Improvement of Planning Level Analysis Procedures for Two-Lane Highways

Final Report
October 2005

Contract #: BC-354-89
UF Project #: 49104504-985-12

Prepared for:
The Florida Department of Transportation

Prepared by:
Transportation Research Center
Department of Civil and Coastal Engineering
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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Improvement of Planning Level Analysis Procedures for Two-Lane Highways		5. Report Date October 2005 6. Performing Organization Code UF-TRC
7. Author(s) Scott S. Washburn		8. Performing Organization Report No. TRC-FDOT-985-2005
9. Performing Organization Name and Address University of Florida Dept. of Civil and Coastal Engineering 365 Weil Hall / P.O. Box 116580 Gainesville, FL 32611-6580		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee St. MS 30 Tallahassee, Florida 32399 (850) 414 - 4615		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

There were three main research components to this project. The first component addressed the issue of testing the revisions to the HCM 2000 two-lane highway directional analysis methodology as part of NCHRP 20-7 (task 160) and implementing these revisions into the HIGHPLAN software program. The second component addressed the issue of two-lane highway classification categories and the preferred level of service performance measures for those categories. The third component addressed the development of a methodology for performing a two-lane highway level of service analysis at the facility level, primarily with respect to the combination of basic two-lane highway segments and signalized intersections.

17. Key Words Level of service, quality of service, two-lane highways		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA, 22161	
19 Security Classif. (of this report) Unclassified	20.Security Classif. (of this page) Unclassified	21.No. of Pages 375	22 Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Acknowledgments

The authors would like to express their sincere appreciation to Ms. Gina Bonyani and Mr. Doug McLeod of the Florida Department of Transportation (Central Office) for the support and guidance they provided on this project.

Report Organization

There were three research components to this project. The first component, labeled Task 1[1], addressed the issue of testing the revisions to the two-lane directional analysis methodology as part of NCHRP 20-7 (task 160) and implementing these revisions into the HIGHPLAN software program.

The second component addressed the issue of two-lane highway classification categories and the preferred level of service performance measures for those categories. This component includes two tasks, labeled Task 2a and 2b. In Task 2a, a roundtable discussion was organized with several transportation professionals from the northern part of Florida to discuss two-lane highway analysis issues. The conducting of this roundtable session and subsequent write-up for the report was done with the assistance of graduate student Mr. Brad Choi.

In Task 2b, focus group sessions were conducted with recruited citizens in an effort to identify the preferred performance measures for assessing level of service on various types of two-lane highways. The report content for Task 2b, under the section titled “Identification of Preferred Performance Measures for the Assessment of Level of Service on Two-Lane Highways”, is in large part the Masters thesis prepared by Ms. Jessica Morriss under the supervision of Dr. Scott Washburn. The front matter that was relevant only to the graduate school of the University of Florida has been removed.

The third component, labeled Task 3, addressed the development of a methodology for performing a two-lane highway level of service analysis at the facility level, primarily with respect to the combination of basic two-lane highway segments and signalized intersections. The report content for Task 3, under the section titled “A Methodology for the Operational Performance Assessment of Two-Lane Highway Facilities”, is in large part the draft dissertation prepared by Mr. Qingyong (Steven) Yu under the supervision of Dr. Scott Washburn. The front matter that is relevant only to the graduate school of the University of Florida has been removed.

[1] Note: This task was not included in the original scope of work.

Task 1

HIGHPLAN Revisions
Based on NCHRP 20-7 (Task 160) Results

Although not originally part of the scope, a major task was undertaken as part of this project due to its significance to the overall objective of improving the analysis methods of two-lane highways and its importance to the level of service program for the Florida DOT. This task dealt with NCHRP project 20-7 (Task 160), which resulted in significant changes to the directional analysis methodology for two-lane highways in the Highway Capacity Manual (HCM) 2000.

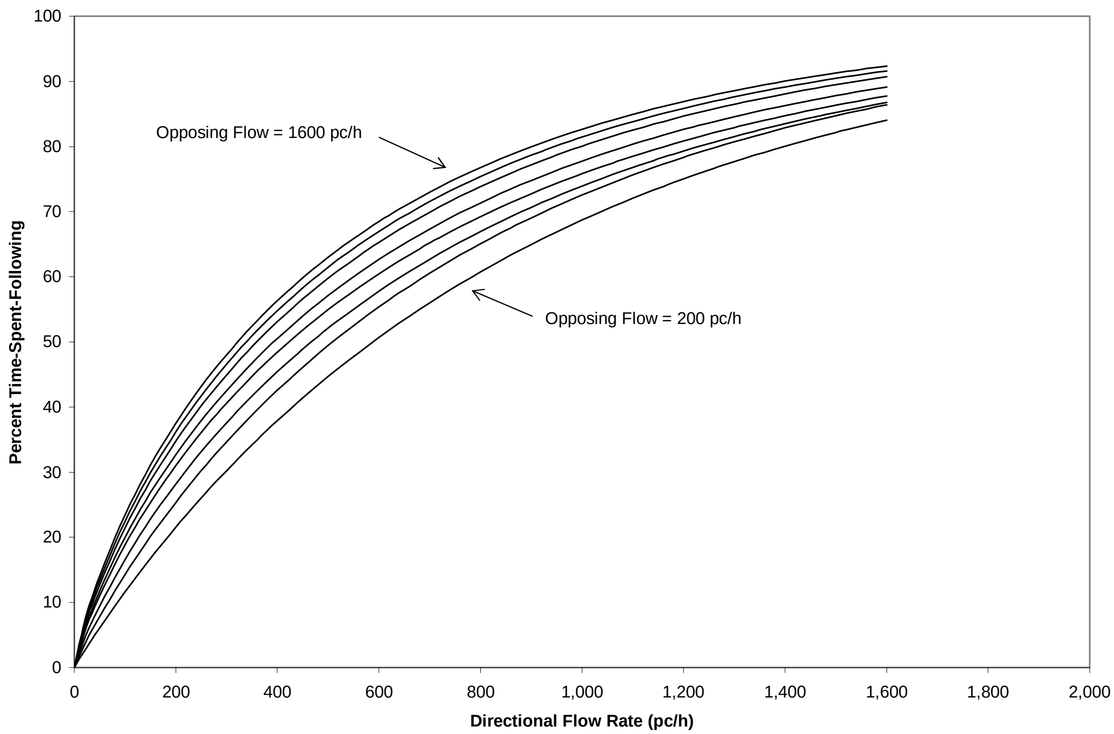
This task entailed the following components:

- A preliminary review and testing of the revised two-lane highway directional analysis methodology proposed in NCHRP 20-7 was performed. This was done during the months of August and September 2003.
- A beta version of HIGHPLAN was produced with the NCHRP 20-7 revisions and supplied to FDOT in December 2003. Fairly extensive modifications to the program code and one table implementation were necessary.
- More comprehensive testing of the new procedure was performed and revealed a numerical discrepancy related to certain levels of traffic directional split—this required coordination with the research contractor for NCHRP 20-7 (Midwest Research Institute) to troubleshoot and identify the source of the discrepancy. This was done during the spring and summer semesters of 2004.
- After this issue was resolved and verified by additional testing, the HIGHPLAN program code and data table were modified again as necessary. The methodological components that were affected by NCHRP 20-7 are included in the following pages. Note: This material is excerpted directly from the NCHRP 20-7 report.
- Comprehensive testing of the revised HIGHPLAN program was performed. As part of this testing effort, the entire sequence of computational steps was documented in a Mathcad format. Multiple tests were made comparing the results of HIGHPLAN (including each of the intermediate outputs that can be viewed in the diagnostic mode) with those generated from the Mathcad worksheet. Three example problems are included later in this section. For the data inputs shown at the top of each Mathcad worksheet, HIGHPLAN will return the same final results.
- Another beta version of the new HIGHPLAN program was provided to FDOT staff for final testing in May 2005.

MODIFICATIONS TO HCM2000 CHAPTERS 12 AND 20 FOR COMPATIBILITY OF THE TWO-WAY SEGMENT AND DIRECTIONAL SEGMENT PROCEDURES FOR TWO-LANE HIGHWAYS

The following changes should be made to HCM Chapters 12 and 20 to make the two-way and directional segment procedures for two-lane highways compatible with one another:

1. Replace HCM Exhibit 12–7b with the following figure:



2. Replace HCM Exhibit 20–20 with the following table:

Exhibit 20-20. ADJUSTMENT (f_{np}) TO PERCENT TIME-SPENT-FOLLOWING FOR PERCENTAGE OF NO-PASSING ZONES IN 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	15.8	38.2	47.8	53.2	55.2	56.8
800	15.8	33.8	40.4	44.0	44.8	46.6
1400	12.8	20.0	23.8	26.2	27.4	28.6
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	3.3	4.7	5.1	5.5	5.7	6.1
Directional split = 60/40						
≤ 200	11.0	30.6	41.0	51.2	52.3	53.5
400	14.6	36.1	44.8	53.4	55.0	56.3
600	14.8	36.9	44.0	51.1	52.8	54.6
800	13.6	28.2	33.4	38.6	39.9	41.3
1400	11.8	18.9	22.1	25.4	26.4	27.3
2000	9.1	13.5	15.6	16.0	16.8	17.3
2600	5.9	7.7	8.6	9.6	10.0	10.2
Directional split = 70/30						
≤ 200	9.9	28.1	38.0	47.8	48.5	49.0
400	10.6	30.3	38.6	46.7	47.7	48.8
600	10.9	30.9	37.5	43.9	45.4	47.0
800	10.3	23.6	28.4	33.3	34.5	35.5
1400	8.0	14.6	17.7	20.8	21.6	22.3
2000	7.3	9.7	15.7	13.3	14.0	14.5
Directional split = 80/20						
≤ 200	8.9	27.1	37.1	47.0	47.4	47.9
400	6.6	26.1	34.5	42.7	43.5	44.1
600	4.0	24.5	31.3	38.1	39.1	40.0
800	4.8	18.5	23.5	28.4	29.1	29.8
1400	3.5	10.3	13.3	16.3	16.9	32.2
2000	3.5	7.0	8.5	10.1	10.4	10.7
Directional split = 90/10						
≤ 200	4.6	24.1	33.6	43.1	43.4	43.6
400	0.0	20.2	28.3	36.3	36.7	37.0
600	-3.1	16.8	23.5	30.1	30.6	31.1
800	-2.8	10.5	15.2	19.9	20.3	20.8
1400	-1.2	5.5	8.3	11.0	11.5	11.9

3. Replace HCM Exhibit 20–21 with the following table:

Exhibit 20-21. 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

4. Replace HCM Equation (20–16) with the following equation:

$$PTSF_d = BPTSF_d + f_{np}\left(\frac{V_d}{V_d + V_0}\right) \qquad (20\text{-}16)$$

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 percent no-passing zones in the direction analyzed

5. To reduce the potential for misunderstanding, HCM Equation (20–7) should be rewritten using the exp function, as shown below, rather than as e raised to a power:

$$BPTSF = 100\left(1 - \exp(-0.000879 v_p)\right) \qquad (20\text{-}7)$$

where: BPTSF = base percent time-spent-following for both directions of travel combined
v_p = two-way passenger-car equivalent flow rate, pc/h

6. To reduce the potential for misunderstanding, HCM Equation (20–17) should be rewritten using the exp function, as shown below, rather than as e raised to a power:

$$BPTSF_d = 100\left(1 - \exp(a v_d^{\,b})\right) \qquad (20\text{-}17)$$

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

Mathcad Computations for Example 1

HIGHPLAN Computational Methodology Update for NCHRP 20-7 Revisions

UF-TRC

Application of the HIGHPLAN Computational Steps to Example Problem 1

Inputs and Initial Computations.

