77.0	35.4	64.5	5.3	28.0	5.3	22.7	0.0	−22.6
800	80	80	640	160	60.9	67.0	87.1	68.1	83.3	78.2	22.2	67.0	6.1	22.4	6.1	16.3	0.0	−16.3
800	90	80	720	80	63.1	69.5	87.9	60.7	85.2	76.0	10.7	69.5	6.4	22.1	6.4	15.7	0.0	−15.7
1000	50	80	500	500	61.6	70.6	84.7	84.7	84.7	70.4	70.4	70.4	9.0	23.1	8.8	14.1	−0.2	−14.3
1000	60	80	600	400	63.0	70.2	86.4	80.1	83.9	79.1	56.8	70.2	7.2	20.9	7.2	13.7	0.0	−13.7
1000	70	80	700	300	64.3	70.5	98.7	78.5	92.6	83.2	40.7	70.4	6.2	28.3	6.1	22.1	−0.1	−22.2
1000	80	80	800	200	66.0	72.5	93.9	73.4	89.8	84.1	25.3	72.3	6.5	23.8	6.3	17.3	−0.2	−17.5
1000	90	80	900	100	68.8	74.6	93.4	70.1	91.1	81.7	12.5	74.8	5.8	22.3	6.0	16.5	0.2	−16.3
1200	50	80	600	600	65.9	74.9	86.0	86.0	86.0	74.7	74.7	74.7	9.0	20.1	8.8	11.1	−0.2	−11.3
1200	60	80	720	480	67.6	74.8	90.5	84.9	88.3	83.6	61.6	74.8	7.2	20.7	7.2	13.5	0.0	−13.5
1200	70	80	840	360	69.1	75.1	97.0	82.7	92.7	87.6	45.7	75.1	6.0	23.6	6.0	17.6	0.0	−17.6
1200	80	80	960	240	71.2	76.8	100.0	80.8	96.2	88.3	29.0	76.5	5.6	25.0	5.3	19.4	−0.3	−19.7
1200	90	80	1080	120	74.5	78.5	98.4	75.9	96.2	85.5	16.3	78.6	4.0	21.7	4.1	17.7	0.1	−17.6
1400	50	80	700	700	70.2	78.1	89.6	89.6	89.6	78.1	78.1	78.1	7.9	19.4	7.9	11.5	0.0	−11.5
1400	60	80	840	560	72.1	78.4	91.7	87.6	90.1	86.9	65.6	78.4	6.3	18.0	6.3	11.7	0.0	−11.7
1400	70	80	980	420	73.9	78.7	94.9	86.1	92.3	90.9	50.3	78.7	4.8	18.4	4.8	13.6	0.0	−13.6
1400	80	80	1120	280	76.3	79.9	100.0	83.9	96.8	91.2	34.6	79.9	3.6	20.5	3.6	16.9	0.0	−16.9
1400	90	80	1260	140	80.2	81.2	100.0	79.8	98.0	87.8	21.0	81.2	1.0	17.8	1.0	16.8	0.0	−16.8
1600	50	80	800	800	74.5	81.7	89.9	89.9	89.9	81.7	81.7	81.7	7.2	15.4	7.2	8.2	0.0	−8.2
1600	60	80	960	640	76.7	81.9	93.1	89.8	91.8	90.0	69.5	81.8	5.2	15.1	5.1	9.9	−0.1	−10.0
1600	70	80	1120	480	78.7	82.1	96.9	88.1	94.3	93.9	54.1	81.9	3.4	15.6	3.2	12.2	−0.2	−12.3
1600	80	80	1280	320	81.5	83.1	100.0	86.3	97.3	94.3	41.4	83.7	1.6	15.8	2.2	14.2	0.6	−13.5