1. Input Roadway and Traffic Data.

Roadway Variables

Class := 1		Median := 1		0 = No, 1 = Yes
NumberofLanes := 2		LeftTurnLane := 1		0 = No, 1 = Yes
AnalysisType := 1	0 = Segment, 1 = Facility	%NPZ := 60		
Terrain := 2	1 = Level, 2 = Rolling	PresencePassingLane := 1		0 = No, 1 = Yes
PostedSpeed := 50	mi/hr	Spacing := 5	mi	

Traffic Variables

AADT := 10000	PercentHeavyVehicles := 0.04	P_T := PercentHeavyVehicles
K := 0.096	BaseCapacity := 1700	
D := 0.55	LocalAdjustmentFactor := 0.95	LAF := LocalAdjustmentFactor
PHF := 0.91		

2. Calculate DDHV (Design Directional Hour Volume)

Calculation:

DDHV := AADT·K·D

DDHV = 528

3. Determine adjustment for the presence of a median and/or left turn lanes.

Left Turn Lane Adjustment (LTadj) = -0.2 for left turn lanes NOT present, LTadj = 0 otherwise.

Median Adjustment (MedAdj) = 0.05 for median present, MadAdj = 0 otherwise.

Calculations:

Left Turn Lane:

$$\text{LTadj(LeftTurnLane)} := \begin{array}{|l} \text{out} \leftarrow -0.2 \text{ if LeftTurnLane} = 0 \\ \text{out} \leftarrow 0 \text{ if LeftTurnLane} = 1 \\ \text{out} \end{array}$$

LTadj(LeftTurnLane) = 0 LTadj := LTadj(LeftTurnLane) LTadj = 0

Median:

$$\text{MedAdj(Median)} := \begin{array}{|l} \text{out} \leftarrow 0 \text{ if Median} = 0 \\ \text{out} \leftarrow 0.05 \text{ if Median} = 1 \\ \text{out} \end{array}$$

MedAdj(Median) = 0.05 MedAdj := MedAdj(Median) MedAdj = 0.05

Final Adjustment Value for Left Turn Lane and Median:

AdjMedLTL := 1 + LTadj + MedAdj

AdjMedLTL = 1.05

4. Determine Facility Adjustment Factor (FacAdj).

FacAdj = 1.0 for Analysis Type = Segment

FacAdj = 0.9 for Analysis Type = Facility

Calculation:

$$\text{FacAdj(AnalysisType)} := \begin{array}{|l} \text{out} \leftarrow 1.0 \text{ if AnalysisType} = 0 \\ \text{out} \leftarrow 0.9 \text{ if AnalysisType} = 1 \\ \text{out} \end{array}$$

FacAdj(AnalysisType) = 0.9 FacAdj := FacAdj(AnalysisType) FacAdj = 0.9

5. Calculate Adjusted Volume (AdjVol).

Calculation:

$$\text{AdjVol} := \frac{\text{DDHV}}{\text{PHF} \cdot \text{LAF} \cdot \text{AdjMedLTL} \cdot \text{FacAdj}}$$

AdjVol = 646.3 veh/h V := AdjVol V = 646.304 veh/h

Calculations for Percent Time Spent Following (PTSF)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} E_T \leftarrow 1.1 \;\; \text{if } 0 \le V \le 300 \\ E_T \leftarrow 1.1 \;\; \text{if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \;\; \text{if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} E_T \leftarrow 1.8 \;\; \text{if } 0 \le V \le 300 \\ E_T \leftarrow 1.5 \;\; \text{if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \;\; \text{if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-10
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.0 \\ 1.0 \end{pmatrix}$$

$$E_T := PCEs(Terrain, V)_1 \qquad E_T = 1.0$$

$$E_R := PCEs(Terrain, V)_2 \qquad E_R = 1.0$$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 1.00$$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$
f_G(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ out \leftarrow f_G \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.77 \ \text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.94 \ \text{ if } 300 < V \le 600 \\ f_G \leftarrow 1.0 \ \text{ if } V > 600 \\ out \leftarrow f_G \\ out \end{array} \\ out \end{array}
$$

From Exhibit 20-8
HCM 2000

$f_G(Terrain, V) = 1$ $\quad$ $f_G := f_G(Terrain, V)$ $\quad$ $f_G = 1.00$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 646.3$ pc/hr $\quad$ $v_{dPTSF} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

An approximate equivalent is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 528.8$

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine values of coefficients 'a' and 'b' for HCM Equation 20-17.

Look up values from HCM Exhibit 20-21 (linear interpolation if necessary).

Input:

v_o is rounded to the nearest 10 veh/h.

$\text{round}(v_o, -1) = 530$ pc/hr

From Exhibit, for $v_o = 400$; $a_1 := -0.0022$ $b_1 := 0.923$

From Exhibit, for $v_o = 600$; $a_2 := -0.0033$ $b_2 := 0.870$

From Exhibit 20-21
HCM 2000

Calculations:

$$a := a_1 + (530 - 400) \cdot \left(\frac{a_1 - a_2}{400 - 600} \right)$$

$a = -0.00292$

$$b := b_1 + (530 - 400) \cdot \frac{b_1 - b_2}{400 - 600}$$

$b = 0.88855$

12. Calculate base percent time spent following (BPTSF).

Calculations:

$$BPTSF_d := 100 \cdot \left(1 - e^{a \cdot v_d^{\,b}}\right)$$

From Equation 20-17
HCM 2000

$BPTSF_d = 59.98$

13. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-16.

Look up value from HCM Exhibit 20-20 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

$PostedSpeed = 50$ $\qquad$ $\%NPZ = 60$ $\qquad$ $v_o = 528.8$

$FFS := PostedSpeed + 5$

$FFS = 55$

Calculation:

This example calls for interpolation by volume and by directional split

$v_p := v_d + v_o$ $\qquad$ $v_p = 1175.10$

From Exhibit, for $v_o = 400$; $\qquad$ $\%NPZ = 60$

From Exhibit, for $v_o = 600$; $\qquad$ $D = 0.55$

$Split_1 := 50$

$\%NPZ_{Low} := 60$ $\qquad$ $\%NPZ_{High} := 80$

$v_{p1} := 800$ $\qquad$ $f_1 := 44.0$ $\qquad$ $g_1 := 44.8$

$v_{p2} := 1400$ $\qquad$ $f_2 := 26.2$ $\qquad$ $g_2 := 27.4$

From Exhibit 20-22
HCM 2000

$$Val_1 := \frac{f_2 - f_1}{v_{p2} - v_{p1}} \cdot \left(v_p - v_{p1}\right) + f_1 \qquad Val_1 = 32.872$$

$Split_2 := 60$

$\%NPZ_L := 60$ $\%NPZ_H := 80$

$v_{p3} := 800$ $f_3 := 38.6$ $g_3 := 39.9$

$v_{p4} := 1400$ $f_4 := 25.4$ $g_4 := 26.4$

$$Val_2 := \frac{f_4 - f_3}{v_{p4} - v_{p3}} \cdot (v_p - v_{p3}) + f_3 \qquad Val_2 = 30.348$$

$$DoubleInterp := \frac{Val_2 - Val_1}{Split_2 - Split_1} \cdot (100 \cdot D - Split_1) + Val_1 \qquad DoubleInterp = 31.61$$

$f_{np} := DoubleInterp$

$f_{np} = 31.610$

14. Calculate percent time spent following (PTSF).

Calculations:

$$PTSF_d := BPTSF_d + f_{np} \cdot \left(\frac{v_d}{v_o + v_d} \right)$$

From Equation 20-16
HCM 2000

$PTSF_d = 77.37$

If passing lanes are present, see calculations later in file.

Calculations for Average Travel Speed (ATS)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} E_T \leftarrow 1.7 \;\; \text{if } 0 \le V \le 300 \\ E_T \leftarrow 1.2 \;\; \text{if } 300 < V \le 600 \\ E_T \leftarrow 1.1 \;\; \text{if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} E_T \leftarrow 2.5 \;\; \text{if } 0 \le V \le 300 \\ E_T \leftarrow 1.9 \;\; \text{if } 300 < V \le 600 \\ E_T \leftarrow 1.5 \;\; \text{if } V > 600 \\ E_R \leftarrow 1.1 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-9
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.5 \\ 1.1 \end{pmatrix}$$

$E_T := PCEs(Terrain, V)_1$ $\quad$ $E_T = 1.5$

$E_R := PCEs(Terrain, V)_2$ $\quad$ $E_R = 1.1$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)}$$

$f_{HV} = 0.98$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$f_G(\text{Terrain}, V) := \begin{array}{l} \text{if Terrain} = 1 \\ \quad \left| \begin{array}{l} f_G \leftarrow 1.0 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \right. \\ \text{if Terrain} = 2 \\ \quad \left| \begin{array}{l} f_G \leftarrow 0.71 \text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.93 \text{ if } 300 < V \le 600 \\ f_G \leftarrow 0.99 \text{ if } V > 600 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \right. \\ \text{out} \end{array}$$

From Exhibit 20-7
HCM 2000

$f_G(\text{Terrain}, V) = 0.99$ $\quad f_G := f_G(\text{Terrain}, V)$ $\quad f_G = 0.99$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 665.9$ pc/h $\quad v_{dATS} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 544.8$ pc/h

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-15.

Look up value from HCM Exhibit 20-19 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

PostedSpeed = 50 %NPZ = 60 $v_o = 544.819$

FFS := PostedSpeed + 5

FFS = 55

Calculation:

This example only calls for interpolation by volume,

$$f_{np} := 2.4 + (v_o - 400) \cdot \left(\frac{2.4 - 1.6}{400 - 600}\right)$$

$f_{np} = 1.82$

12. Calculate average travel speed (ATS).

Input:

$FFS_d := FFS$	$FFS_d = 55$	from inputs
$v_d = 665.9$	from step 9	
$v_o = 544.8$	from step 10	
$f_{np} = 1.82$	from step 11	

Calculation:

$$ATS_d := FFS_d - 0.00776 \cdot (v_d + v_o) - f_{np}$$

From Equation 20-5 HCM 2000

$ATS_d = 43.8$ mi/h

If passing lanes are present, see calculations below.

Additional Calculations for When Passing Lanes are Included

1. Input Roadway and Traffic Data.

Roadway Variables

$PassingLaneSpacing := 5$ mi

$L_t := PassingLaneSpacing \qquad L_t = 5$

Traffic Variables

$v_{dATS} = 665.889 \qquad v_{dPTSF} = 646.304$

2. Determine the Downstream Length of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain.

L_{de} = Downstream Length of Affected Roadway

The L_{de} for the PTSF and ATS must be calculated using their respective v_d values. The ATS is a constant 1.7, but the PTSF must be interpolated from Exhibit 20-23.

$v_{d1} := 400 \qquad L_{de1} := 8.1$

$v_{d2} := 700 \qquad L_{de2} := 5.7$

$$L_{dePTSF} := \frac{L_{de2} - L_{de1}}{v_{d2} - v_{d1}} \cdot \left(v_{dPTSF} - v_{d1}\right) + L_{de1}$$

$L_{dePTSF} = 6.13 \qquad L_{deATS} := 1.7$

Equation 20-18

$$L_d = L_t - (L_u + L_{pl} + L_{de})$$

L_d = Length of the two-lane highway downstream of the passing lane and beyond its effective length,
L_t = total length of analysis segment,
L_u = length of two lane highway upstream of the passing lane,
L_{pl} = length of the passing lane including tapers, and
L_{de} = downstream length of the two-lane highway within the effective length of the passing lane.

HighPlan assumes that the L_u equals 0 and that L_{pl} equals 1.

$L_u := 0 \qquad L_{pl} := 1 \qquad L_t := PassingLaneSpacing \qquad L_t = 5$

$L_{dPTSF} := L_t - \left(L_u + L_{pl} + L_{dePTSF}\right) \qquad L_{dPTSF} = -2.13 \qquad L_{Primede} := L_t - L_{pl}$

$L_{dATS} := L_t - \left(L_u + L_{pl} + L_{deATS}\right) \qquad L_{dATS} = 2.3 \qquad L_{Primede} = 4$

3. Determine the Factors for Estimation of Average Travel Speed and Percent Time Spent Following within a Passing Lane.

$$f\_f_{plPTSF}(v_{dPTSF}) := \begin{array}{|l} out \leftarrow 0.58 \ \text{ if } \ 0 \le v_{dPTSF} < 300 \\ out \leftarrow 0.61 \ \text{ if } \ 300 \le v_{dPTSF} < 600 \\ out \leftarrow 0.62 \ \text{ if } \ v_{dPTSF} \ge 600 \\ \text{return } out \end{array}$$

From Exhibit 20-24
HCM 2000

$$f\_f_{plATS}(v_{dATS}) := \begin{array}{|l} out \leftarrow 1.08 \ \text{ if } \ 0 \le v_{dATS} < 300 \\ out \leftarrow 1.10 \ \text{ if } \ 300 \le v_{dATS} < 600 \\ out \leftarrow 1.11 \ \text{ if } \ v_{dATS} \ge 600 \\ \text{return } out \end{array}$$

$f\_f_{plPTSF}(v_{dPTSF}) = 0.62$

$f_{plPTSF} := f\_f_{plPTSF}(v_{dPTSF})$

$f_{plPTSF} = 0.62$

$f\_f_{plATS}(v_{dATS}) = 1.11$

$f_{plATS} := f\_f_{plATS}(v_{dATS})$

$f_{plATS} = 1.11$

4a. Adjust the Precent Time Spent Following for Passing Lanes

$$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) := \begin{array}{|l} \text{if } L_{dPTSF} \ge 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + L_{dPTSF} + f_{plPTSF} \cdot L_{pl} + \left(\dfrac{1 + f_{plPTSF}}{2}\right) \cdot L_{dePTSF}\right]}{PassingLaneSpacing} \\ out \end{array} \\ \text{if } L_{dPTSF} < 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + f_{plPTSF} \cdot L_{pl} + f_{plPTSF} \cdot (L_{Primede}) + \left(\dfrac{1 - f_{plPTSF}}{2}\right) \cdot \left(\dfrac{L_{Primede}^{\ 2}}{L_{dePTSF}}\right)\right]}{PassingLaneSpacing} \\ out \end{array} \\ out \end{array}$$

Equation 20-19

Equation 20-20

$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) = 55.644$

$PTSF_{Final} := PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede})$

$PTSF_{Final} = 55.644$

4b. Adjust Average Travel Time for Passing Lanes

$$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) := \begin{array}{|l} \text{if } L_{dATS} \geq 0 \\ \quad \left| \begin{array}{l} out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + L_{dATS} + \dfrac{L_{pl}}{f_{plATS}} + 2 \cdot \dfrac{L_{deATS}}{1 + f_{plATS}}} \\ out \end{array} \right. \\ \text{if } L_{dATS} < 0 \\ \quad \left| \begin{array}{l} out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + \dfrac{L_{pl}}{f_{plATS}} + \dfrac{2 \cdot (L_{Primede})}{1 + f_{plATS} + (f_{plATS} - 1) \cdot \dfrac{L_{deATS} - (L_{Primede})}{L_{deATS}}}} \\ out \end{array} \right. \\ out \end{array}$$

Equation 20-21

Equation 20-22

$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) = 45.492$

$ATS_{Final} := ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede})$

$ATS_{Final} = 45.492$

Determine Level of Service.

$$
\mathrm{Los}(\mathrm{Class},\mathrm{PTSF},\mathrm{ATS},\mathrm{FFS}) :=
\left|
\begin{array}{l}
\text{if Class} = 1 \\
\quad \left|
\begin{array}{l}
out_1 \leftarrow \text{"A"} \;\; \text{if} \;\; \mathrm{PTSF} \le 35 \\
out_1 \leftarrow \text{"B"} \;\; \text{if} \;\; 35 < \mathrm{PTSF} \le 50 \\
out_1 \leftarrow \text{"C"} \;\; \text{if} \;\; 50 < \mathrm{PTSF} \le 65 \\
out_1 \leftarrow \text{"D"} \;\; \text{if} \;\; 65 < \mathrm{PTSF} \le 80 \\
out_1 \leftarrow \text{"E"} \;\; \text{if} \;\; \mathrm{PTSF} > 80 \\
out_2 \leftarrow \text{"A"} \;\; \text{if} \;\; \mathrm{ATS} > 55 \\
out_2 \leftarrow \text{"B"} \;\; \text{if} \;\; 50 < \mathrm{ATS} \le 55 \\
out_2 \leftarrow \text{"C"} \;\; \text{if} \;\; 45 < \mathrm{ATS} \le 50 \\
out_2 \leftarrow \text{"D"} \;\; \text{if} \;\; 40 < \mathrm{ATS} \le 45 \\
out_2 \leftarrow \text{"E"} \;\; \text{if} \;\; \mathrm{ATS} \le 40 \\
out \leftarrow \begin{pmatrix} out_1 \\ out_2 \end{pmatrix}
\end{array}
\right. \\
\text{if Class} = 2 \\
\quad \left|
\begin{array}{l}
out \leftarrow \text{"A"} \;\; \text{if} \;\; \mathrm{PTSF} \le 40 \\
out \leftarrow \text{"B"} \;\; \text{if} \;\; 40 < \mathrm{PTSF} \le 55 \\
out \leftarrow \text{"C"} \;\; \text{if} \;\; 55 < \mathrm{PTSF} \le 70 \\
out \leftarrow \text{"D"} \;\; \text{if} \;\; 70 < \mathrm{PTSF} \le 85 \\
out \leftarrow \text{"E"} \;\; \text{if} \;\; \mathrm{PTSF} > 80 \\
out
\end{array}
\right. \\
\text{if Class} = 3 \\
\quad \left|
\begin{array}{l}
out \leftarrow \text{"A"} \;\; \text{if} \;\; \dfrac{\mathrm{ATS}}{\mathrm{FFS}} > 0.917 \\
out \leftarrow \text{"B"} \;\; \text{if} \;\; 0.833 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.917 \\
out \leftarrow \text{"C"} \;\; \text{if} \;\; 0.750 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.833 \\
out \leftarrow \text{"D"} \;\; \text{if} \;\; 0.667 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.750 \\
out \leftarrow \text{"E"} \;\; \text{if} \;\; 0.583 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.667 \\
out \leftarrow \text{"F"} \;\; \text{if} \;\; \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.583 \\
out
\end{array}
\right. \\
out
\end{array}
\right.
$$

From Exhibit 20-2
HCM 2000

From Exhibit 20-4
HCM 2000

$$\mathrm{Los}(\mathrm{Class},\mathrm{PTSF}_d,\mathrm{ATS}_d,\mathrm{FFS}) = \begin{pmatrix} \text{"D"} \\ \text{"D"} \end{pmatrix}$$

If Class I, the LOWER LOS GOVERNS

$$\mathrm{Los}(\mathrm{Class},\mathrm{PTSF}_{Final},\mathrm{ATS}_{Final},\mathrm{FFS}) = \begin{pmatrix} \text{"C"} \\ \text{"C"} \end{pmatrix}$$

If Class I, the LOWER LOS GOVERNS

Mathcad Computations for Example 2

HIGHPLAN Computational Methodology Update for NCHRP 20-7 Revisions

UF-TRC

Application of the HIGHPLAN Computational Steps to Example Problem 2

Inputs and Initial Computations

1. Input Roadway and Traffic Data.

Roadway Variables

Class := 1

NumberofLanes := 2

AnalysisType := 1   0 = Segment, 1 = Facility

Terrain := 1   Level = 1, Rolling = 2

PostedSpeed := 50   mi/hr

Median := 1   0 = No, 1 = Yes

LeftTurnLane := 1   0 = No, 1 = Yes

%NPZ := 80

PresencePassingLane := 1   0 = No, 1 = Yes

Spacing := 2   mi

Traffic Variables

AADT := 10000

K := 0.095

D := 0.55

PHF := 0.925

PercentHeavyVehicles := 0.02

BaseCapacity := 1700

LocalAdjustmentFactor := 1

P_T := PercentHeavyVehicles

LAF := LocalAdjustmentFactor

2. Calculate DDHV (Design Directional Hour Volume)

Calculation:

DDHV := AADT·K·D

DDHV = 522.5

3. Determine adjustment for the presence of a median and/or left turn lanes.

Left Turn Lane Adjustment (LTadj) = -0.2 for left turn lanes NOT present, LTadj = 0 otherwise.