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TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
1600	90	80	1440	160	85.8	85.9	100.0	83.2	98.3	91.6	23.9	84.8	0.1	12.5	−1.0	12.4	−1.1	−13.5
1800	50	80	900	900	78.7	84.6	92.8	92.8	92.8	84.6	84.6	84.6	5.9	14.1	5.9	8.2	0.0	−8.2
1800	60	80	1080	720	81.2	84.6	94.3	90.9	92.9	92.5	72.4	84.5	3.4	11.7	3.3	8.3	−0.1	−8.5
1800	70	80	1260	540	83.5	84.6	97.4	89.6	95.1	95.7	60.6	85.2	1.1	11.6	1.7	10.5	0.6	−9.9
1800	80	80	1440	360	86.6	85.6	100.0	88.4	97.7	96.2	45.4	86.0	−1.0	11.1	−0.6	12.1	0.4	−11.7
2000	50	80	1000	1000	83.0	86.9	92.7	92.7	92.7	86.9	86.9	86.9	3.9	9.7	3.9	5.8	0.0	−5.8
2000	60	80	1200	800	85.7	86.8	93.9	91.6	93.0	94.4	75.3	86.8	1.1	7.3	1.1	6.2	0.0	−6.2
2000	70	80	1400	600	88.2	86.7	97.0	90.9	95.2	96.6	63.4	86.7	−1.5	7.0	−1.5	8.5	0.0	−8.5
2000	80	80	1600	400	91.7	87.5	100.0	90.0	98.0	97.2	48.3	87.5	−4.2	6.3	−4.2	10.5	0.0	−10.5
2200	50	80	1100	1100	87.2	89.0	93.6	93.6	93.6	89.2	89.2	89.2	1.8	6.4	2.0	4.6	0.2	−4.4
2200	60	80	1320	880	90.2	88.9	95.8	92.7	94.6	95.8	79.7	89.3	−1.3	4.4	−0.9	5.7	0.4	−5.2
2200	70	80	1540	660	93.0	89.4	98.3	92.2	96.5	99.0	67.6	89.6	−3.6	3.5	−3.4	7.1	0.2	−6.9
2400	50	80	1200	1200	91.5	90.8	93.8	93.8	93.8	91.0	91.0	91.0	−0.7	2.3	−0.5	3.0	0.2	−2.8
2400	60	80	1440	960	94.8	90.6	95.8	93.6	94.9	96.8	82.3	91.0	−4.2	0.1	−3.8	4.3	0.4	−4.0
2600	50	80	1300	1300	95.7	92.1	94.6	94.6	94.6	92.1	92.1	92.1	−3.6	−1.1	−3.6	2.5	0.0	−2.5
2600	60	80	1560	1040	99.3	91.9	95.6	94.1	95.0	97.2	84.0	91.9	−7.4	−4.3	−7.4	3.1	0.0	−3.1
2800	50	80	1400	1400	100.0	93.4	95.0	95.0	95.0	93.6	93.6	93.6	−6.6	−5.0	−6.4	1.6	0.2	−1.4
3000	50	80	1500	1500		94.4	95.5	95.5	95.5	94.9	94.9	94.9				1.1	0.5	−0.6
3200	50	80	1600	1600		95.2	95.6	95.6	95.6	95.2	95.2	95.2				0.4	0.0	−0.4
200	50	100	100	100	33.9	37.9	51.2	51.2	51.2	37.9	37.9	37.9	4.0	17.3	4.0	13.3	0.0	−13.3
200	60	100	120	80	34.5	39.8	53.9	48.8	51.9	45.8	30.9	39.8	5.3	17.4	5.3	12.1	0.0	−12.0
200	70	100	140	60	35.0	41.6	56.3	46.0	53.2	50.1	21.9	41.6	6.6	18.2	6.6	11.6	0.0	−11.6
200	80	100	160	40	35.8	47.7	58.6	42.6	55.4	56.1	14.5	47.8	11.9	19.6	12.0	7.7	0.1	−7.6
200	90	100	180	20	36.9	53.7	60.7	38.2	58.5	58.9	6.9	53.7	16.8	21.6	16.8	4.8	0.0	−4.7
400	50	100	200	200	42.9	54.4	65.8	65.8	65.8	54.4	54.4	54.4	11.5	22.9	11.5	11.4	0.0	−11.4
400	60	100	240	160	44.0	51.8	68.2	68.8	68.4	59.6	40.2	51.9	7.8	24.4	7.9	16.6	0.1	−16.6
400	70	100	280	120	45.0	52.8	70.1	65.7	68.8	63.5	27.9	52.8	7.8	23.8	7.8	16.0	0.0	−15.9
400	80	100	320	80	46.1	57.6	72.4	58.8	69.7	67.7	17.8	57.7	11.5	23.6	11.6	12.1	0.1	−12.0
400	90	100	360	40	47.9	62.4	75.1	48.1	72.4	68.4	8.3	62.4	14.5	24.5	14.5	10.0	0.0	−10.0
600	50	100	300	300	50.1	61.5	84.1	84.1	84.1	61.5	61.5	61.5	11.4	34.0	11.4	22.6	0.0	−22.6
600	60	100	360	240	51.4	61.7	86.3	76.3	82.3	71.1	47.6	61.7	10.3	30.9	10.3	20.6	0.0	−20.6
600	70	100	420	180	52.6	61.9	81.1	68.5	77.3	74.4	32.6	61.9	9.3	24.7	9.3	15.4	0.0	−15.5
600	80	100	480	120	54.2	65.5	82.4	63.4	78.6	76.7	20.6	65.5	11.3	24.4	11.3	13.1	0.0	−13.1
600	90	100	540	60	56.8	69.0	84.7	54.0	81.6	75.6	9.7	69.0	12.2	24.8	12.2	12.6	0.0	−12.7