Median Adjustment (MedAdj) = 0.05 for median present, MadAdj = 0 otherwise.

Calculations:

Left Turn Lane:

$$LTadj(LeftTurnLane) := \left| \begin{array}{l} out \leftarrow -0.2 \ \text{ if } \ LeftTurnLane = 0 \\ out \leftarrow 0 \ \text{ if } \ LeftTurnLane = 1 \\ out \end{array} \right.$$

$LTadj(LeftTurnLane) = 0$ $\qquad LTadj := LTadj(LeftTurnLane)$ $\qquad LTadj = 0$

Median:

$$MedAdj(Median) := \left| \begin{array}{l} out \leftarrow 0 \ \text{ if } \ Median = 0 \\ out \leftarrow 0.05 \ \text{ if } \ Median = 1 \\ out \end{array} \right.$$

$MedAdj(Median) = 0.05$ $\qquad MedAdj := MedAdj(Median)$ $\qquad MedAdj = 0.05$

Final Adjustment Value for Left Turn Lane and Median:

$$AdjMedLTL := 1 + LTadj + MedAdj$$

$AdjMedLTL = 1.05$

4. Determine Facility Adjustment Factor (FacAdj).

FacAdj = 1.0 for Analysis Type = Segment

FacAdj = 0.9 for Analysis Type = Facility

Calculation:

$$FacAdj(AnalysisType) := \left| \begin{array}{l} out \leftarrow 1.0 \ \text{ if } \ AnalysisType = 0 \\ out \leftarrow 0.9 \ \text{ if } \ AnalysisType = 1 \\ out \end{array} \right.$$

$FacAdj(AnalysisType) = 0.9$ $\qquad FacAdj := FacAdj(AnalysisType)$ $\qquad FacAdj = 0.9$

5. Calculate Adjusted Volume (AdjVol).

Calculation:

$$AdjVol := \frac{DDHV}{PHF \cdot LAF \cdot AdjMedLTL \cdot FacAdj}$$

$AdjVol = 597.7$ veh/h $\qquad V := AdjVol$ $\qquad V = 597.741$ veh/h

Calculations for Percent Time Spent Following (PTSF)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \left| \begin{array}{l} \text{if } Terrain = 1 \\ \quad \left| \begin{array}{l} E_T \leftarrow 1.1 \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.1 \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \text{ if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \right. \\ \text{if } Terrain = 2 \\ \quad \left| \begin{array}{l} E_T \leftarrow 1.8 \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.5 \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \text{ if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \right. \\ out \end{array} \right.$$

From Exhibit 20-10
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.1 \\ 1.0 \end{pmatrix}$$

$E_T := PCEs(Terrain, V)_1$ $\quad E_T = 1.1$

$E_R := PCEs(Terrain, V)_2$ $\quad E_R = 1.0$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)}$$

$f_{HV} = 0.998$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$f_G(\text{Terrain}, V) := \begin{array}{|l} \text{if Terrain} = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \\ \text{if Terrain} = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.77 \ \text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.94 \ \text{ if } 300 < V \le 600 \\ f_G \leftarrow 1.0 \ \text{ if } V > 600 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \\ \text{out} \end{array}$$

From Exhibit 20-8
HCM 2000

$f_G(\text{Terrain}, V) = 1$ $\qquad$ $f_G := f_G(\text{Terrain}, V)$ $\qquad$ $f_G = 1.0$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 598.9$ pc/hr $\qquad$ $v_{dPTSF} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 490$

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine values of coefficients 'a' and 'b' for HCM Equation 20-17.

Look up values from HCM Exhibit 20-21 (linear interpolation if necessary).

Input:

v_o is rounded to the nearest 10 veh/h.

$\text{round}(v_o, -1) = 490$ pc/hr

From Exhibit, for $v_o = 400$; $a_1 := -0.0022$ $b_1 := 0.923$

From Exhibit, for $v_o = 600$; $a_2 := -0.0033$ $b_2 := 0.870$

From Exhibit 20-21
HCM 2000

Calculations:

$$a := a_1 + (490 - 400) \cdot \left(\frac{a_1 - a_2}{400 - 600} \right)$$

$a = -2.695 \times 10^{-3}$

$$b := b_1 + (490 - 400) \cdot \frac{b_1 - b_2}{400 - 600}$$

$b = 0.899$

12. Calculate base percent time spent following (BPTSF).

Calculations:

$$BPTSF_d := 100 \cdot \left(1 - e^{a \cdot v_d^{\,b}}\right)$$

From Equation 20-17
HCM 2000

$BPTSF_d = 57.1$

13. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-16.

Look up value from HCM Exhibit 20-20 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

PostedSpeed = 50 %NPZ = 80 $v_o = 490$

FFS := PostedSpeed + 5

FFS = 55

Calculation:

This example calls for interpolation by volume and by directional split

$v_p := v_d + v_o$ $v_p = 1.089 \times 10^3$

%NPZ = 80

D = 0.55

$Split_1 := 50$

$\%NPZ_{Low} := 60$ $\%NPZ_{High} := 80$

$v_{p1} := 800$ $f_1 := 44.0$ $g_1 := 44.8$

$v_{p2} := 1400$ $f_2 := 26.2$ $g_2 := 27.4$

From Exhibit 20-22
HCM 2000

$$Val_1 := \frac{g_2 - g_1}{v_{p2} - v_{p1}} \cdot \left(v_p - v_{p1}\right) + g_1$$ $Val_1 = 36.42$

$Split_2 := 60$

$\%NPZ_L := 60$ $\%NPZ_H := 80$

$v_{p3} := 800$ $f_3 := 38.6$ $g_3 := 39.9$

$v_{p4} := 1400$ $f_4 := 25.4$ $g_4 := 26.4$

$$Val_2 := \frac{g_4 - g_3}{v_{p4} - v_{p3}} \cdot (v_p - v_{p3}) + g_3 \qquad Val_2 = 33.398$$

$$DoubleInterp := \frac{Val_2 - Val_1}{Split_2 - Split_1} \cdot (100 \cdot D - Split_1) + Val_1 \qquad DoubleInterp = 34.909$$

$f_{np} := DoubleInterp$

$f_{np} = 34.9$

14. Calculate percent time spent following (PTSF).

Calculations:

$$PTSF_d := BPTSF_d + f_{np} \cdot \left(\frac{v_d}{v_o + v_d} \right)$$

From Equation 20-16
HCM 2000

$PTSF_d = 76.3$

If passing lanes are present, see calculations later in file.

Calculations for Average Travel Speed (ATS)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} E_T \leftarrow 1.7 \ \text{ if } \ 0 \le V \le 300 \\ E_T \leftarrow 1.2 \ \text{ if } \ 300 < V \le 600 \\ E_T \leftarrow 1.1 \ \text{ if } \ V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} E_T \leftarrow 2.5 \ \text{ if } \ 0 \le V \le 300 \\ E_T \leftarrow 1.9 \ \text{ if } \ 300 < V \le 600 \\ E_T \leftarrow 1.5 \ \text{ if } \ V > 600 \\ E_R \leftarrow 1.1 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-9
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.2 \\ 1.0 \end{pmatrix}$$

$E_T := PCEs(Terrain, V)_1$ $\quad E_T = 1.2$

$E_R := PCEs(Terrain, V)_2$ $\quad E_R = 1.0$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 0.996$$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$f_G(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ out \leftarrow f_G \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.71 \text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.93 \text{ if } 300 < V \le 600 \\ f_G \leftarrow 0.99 \text{ if } V > 600 \\ out \leftarrow f_G \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-7
HCM 2000

$f_G(Terrain, V) = 1$ $\qquad f_G := f_G(Terrain, V)$ $\qquad f_G = 1$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 600.1$ pc/h $\qquad v_{dATS} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 491$ pc/h

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-15.

Look up value from HCM Exhibit 20-19 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

PostedSpeed = 50 %NPZ = 80 $v_o = 491.017$

FFS := PostedSpeed + 5

FFS = 55

Calculation:

This example only calls for interpolation by volume,

$$f_{np} := 2.7 + (v_o - 400) \cdot \left(\frac{2.7 - 1.8}{400 - 600} \right)$$

$f_{np} = 2.29$

12. Calculate average travel speed (ATS).

Input:

$FFS_d := FFS$	$FFS_d = 55$	from inputs
$v_d = 600.1$	from step 9	
$v_o = 491$	from step 10	
$f_{np} = 2.29$	from step 11	

Calculation:

$$ATS_d := FFS_d - 0.00776 \cdot (v_d + v_o) - f_{np}$$

From Equation 20-5 HCM 2000

$ATS_d = 44.2$ mi/h

If passing lanes are present, see calculations below.

Additional Calculations for When Passing Lanes are Included

1. Input Roadway and Traffic Data.

Roadway Variables

$PassingLaneSpacing := 2$ mi

$L_t := PassingLaneSpacing \quad L_t = 2$

Traffic Variables

$v_{dATS} = 600.132 \qquad v_{dPTSF} = 598.936$

2. Determine the Downstream Length of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain.

L_{de} = Downstream Length of Affected Roadway

The L_{de} for the PTSF and ATS must be calculated using their respective v_d values. The ATS is a constant 1.7, but the PTSF must be interpolated from Exhibit 20-23.

$v_{d1} := 400 \qquad L_{de1} := 8.1$

$v_{d2} := 700 \qquad L_{de2} := 5.7$

$$L_{dePTSF} := \frac{L_{de2} - L_{de1}}{v_{d2} - v_{d1}} \cdot (v_{dPTSF} - v_{d1}) + L_{de1}$$

$L_{dePTSF} = 6.509 \qquad L_{deATS} := 1.7$

Equation 20-18

$$L_d = L_t - (L_u + L_{pl} + L_{de})$$

L_d = Length of the two-lane highway downstream of the passing lane and beyond its effective length,
L_t = total length of analysis segment,
L_u = length of two lane highway upstream of the passing lane,
L_{pl} = length of the passing lane including tapers, and
L_{de} = downstream length of the two-lane highway within the effective length of the passing lane.

HighPlan assumes that the L_u equals 0 and that L_{pl} equals 1.

$L_u := 0 \qquad L_{pl} := 1 \qquad L_t := PassingLaneSpacing \qquad L_t = 2$

$L_{dPTSF} := L_t - (L_u + L_{pl} + L_{dePTSF}) \qquad L_{dPTSF} = -5.509 \qquad L_{Primede} := L_t - L_{pl}$

$L_{dATS} := L_t - (L_u + L_{pl} + L_{deATS}) \qquad L_{dATS} = -0.7 \qquad L_{Primede} = 1$

3. Determine the Factors for Estimation of Average Travel Speed and Percent Time Spent Following within a Passing Lane.

$$f\_f_{plPTSF}(v_{dPTSF}) := \begin{array}{|l} out \leftarrow 0.58 \ \text{ if } \ 0 \le v_{dPTSF} < 300 \\ out \leftarrow 0.61 \ \text{ if } \ 300 \le v_{dPTSF} < 600 \\ out \leftarrow 0.62 \ \text{ if } \ v_{dPTSF} \ge 600 \\ \text{return } out \end{array}$$

From Exhibit 20-24
HCM 2000

$$f\_f_{plATS}(v_{dATS}) := \begin{array}{|l} out \leftarrow 1.08 \ \text{ if } \ 0 \le v_{dATS} < 300 \\ out \leftarrow 1.10 \ \text{ if } \ 300 \le v_{dATS} < 600 \\ out \leftarrow 1.11 \ \text{ if } \ v_{dATS} \ge 600 \\ \text{return } out \end{array}$$

$f\_f_{plPTSF}(v_{dPTSF}) = 0.61$

$f_{plPTSF} := f\_f_{plPTSF}(v_{dPTSF})$

$f_{plPTSF} = 0.61$

$f\_f_{plATS}(v_{dATS}) = 1.11$

$f_{plATS} := f\_f_{plATS}(v_{dATS})$

$f_{plATS} = 1.11$

4a. Adjust the Precent Time Spent Following for Passing Lanes

$$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) := \begin{array}{|l} \text{if } L_{dPTSF} \ge 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + L_{dPTSF} + f_{plPTSF} \cdot L_{pl} + \left(\dfrac{1 + f_{plPTSF}}{2}\right) \cdot L_{dePTSF}\right]}{PassingLaneSpacing} \\ out \end{array} \\ \text{if } L_{dPTSF} < 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + f_{plPTSF} \cdot L_{pl} + f_{plPTSF} \cdot (L_{Primede}) + \left(\dfrac{1 - f_{plPTSF}}{2}\right) \cdot \left(\dfrac{L_{Primede}^2}{L_{dePTSF}}\right)\right]}{PassingLaneSpacing} \\ out \end{array} \\ out \end{array}$$

Equation 20-19

Equation 20-20

$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) = 47.702$

$PTSF_{Final} := PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede})$

$PTSF_{Final} = 47.702$

4b. Adjust Average Travel Time for Passing Lanes

$$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) := \begin{cases} \text{if } L_{dATS} \geq 0 \\ \quad out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + L_{dATS} + \dfrac{L_{pl}}{f_{plATS}} + 2 \cdot \dfrac{L_{deATS}}{1 + f_{plATS}}} \\ \quad out \\ \text{if } L_{dATS} < 0 \\ \quad out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + \dfrac{L_{pl}}{f_{plATS}} + \dfrac{2 \cdot (L_{Primede})}{1 + f_{plATS} + (f_{plATS} - 1) \cdot \dfrac{L_{deATS} - (L_{Primede})}{L_{deATS}}}} \\ \quad out \\ out \end{cases}$$

Equation 20-21

Equation 20-22

$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) = 48.383$

$ATS_{Final} := ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede})$

$ATS_{Final} = 48.383$

Determine Level of Service.

$$\text{Los}(\text{Class},\text{PTSF},\text{ATS},\text{FFS}) := \left| \begin{array}{l} \text{if Class} = 1 \\ \quad \left| \begin{array}{l} out_1 \leftarrow \text{"A" if PTSF} \le 35 \\ out_1 \leftarrow \text{"B" if } 35 < \text{PTSF} \le 50 \\ out_1 \leftarrow \text{"C" if } 50 < \text{PTSF} \le 65 \\ out_1 \leftarrow \text{"D" if } 65 < \text{PTSF} \le 80 \\ out_1 \leftarrow \text{"E" if PTSF} > 80 \\ out_2 \leftarrow \text{"A" if ATS} > 55 \\ out_2 \leftarrow \text{"B" if } 50 < \text{ATS} \le 55 \\ out_2 \leftarrow \text{"C" if } 45 < \text{ATS} \le 50 \\ out_2 \leftarrow \text{"D" if } 40 < \text{ATS} \le 45 \\ out_2 \leftarrow \text{"E" if ATS} \le 40 \\ out \leftarrow \begin{pmatrix} out_1 \\ out_2 \end{pmatrix} \end{array} \right. \\ \text{if Class} = 2 \\ \quad \left| \begin{array}{l} out \leftarrow \text{"A" if PTSF} \le 40 \\ out \leftarrow \text{"B" if } 40 < \text{PTSF} \le 55 \\ out \leftarrow \text{"C" if } 55 < \text{PTSF} \le 70 \\ out \leftarrow \text{"D" if } 70 < \text{PTSF} \le 85 \\ out \leftarrow \text{"E" if PTSF} > 80 \\ out \end{array} \right. \\ \text{if Class} = 3 \\ \quad \left| \begin{array}{l} out \leftarrow \text{"A" if } \frac{\text{ATS}}{\text{FFS}} > 0.917 \\ out \leftarrow \text{"B" if } 0.833 < \frac{\text{ATS}}{\text{FFS}} \le 0.917 \\ out \leftarrow \text{"C" if } 0.750 < \frac{\text{ATS}}{\text{FFS}} \le 0.833 \\ out \leftarrow \text{"D" if } 0.667 < \frac{\text{ATS}}{\text{FFS}} \le 0.750 \\ out \leftarrow \text{"E" if } 0.583 < \frac{\text{ATS}}{\text{FFS}} \le 0.667 \\ out \leftarrow \text{"F" if } \frac{\text{ATS}}{\text{FFS}} \le 0.583 \\ out \end{array} \right. \\ out \end{array} \right.$$

From Exhibit 20-2 HCM 2000

From Exhibit 20-4 HCM 2000

$$\text{Los}(\text{Class},\text{PTSF}_d,\text{ATS}_d,\text{FFS}) = \begin{pmatrix} \text{"D"} \\ \text{"D"} \end{pmatrix}$$

If Class 1, the LOWER LOS GOVERNS

$$\text{Los}(\text{Class},\text{PTSF}_{Final},\text{ATS}_{Final},\text{FFS}) = \begin{pmatrix} \text{"B"} \\ \text{"C"} \end{pmatrix}$$

If Class 1, the LOWER LOS GOVERNS

Mathcad Computations for Example 3

HIGHPLAN Computational Methodology Update for NCHRP 20-7 Revisions

UF-TRC

Application of the HIGHPLAN Computational Steps to Example Problem 3

Inputs and Initial Computations

1. Input Roadway and Traffic Data.

Roadway Variables

Class := 1

NumberofLanes := 2

AnalysisType := 1   0 = Segment, 1 = Facility

Terrain := 1   Level = 1, Rolling = 2

PostedSpeed := 55   mi/hr

Median := 1   0 = No, 1 = Yes

LeftTurnLane := 1   0 = No, 1 = Yes

%NPZ := 20

PresencePassingLane := 1   0 = No, 1 = Yes

Spacing := 2   mi

Traffic Variables

AADT := 5000

K := 0.098

D := 0.60

PHF := 0.88

PercentHeavyVehicles := 0.05

BaseCapacity := 1700

LocalAdjustmentFactor := 0.9

P_T := PercentHeavyVehicles

LAF := LocalAdjustmentFactor

2. Calculate DDHV (Design Directional Hour Volume)

Calculation:

DDHV := AADT·K·D

DDHV = 294

3. Determine adjustment for the presence of a median and/or left turn lanes.

Left Turn Lane Adjustment (LTadj) = -0.2 for left turn lanes NOT present, LTadj = 0 otherwise.

Median Adjustment (MedAdj) = 0.05 for median present, MadAdj = 0 otherwise.