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
800	50	100	400	400	56.8	65.9	81.5	81.5	81.5	65.9	65.9	65.9	9.1	24.7	9.1	15.6	0.0	−15.6
800	60	100	480	320	58.5	64.9	92.9	79.3	87.5	74.1	51.1	64.9	6.4	29.0	6.4	22.6	0.0	−22.5
800	70	100	560	240	60.1	65.1	96.5	74.4	89.9	77.7	35.7	65.1	5.0	29.8	5.0	24.8	0.0	−24.8
800	80	100	640	160	61.5	67.5	90.7	69.5	86.5	78.8	22.4	67.5	6.0	25.0	6.0	19.0	0.0	−18.9
800	90	100	720	80	63.7	69.9	91.7	61.9	88.7	76.5	10.7	69.9	6.2	25.0	6.2	18.8	0.0	−18.8
1000	50	100	500	500	62.2	71.4	86.6	86.6	86.6	71.2	71.2	71.2	9.2	24.4	9.0	15.2	−0.2	−15.4
1000	60	100	600	400	63.6	70.8	88.6	81.6	85.8	79.8	57.3	70.8	7.2	22.2	7.2	15.0	0.0	−15.0
1000	70	100	700	300	64.9	70.9	100.0	79.8	93.9	83.8	41.0	71.0	6.0	29.0	6.1	23.0	0.1	−23.0
1000	80	100	800	200	66.6	73.0	97.4	74.4	92.8	84.8	25.4	72.9	6.4	26.2	6.3	19.8	−0.1	−19.9
1000	90	100	900	100	69.4	75.0	97.2	70.9	94.6	82.1	12.5	75.1	5.6	25.2	5.7	19.6	0.1	−19.5
1200	50	100	600	600	66.5	75.6	87.5	87.5	87.5	75.4	75.4	75.4	9.1	21.0	8.9	11.9	−0.2	−12.1
1200	60	100	720	480	68.2	75.4	92.4	86.1	89.9	84.3	62.0	75.4	7.2	21.7	7.2	14.5	0.0	−14.5
1200	70	100	840	360	69.7	75.6	99.5	83.7	94.8	88.2	46.0	75.5	5.9	25.1	5.8	19.2	−0.1	−19.2
1200	80	100	960	240	71.8	77.2	100.0	81.5	96.3	88.8	29.1	76.9	5.4	24.5	5.1	19.1	−0.3	−19.4
1200	90	100	1080	120	75.1	78.8	100.0	76.5	97.7	86.0	16.4	79.0	3.7	22.6	3.9	18.9	0.2	−18.6
1400	50	100	700	700	70.8	78.7	90.8	90.8	90.8	78.7	78.7	78.7	7.9	20.0	7.9	12.1	0.0	−12.1
1400	60	100	840	560	72.7	78.9	93.3	88.5	91.4	87.5	66.0	78.9	6.2	18.7	6.2	12.5	0.0	−12.5
1400	70	100	980	420	74.5	79.1	97.0	86.7	93.9	91.4	50.5	79.1	4.6	19.4	4.6	14.8	0.0	−14.8
1400	80	100	1120	280	76.9	80.3	100.0	84.4	96.9	91.7	34.7	80.3	3.4	20.0	3.4	16.6	0.0	−16.6
1400	90	100	1260	140	80.6	81.5	100.0	80.2	98.0	88.2	21.0	81.5	0.9	17.4	0.9	16.5	0.0	−16.5
1600	50	100	800	800	75.1	82.3	90.9	90.9	90.9	82.2	82.2	82.2	7.2	15.8	7.1	8.6	−0.1	−8.7
1600	60	100	960	640	77.2	82.3	94.5	90.5	92.9	90.5	69.9	82.3	5.1	15.7	5.1	10.6	0.0	−10.6
1600	70	100	1120	480	79.2	82.4	98.8	86.6	95.7	94.3	54.3	82.3	3.2	16.5	3.1	13.3	−0.1	−13.5
1600	80	100	1280	320	81.9	83.5	100.0	86.6	97.3	94.7	41.5	84.1	1.6	15.4	2.2	13.8	0.6	−13.3
1600	90	100	1440	160	86.2	86.2	100.0	83.5	98.4	91.9	23.9	85.1	0.0	12.2	−1.1	12.2	−1.1	−13.2
1800	50	100	900	900	79.2	85.0	93.6	93.6	93.6	85.0	85.0	85.0	5.8	14.4	5.8	8.6	0.0	−8.6
1800	60	100	1080	720	81.6	85.0	95.5	91.4	93.9	92.9	72.7	84.8	3.4	12.3	3.2	8.9	−0.2	−9.0
1800	70	100	1260	540	83.9	85.0	99.1	90.0	96.4	96.1	60.7	85.5	1.1	12.5	1.6	11.4	0.5	−10.8
1800	80	100	1440	360	86.9	85.8	100.0	88.7	97.7	96.5	45.4	86.3	−1.1	10.8	−0.6	11.9	0.5	−11.4
2000	50	100	1000	1000	83.4	87.2	93.3	93.3	93.3	87.2	87.2	87.2	3.8	9.9	3.8	6.1	0.0	−6.1
2000	60	100	1200	800	86.0	87.1	94.9	92.0	93.7	94.7	75.6	87.1	1.1	7.7	1.1	6.6	0.0	−6.7
2000	70	100	1400	600	88.5	87.0	98.5	91.2	96.3	97.0	63.6	87.0	−1.5	7.8	−1.5	9.3	0.0	−9.3
2000	80	100	1600	400	91.9	87.7	100.0	90.3	98.1	97.5	48.4	87.7	−4.2	6.2	−4.2	10.4	0.0	−10.4
2200	50	100	1100	1100	87.5	89.2	94.1	94.1	94.1	89.4	89.4	89.4	1.7	6.6	1.9	4.9	0.2	−4.7