Calculations:

Left Turn Lane:

$$\mathrm{LTadj(LeftTurnLane)} := \left| \begin{array}{l} \mathrm{out} \leftarrow -0.2 \ \text{ if } \ \mathrm{LeftTurnLane} = 0 \\ \mathrm{out} \leftarrow 0 \ \text{ if } \ \mathrm{LeftTurnLane} = 1 \\ \mathrm{out} \end{array} \right.$$

$\mathrm{LTadj(LeftTurnLane)} = 0$ $\quad$ $\mathrm{LTadj} := \mathrm{LTadj(LeftTurnLane)}$ $\quad$ $\mathrm{LTadj} = 0$

Median:

$$\mathrm{MedAdj(Median)} := \left| \begin{array}{l} \mathrm{out} \leftarrow 0 \ \text{ if } \ \mathrm{Median} = 0 \\ \mathrm{out} \leftarrow 0.05 \ \text{ if } \ \mathrm{Median} = 1 \\ \mathrm{out} \end{array} \right.$$

$\mathrm{MedAdj(Median)} = 0.05$ $\quad$ $\mathrm{MedAdj} := \mathrm{MedAdj(Median)}$ $\quad$ $\mathrm{MedAdj} = 0.05$

Final Adjustment Value for Left Turn Lane and Median:

$$\mathrm{AdjMedLTL} := 1 + \mathrm{LTadj} + \mathrm{MedAdj}$$

$\mathrm{AdjMedLTL} = 1.05$

4. Determine Facility Adjustment Factor (FacAdj).

FacAdj = 1.0 for Analysis Type = Segment

FacAdj = 0.9 for Analysis Type = Facility

Calculation:

$$\mathrm{FacAdj(AnalysisType)} := \left| \begin{array}{l} \mathrm{out} \leftarrow 1.0 \ \text{ if } \ \mathrm{AnalysisType} = 0 \\ \mathrm{out} \leftarrow 0.9 \ \text{ if } \ \mathrm{AnalysisType} = 1 \\ \mathrm{out} \end{array} \right.$$

$\mathrm{FacAdj(AnalysisType)} = 0.9$ $\quad$ $\mathrm{FacAdj} := \mathrm{FacAdj(AnalysisType)}$ $\quad$ $\mathrm{FacAdj} = 0.9$

5. Calculate Adjusted Volume (AdjVol).

Calculation:

$$\mathrm{AdjVol} := \frac{\mathrm{DDHV}}{\mathrm{PHF} \cdot \mathrm{LAF} \cdot \mathrm{AdjMedLTL} \cdot \mathrm{FacAdj}}$$

$\mathrm{AdjVol} = 392.8$ veh/h $\quad$ $\mathrm{V} := \mathrm{AdjVol}$ $\quad$ $\mathrm{V} = 392.817$ veh/h

Calculations for Percent Time Spent Following (PTSF)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} E_T \leftarrow 1.1 \ \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.1 \ \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \ \text{ if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} E_T \leftarrow 1.8 \ \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.5 \ \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.0 \ \text{ if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-10
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.1 \\ 1.0 \end{pmatrix}$$

$$E_T := PCEs(Terrain, V)_1 \qquad E_T = 1.1$$

$$E_R := PCEs(Terrain, V)_2 \qquad E_R = 1.0$$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 0.995$$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$f_G(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ out \leftarrow f_G \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.77 \;\text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.94 \;\text{ if } 300 < V \le 600 \\ f_G \leftarrow 1.0 \;\text{ if } V > 600 \\ out \leftarrow f_G \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-8
HCM 2000

$f_G(Terrain, V) = 1$ $\qquad f_G := f_G(Terrain, V)$ $\qquad f_G = 1.0$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 394.8$ pc/hr $\qquad v_{dPTSF} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 263.2$

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine values of coefficients 'a' and 'b' for HCM Equation 20-17.

Look up values from HCM Exhibit 20-21 (linear interpolation if necessary).

Input:

v_o is rounded to the nearest 10 veh/h.

$\text{round}(v_o, -1) = 260$ pc/hr

From Exhibit, for $v_o = 200$ $a_1 := -0.0014$ $b_1 := 0.973$

From Exhibit, for $v_o = 400$; $a_2 := -0.0022$ $b_2 := 0.923$

From Exhibit 20-21
HCM 2000

Calculations:

$$a := a_1 + (260 - 200) \cdot \left(\frac{a_1 - a_2}{200 - 400} \right)$$

$a = -1.64 \times 10^{-3}$

$$b := b_1 + (260 - 200) \cdot \frac{b_1 - b_2}{200 - 400}$$

$b = 0.958$

12. Calculate base percent time spent following (BPTSF).

Calculations:

$$BPTSF_d := 100 \cdot \left(1 - e^{a \cdot v_d^{\,b}}\right)$$

From Equation 20-17
HCM 2000

$BPTSF_d = 39.6$

13. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-16.

Look up value from HCM Exhibit 20-20 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

$PostedSpeed = 55$ $\quad$ $\%NPZ = 20$ $\quad$ $v_o = 263.2$

$FFS := PostedSpeed + 5$

$FFS = 60$

Calculation:

This example calls for interpolation by volume and by directional split

$v_p := v_d + v_o$ $\quad$ $v_p = 657.969$

$\%NPZ = 20$

$D = 0.6$

Split = 60/40 $\quad$ %NPZ = 20

$v_{p1} := 600$ $\quad$ $f_1 := 36.9$

$v_{p2} := 800$ $\quad$ $f_2 := 28.2$

From Exhibit 20-22
HCM 2000

$$Val_1 := \frac{f_2 - f_1}{v_{p2} - v_{p1}} \cdot \left(v_p - v_{p1}\right) + f_1 \qquad Val_1 = 34.378$$

$DoubleInterp := Val_1$ $\qquad$ $DoubleInterp = 34.378$

$f_{np} := \text{DoubleInterp}$

$f_{np} = 34.4$

14. Calculate percent time spent following (PTSF).

Calculations:

$$PTSF_d := BPTSF_d + f_{np} \cdot \left(\frac{v_d}{v_o + v_d} \right)$$

From Equation 20-16
HCM 2000

$PTSF_d = 60.2$

If passing lanes are present, see calculations later in file.

Calculations for Average Travel Speed (ATS)

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$PCEs(Terrain, V) := \left| \begin{array}{l} \text{if } Terrain = 1 \\ \quad \left| \begin{array}{l} E_T \leftarrow 1.7 \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.2 \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.1 \text{ if } V > 600 \\ E_R \leftarrow 1.0 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \right. \\ \text{if } Terrain = 2 \\ \quad \left| \begin{array}{l} E_T \leftarrow 2.5 \text{ if } 0 \le V \le 300 \\ E_T \leftarrow 1.9 \text{ if } 300 < V \le 600 \\ E_T \leftarrow 1.5 \text{ if } V > 600 \\ E_R \leftarrow 1.1 \\ out \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\ out \end{array} \right. \\ out \end{array} \right.$$

From Exhibit 20-9
HCM 2000

$$PCEs(Terrain, V) = \begin{pmatrix} 1.2 \\ 1.0 \end{pmatrix}$$

$$E_T := PCEs(Terrain, V)_1 \qquad E_T = 1.2$$

$$E_R := PCEs(Terrain, V)_2 \qquad E_R = 1.0$$

7. Calculate heavy vehicle factor (f_{HV}).

Calculation:

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 0.99$$

From Equation 20-4
HCM 2000

8. Determine grade adjustment factor (f_G).

Calculation:

$$f_G(Terrain, V) := \begin{array}{|l} \text{if } Terrain = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ out \leftarrow f_G \\ out \end{array} \\ \text{if } Terrain = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.71 \ \text{ if } 0 \le V \le 300 \\ f_G \leftarrow 0.93 \ \text{ if } 300 < V \le 600 \\ f_G \leftarrow 0.99 \ \text{ if } V > 600 \\ out \leftarrow f_G \\ out \end{array} \\ out \end{array}$$

From Exhibit 20-7
HCM 2000

$f_G(Terrain, V) = 1$ $\qquad f_G := f_G(Terrain, V)$ $\qquad f_G = 1$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

Since the PHF was already accounted for in Step 5, the following equation is used:

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 396.7$ pc/h $\qquad v_{dATS} := v_d$

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 264.5$ pc/h

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-15.

Look up value from HCM Exhibit 20-19 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

$PostedSpeed = 55$ $\%NPZ = 20$ $v_o = 264.497$

$FFS := PostedSpeed + 5$

$FFS = 60$

Calculation:

This example only calls for interpolation by volume,

$$f_{np} := \frac{1.4 - 1.9}{400 - 200} \cdot (v_o - 200) + 1.9$$

$f_{np} = 1.74$

12. Calculate average travel speed (ATS).

Input:

$FFS_d := FFS$	$FFS_d = 60$	from inputs
$v_d = 396.7$	from step 9	
$v_o = 264.5$	from step 10	
$f_{np} = 1.74$	from step 11	

Calculation:

$$ATS_d := FFS_d - 0.00776 \cdot (v_d + v_o) - f_{np}$$

From Equation 20-5
HCM 2000

$ATS_d = 53.1$ mi/h

If passing lanes are present, see calculations later in file.

Additional Calculations for When Passing Lanes are Included

1. Input Roadway and Traffic Data.

Roadway Variables

$PassingLaneSpacing := 2$ mi

$L_t := PassingLaneSpacing$ $\quad L_t = 2$

Traffic Variables

$v_{dATS} = 396.745$ $\quad v_{dPTSF} = 394.781$

2. Determine the Downstream Length of Roadway Affected by Passing Lanes on Directional Segments in Level and Rolling Terrain.

L_{de} = Downstream Length of Affected Roadway

The L_{de} for the PTSF and ATS must be calculated using their respective v_d values. The ATS is a constant 1.7, but the PTSF must be interpolated from Exhibit 20-23.

$v_{d1} := 400$ $\quad L_{de1} := 8.1$

$v_{d2} := 700$ $\quad L_{de2} := 5.7$

$$L_{dePTSF} := \frac{L_{de2} - L_{de1}}{v_{d2} - v_{d1}} \cdot \left(v_{dPTSF} - v_{d1}\right) + L_{de1}$$

$L_{dePTSF} = 8.142$ $\quad L_{deATS} := 1.7$

Equation 20-18

$$L_d = L_t - (L_u + L_{pl} + L_{de})$$

L_d = Length of the two-lane highway downstream of the passing lane and beyond its effective length,
L_t = total length of analysis segment,
L_u = length of two lane highway upstream of the passing lane,
L_{pl} = length of the passing lane including tapers, and
L_{de} = downstream length of the two-lane highway within the effective length of the passing lane.

HighPlan assumes that the L_u equals 0 and that L_{pl} equals 1.

$L_u := 0$ $\quad L_{pl} := 1$ $\quad L_t := PassingLaneSpacing$ $\quad L_t = 2$

$L_{dPTSF} := L_t - \left(L_u + L_{pl} + L_{dePTSF}\right)$ $\quad L_{dPTSF} = -7.142$ $\quad L_{Primede} := L_t - L_{pl}$

$L_{dATS} := L_t - \left(L_u + L_{pl} + L_{deATS}\right)$ $\quad L_{dATS} = -0.7$ $\quad L_{Primede} = 1$

3. Determine the Factors for Estimation of Average Travel Speed and Percent Time Spent Following within a Passing Lane.

$$f\_f_{plPTSF}(v_{dPTSF}) := \begin{array}{|l} out \leftarrow 0.58 \ \text{ if } \ 0 \le v_{dPTSF} < 300 \\ out \leftarrow 0.61 \ \text{ if } \ 300 \le v_{dPTSF} < 600 \\ out \leftarrow 0.62 \ \text{ if } \ v_{dPTSF} \ge 600 \\ \text{return } out \end{array}$$

From Exhibit 20-24
HCM 2000

$$f\_f_{plATS}(v_{dATS}) := \begin{array}{|l} out \leftarrow 1.08 \ \text{ if } \ 0 \le v_{dATS} < 300 \\ out \leftarrow 1.10 \ \text{ if } \ 300 \le v_{dATS} < 600 \\ out \leftarrow 1.11 \ \text{ if } \ v_{dATS} \ge 600 \\ \text{return } out \end{array}$$

$f\_f_{plPTSF}(v_{dPTSF}) = 0.61$

$f_{plPTSF} := f\_f_{plPTSF}(v_{dPTSF})$

$f_{plPTSF} = 0.61$

$f\_f_{plATS}(v_{dATS}) = 1.1$

$f_{plATS} := f\_f_{plATS}(v_{dATS})$

$f_{plATS} = 1.1$

4a. Adjust the Precent Time Spent Following for Passing Lanes

$$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) := \begin{array}{|l} \text{if } L_{dPTSF} \ge 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + L_{dPTSF} + f_{plPTSF} \cdot L_{pl} + \left(\dfrac{1 + f_{plPTSF}}{2}\right) \cdot L_{dePTSF}\right]}{PassingLaneSpacing} \\ out \end{array} \\ \text{if } L_{dPTSF} < 0 \\ \quad \begin{array}{|l} out \leftarrow \dfrac{PTSF_d \cdot \left[L_u + f_{plPTSF} \cdot L_{pl} + f_{plPTSF} \cdot (L_{Primede}) + \left(\dfrac{1 - f_{plPTSF}}{2}\right) \cdot \left(\dfrac{L_{Primede}^{\ 2}}{L_{dePTSF}}\right)\right]}{PassingLaneSpacing} \\ out \end{array} \\ out \end{array}$$

Equation 20-19

Equation 20-20

$PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede}) = 37.441$

$PTSF_{Final} := PTSF_{pl}(L_{dePTSF}, f_{plPTSF}, L_{dPTSF}, L_{Primede})$

$PTSF_{Final} = 37.441$

4b. Adjust Average Travel Time for Passing Lanes

$$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) := \begin{array}{l} \text{if } L_{dATS} \geq 0 \\ \quad \left| \begin{array}{l} out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + L_{dATS} + \dfrac{L_{pl}}{f_{plATS}} + 2 \cdot \dfrac{L_{deATS}}{1 + f_{plATS}}} \\ out \end{array} \right. \\ \text{if } L_{dATS} < 0 \\ \quad \left| \begin{array}{l} out \leftarrow \dfrac{ATS_d \cdot PassingLaneSpacing}{L_u + \dfrac{L_{pl}}{f_{plATS}} + \dfrac{2 \cdot (L_{Primede})}{1 + f_{plATS} + (f_{plATS} - 1) \cdot \dfrac{L_{deATS} - (L_{Primede})}{L_{deATS}}}} \\ out \end{array} \right. \\ out \end{array}$$

Equation 20-21

Equation 20-22

$$ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede}) = 57.651$$

$$ATS_{Final} := ATS_{plATS}(L_{deATS}, f_{plATS}, L_{dATS}, L_{Primede})$$

$$ATS_{Final} = 57.651$$

Determine Level of Service.

```
Los(Class,PTSF,ATS,FFS) := | if Class = 1
                           |   | out1 ← "A"  if PTSF ≤ 35
                           |   | out1 ← "B"  if 35 < PTSF ≤ 50
                           |   | out1 ← "C"  if 50 < PTSF ≤ 65
                           |   | out1 ← "D"  if 65 < PTSF ≤ 80
                           |   | out1 ← "E"  if PTSF > 80
                           |   | out2 ← "A"  if ATS > 55
                           |   | out2 ← "B"  if 50 < ATS ≤ 55
                           |   | out2 ← "C"  if 45 < ATS ≤ 50
                           |   | out2 ← "D"  if 40 < ATS ≤ 45
                           |   | out2 ← "E"  if ATS ≤ 40
                           |   | out ← (out1, out2)
                           | if Class = 2
                           |   | out ← "A"  if PTSF ≤ 40
                           |   | out ← "B"  if 40 < PTSF ≤ 55
                           |   | out ← "C"  if 55 < PTSF ≤ 70
                           |   | out ← "D"  if 70 < PTSF ≤ 85
                           |   | out ← "E"  if PTSF > 80
                           |   | out
                           | if Class = 3
                           |   | out ← "A"  if ATS/FFS > 0.917
                           |   | out ← "B"  if 0.833 < ATS/FFS ≤ 0.917
                           |   | out ← "C"  if 0.750 < ATS/FFS ≤ 0.833
                           |   | out ← "D"  if 0.667 < ATS/FFS ≤ 0.750
                           |   | out ← "E"  if 0.583 < ATS/FFS ≤ 0.667
                           |   | out ← "F"  if ATS/FFS ≤ 0.583
                           |   | out
                           | out
```

From Exhibit 20-2 HCM 2000 (Class 1)

From Exhibit 20-4 HCM 2000 (Class 2)

$Los(Class, PTSF_d, ATS_d, FFS) = \begin{pmatrix} \text{"C"} \\ \text{"B"} \end{pmatrix}$ If Class I, the LOWER LOS GOVERNS

$Los(Class, PTSF_{Final}, ATS_{Final}, FFS) = \begin{pmatrix} \text{"B"} \\ \text{"A"} \end{pmatrix}$ If Class I, the LOWER LOS GOVERNS

Task 2a

Roundtable Discussion on Two-Lane Highway Classifications and Preferred Service Measures

Typology Field Review

As a precursor to the roundtable meeting, a field review was conducted of several two-lane highways in north central Florida, most of which are also representative of two-lane highways in other parts of the state as well. The field review team consisted of two University of Florida research personnel – Scott Washburn (PI) and Brad Choi (graduate research assistant), and two FDOT systems planning office personnel, Doug McLeod and Gina Bonyani. It was felt that this exercise would facilitate a mutual understanding of the potentially different types of two-lane highways present in Florida between the UF research team and FDOT project management team.

The field study was conducted on May 13, 2003. The purpose of the study was to examine a number of two-lane highways for their physical characteristics, surrounding land development, and primary travel function in an effort to potentially assess the adequacy of the existing two classifications defined in the HCM for analyzing all of the potential two-lane highway situations in the state of Florida. Furthermore, it was intended to use some the of video data collected during this exercise for the roundtable meeting.

The group departed from Gainesville at 11 a.m. and concluded the study at approximately 6 p.m. A camcorder was used to document selected highway segments and related discussion during the study. The studied facilities were as follows:

A. CR 25A from US 301 to US 441
B. CR 326 from US 27 to I-75
C. US 27 from I-75 to Williston
D. Alternate 27 from Williston to Chiefland
E. US 41 from Williston to Newberry
F. SR 26 from Fanning Springs to I-75
G. CR 318 from I-75 to US 301
H. SR 326 from US 301 to SR 40
I. CR 315 from SR 40 to SR 20 (portions via CR 21)
J. SR 20 from CR 21 to SR 24

Figure 1 shows these facilities graphically, referencing each roadway with its corresponding letter. Selected facilities are discussed below.