TABLE A-1. Comparison of PTSF Estimates With Existing and Revised HCM Procedures (Continued)

Two-way flow rate (pc/h)	Directional split	Percent no-passing zones	Directional flow rate (pc/h)		HCM1997 PTSF (Two-way)	HCM2000 PTSF (Two-way)	HCM2000 (Directional)			Revised HCM2000 (Directional)			Differences in PTSF for both directions of travel combined					
			Direction 1	PTSF (d2)			PTSF Direction 1	PTSF Direction 2	PTSF Combined	PTSF Direction 1	PTSF Direction 2	PTSF Combined	HCM1997 vs. HCM2000 (two way)	HCM 1997 vs. HCM2000 (directional)	HCM1997 vs. Revised HCM2000 (directional)	HCM2000 (two-way vs. directional)	HCM2000 (two-way vs. revised)	HCM2000 (directional vs. revised)
2200	60	100	1320	880	90.5	89.1	96.6	93.1	95.2	96.1	79.9	89.6	−1.4	4.7	−0.9	6.1	0.5	−5.6
2200	70	100	1540	660	93.2	89.7	99.6	92.5	97.5	99.3	67.7	89.9	−3.5	4.3	−3.3	7.8	0.2	−7.6
2400	50	100	1200	1200	91.7	91.0	94.2	94.2	94.2	91.2	91.2	91.2	−0.7	2.5	−0.5	3.2	0.2	−3.0
2400	60	100	1440	960	94.9	90.8	96.4	93.9	95.4	96.9	82.4	91.1	−4.1	0.5	−3.8	4.6	0.3	−4.3
2600	50	100	1300	1300	95.8	92.2	95.0	95.0	95.0	92.2	92.2	92.2	−3.6	−0.8	−3.6	2.8	0.0	−2.8
2600	60	100	1560	1040	99.3	92.0	96.2	94.4	95.5	97.4	84.1	92.0	−7.3	−3.8	−7.3	3.5	0.0	−3.4
2800	50	100	1400	1400	100.0	93.6	95.3	95.3	95.3	93.8	93.8	93.8	−6.4	−4.7	−6.2	1.7	0.2	−1.5
3000	50	100	1500	1500		94.5	95.8	95.8	95.8	95.0	95.0	95.0				1.3	0.5	−0.8
3200	50	100	1600	1600		95.4	95.9	95.9	95.9	95.4	95.4	95.4				0.5	0.0	−0.5

APPEND IX B

MODIFICA TIONS TO HCM2000 CHAPTERS 12 AND 20 TO CORRECT OVERESTIMATION OF PTSF

Based on the discussion in Chapter 2 of this report, the following changes are recommended to HCM Chapters 12 and 20 to reduce the overestimation of PTSF:

1. Replace HCM Exhibit 12–7b with Figure 5 from this report.

2. Replace HCM Exhibit 20–20 with Table 10 from this report.

3. Replace HCM Exhibit 20–21 with Table 9 from this report.

4. Replace HCM Equation (20–16) with Equation (7) in this report.

5. To reduce the potential for misunderstanding, rewrite HCM Equations (20–7) and (20–17) using the exp function as shown in Equations (2) and (4) of this report.

6. Revise the worksheets and examples in HCM Chapter 20 to reflect these changes.

APPEND IX C

OPERA TIONAL ANALYSIS PROCEDURES FOR DEVELOPED TWO-LANE HIGHWAYS

It is recommended that the following operational analysis procedures for two-lane highways be implemented in HCM Chapter 15:

- Developed two–lane highway segment not terminated by a signal:
  - use Equation (8) to determine ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

- Developed two–lane highway segment terminated by a signal and having a signal spacing in excess of 1.6 km (1 mi):
  - use Equation (8) to determine ATS and convert ATS to a running time, TR
  - use the HCM Chapter 15 methodology to determine signal delay
  - combine the signal delay and the running time
  - reconvert the combined running time to an ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

- Developed two–lane highway segment terminated by a signal and having a length of 1.6 km (1 mi) or less:
  - use Equation (8) to determine ATS and convert to a running time, TR
  - if the FFS is 56 km/h (35 mi/h) or more and left–turn lanes (or bays) are provided for all public street intersections and "active" driveways, then use Table 11 to determine a running time, TR′. If not, then TR′ is not available.
  - use the HCM Chapter 15 methodology to determine signal delay
  - combine the signal delay with the larger running time, TR or TR′
  - reconvert the combined running time to an ATS
  - use the LOS thresholds defined in Table 12 to determine the LOS for the segment

The following caveats and assumptions should be noted in applying the procedures defined above:

- All applications of HCM Chapter 20 procedures should use the directional segment methodology, not the two–way segment methodology.

- Equation (8) is intended primarily for segments with FFS of 72 km/h (45 mi/h) or more; however, it can be applied to facilities with a lower FFS with caution and provided that values in HCM2000 Exhibit 20–19 are extrapolated. In no case, should the segment FFS be less than 56 km/h (35 mi/h).

- If the percentage of no–passing zones is not known for the developed two–lane highway segment, it should be assumed to be 100 percent.

In addition, a two-lane highway in a small town or a transition area with reduced speeds should be evaluated as a Class II highway if the developed conditions with reduced speeds extend for a distance of 3 kIn (2 mi) or less and if the vast majority of the traffic is through traffic that will soon depart the developed area and return to a Class I highway. However, if the developed area extends for more than 3 kIn (2 mi) or if there is a substantial proportion of local circulating traffic within the developed area, then the modified HCM Chapter 15 procedures described above for two-lane highways with continuous development should be applied.