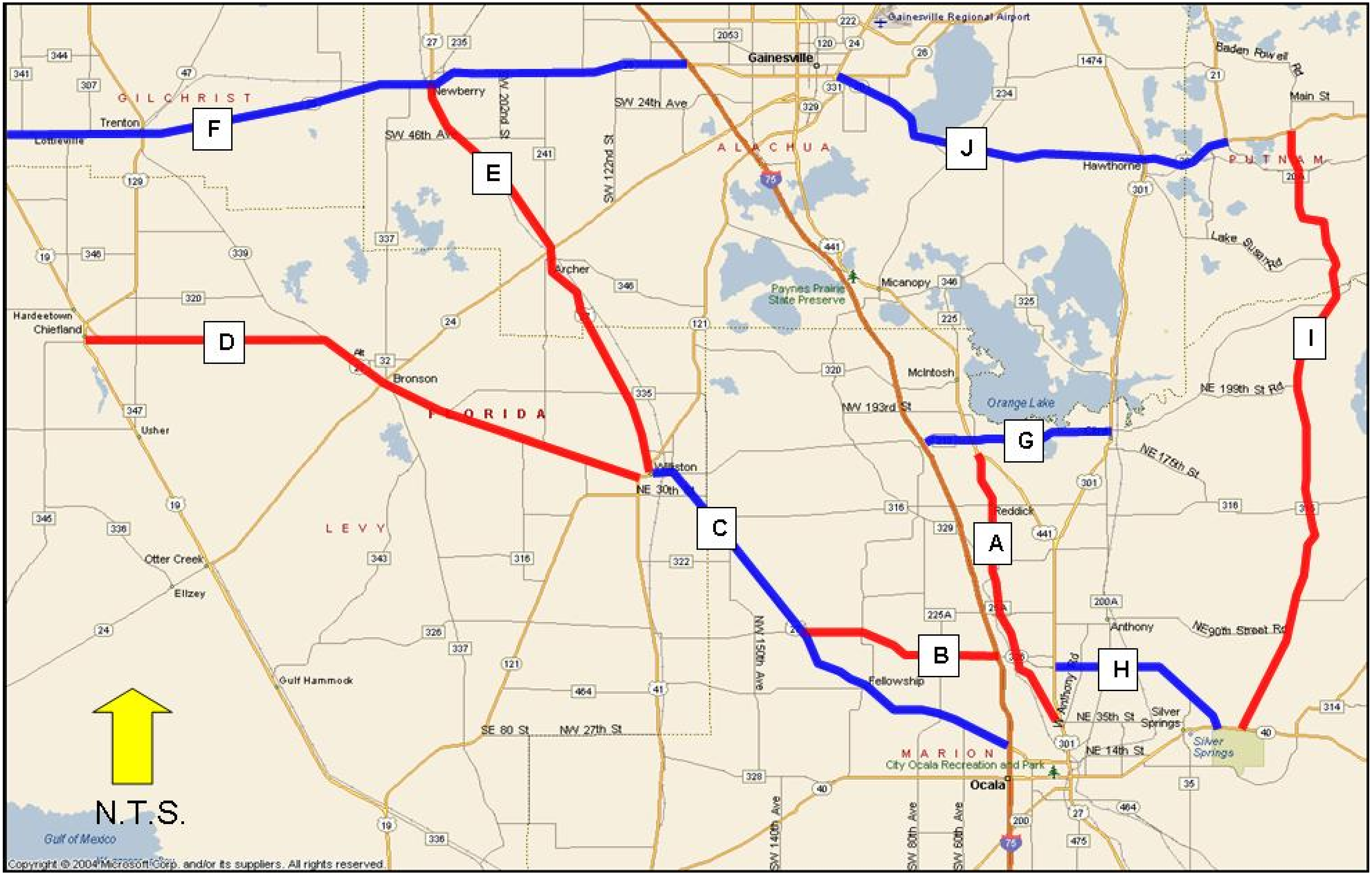


Figure 1. Study Roadway Locations

County Road 25A in Marion County

This facility is approximately 10 miles in length. It connects US 441 from Ocala back to US 441 just north of the town of Reddick. This two-lane facility is primarily rural undeveloped, but becomes rural developed as it passes through the town of Reddick, with a population of 500-1000. As seen in Figure 2, it has narrow lanes (11 ft) and no shoulders. The speed limit drops from 55 mph to 45 mph as it enters the town of Reddick. There are several all-way stop controlled intersections, but no signalized intersections on this facility. It was generally agreed that for the rural undeveloped sections of this highway, it should be analyzed as a Class II (i.e., PTSF as the service measure), but that this is probably not appropriate for the section through the town of Reddick.

Figure 2. CR 25A

County Road 326 in Marion County

This facility is approximately 8 miles in length and connects from US 27 to just west of I-75. This facility is both rural developed and undeveloped. As shown in Figure 3, it has narrow lanes (10 or 11 ft), no shoulders, and speed limit of 55 mph. The field study team concluded that this segment has the characteristics of a Class II facility, although it may also be classified as Class I. Professional judgement should be used on this segment.

Figure 3. CR 326

US 27 in Marion and Levy Counties

This segment of US 27 begines at the intersection of CR 326 and travels north through the cities of Williston, Bronson, and ends in Chiefland. This is a Florida Intrastate Highway System (FIHS) facility. FIHS is a statewide transportation network that provides high-speed and high-volume traffic movements within the state of Florida. The primary function of the system is to serve intrastate and regional commerce and long distance trips. The segment from CR 326 to Williston is currently being expanded into a multilane facility. This is a rural undeveloped facility and has 12-ft lanes and mostly 3-ft shoulders as shown in Figure 4. This is clearly a Class I facility. The portion where it passes through the city of Williston is four-lane with multiple signals. This section should be anazlyzed as a signalized multilane arterial.

Figure 4. US 27

US 41 in Levy and Alachua Counties

The first portion of this segment is four lanes leaving Williston. It then becomes two lanes, passing through the town of Archer and ending in Newberry. There is one isolated signal in the town of Archer (Figure 5). This facility has mostly narrow (11 ft) lanes without shoulders. The speed limit is primarily 60 mph. This facility fits the characteristics of Class I. However, the portion where it passes through Archer and the one where it enters Newberry do not seem to fit well with either Class I or Class II, and thus might be considered a third class, say Class III.

Figure 5. US 41

State Route 26 in Alachua County

This section of SR 26 connects from Newberry to I-75. This is another FIHS facility and is currently undergoing capacity improvements. The current two-lane facility has 12-ft lanes and wide shoulders as shown in Figure 6. This is clearly a Class I facility as it serves as a commuter route into a major traffic generator (Gainesville).

Figure 6. SR 26

County Road 234 in Alachua County

CR 234, as shown in Figure 7, from Micanopy to Rochelle is a designated scenic route. It has narrow (10 or 11 ft) lanes with no shoulder. The posted speed limit is 55 mph. The field review group was undecided as to whether this should be analyzed as a Class I or Class II highway. One member also noted that Class II roadways should be a combination of both ATS and PTSF where ATS would be the primary service measure for residents in the area of the facility and PTSF the service measure for pass-through traffic.

Figure 7. CR 234

State Route 325 in Alachua County

SR 325 in the southeastern corner of Alachua County connects SR 20 to US 301. It has 10-ft lanes with no shoulders. This road has the characteristics of a Class II roadway. It does not connect major traffic generators nor is it a major intercity route.

Figure 8. SR 325

County Road 200A in Marion County

CR 200A branches off of US 301 at the town of Citra and connects back to US 301 just north of Ocala. It was pointed out by Doug McLeod that this route used to be the primary truck route in the 1950's between Ocala and Jacksonville. It is now a secondary route that connects to a four-lane facility (US 301). This segment has 11-ft lanes with no shoulders. The group also noticed a section of no passing zone due to vertical geometry, as shown in Figure 9. Due to its travel function and geometric restrictions on passing, the field study group agreed that this is a Class II highway.

Figure 9. CR 200A

State Road 20 in Putnam and Alachua Counties

This roadway had 12 ft lanes, but no shoulders (Figure 10). This road is higher speed and generally serves traffic traveling between Hawthorne and Gainesville, and was thus considered to be Class I.

Figure 10. SR 20

The field review group raised the questions of how to incorporate isolated signals into uninterrupted flow, and whether to account for driveways on just one side or both sides of a two-lane highway. The group also emphasized the potential applicability of percent free-flow speed as a service measure in rural developed areas.

Roundtable Discussion Meeting

On September 12, 2003, a roundtable discussion session was held in Gainesville, Florida at the North Central Florida Regional Planning Council (NCFRPC) office. Invitation letters were sent out to members of four different regional planning councils, as well as multiple FDOT District Offices. The purpose of this meeting was to bring together personnel from these agencies that are familiar with the planning and operational aspects of two-lane highways in order to gain more insight into the issues regarding the existing analysis methodology. Dr. Scott Washburn and graduate student Brad Choi facilitated the meeting. The other meeting attendees were:

Doug McLeod, FDOT Systems Planning Office
Gina Bonyani, FDOT Systems Planning Office
Mike Escalante, North Central Florida Regional Planning Council
Lea Gabbay, FDOT District Two
Charles Houston, FDOT District Two
Keith McCarron, Appalachee Regional Planning Council

Select samples of the video data collected during the field review, as well as some additional video captured of two-lane highways in a coastal area and through a small town, were utilized in the roundtable meeting[1]. The following text summarizes the main discussion points from this roundtable meeting. A full transcript (edited for content and clarity) of the roundtable session is provided later in this section.

The roundtable session began with Dr. Scott Washburn giving an overview of the background of two-lane highway analysis and the issues of the HCM2000 methodologies. Washburn explained, "the main issue for us right now is whether the existing two classes that are defined in Chapters 12 and 20…whether those adequately cover two-lane highways that we have nationwide, and in particular here in the state of Florida. So that's where we are looking for feedback from people who have used the methodology and have tried to apply it to different two-lane highways in the state."

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[1] Some of these videos were also used in a presentation at a workshop on two-lane highways at the Highway Capacity and Quality of Service (HCQS) Committee meeting at the 2004 Transportation Research Board meeting (Washington, DC).

It was then followed by discussion and input from the participants. Gabbay on several occasions pointed out that percent time-spent following was not a main concern for her. Rather it was the ability to stay close to the speed limit. She noted. “My experience – the time I spend on viewing the sideways, the stores and everything else. It’s not going to bother me how much time I spent following somebody else. How close am I to my destination? And speed does have something to say. If it’s 30 or 40 or 50 I will always try to beat that speed – I don’t care what it is. That’s human nature.”

Escalante echoed this point by noting, “I think that’s a reasonable expectation, that is, if everybody’s going at the speed limit and there’s no tractor on the road to aggravate everybody, then regardless of how long you spend following you should have a high level of service.” He also added, “My concern about using the term ‘percent time spent following’ -- it sounds like you’re trapped behind the vehicle in front of you, you can’t get around and I think actually following somebody at a reasonable speed like we were talking about before is a choice and therefore I have absolutely no problem following somebody for 90% of the time of each trip. So a factor in measuring LOS is to identify whether the driver spending all that time following was a choice or a constraint, over the length of this facility, were there opportunities to pass. In other words, how much of that facility was striped “no passing” or striped to allow passing, regardless of the oncoming traffic. So if he had an opportunity to pass and there are no cars coming, he can pass, but if it’s a double yellow line then that person is trapped, and being trapped may be an issue in the comfort of their ride. It’s not just an issue of… it’s an issue of the opportunity to pass or the choice not to. Given that you’re traveling at an adequate speed.”

Participants raised the point of whether two classes of two-lane highways are enough. Gabbay noted, “Is there a possibility of considering a transitional Class 2? Let me just explain this – you have a clear Class 1 which is obvious to us. Where speed is higher, where you have some interruption but they’re not as difficult to overcome. Then you have the extreme Class 2, which is really already built, you constantly stop and you have to (and sometimes it’s constrained, you can’t do anything – you cannot add lanes or anything). So maybe there's a transition because before you get to this the category of Class 2, that is, the final, you have developable land along a Class 1 that is not on the coast but will become as critical maybe as the coast."

Escalante said, "…maybe somebody needs to fill in between Class 1 and Class 2 and our offer is - like you would see Class 1 as an extreme for the free open road measurement, so to speak, but the question is Class 2 at the other end. Is that the other pole and you're trying to figure out what's in between. Maybe there are developments to a level that's not really urban but to a level that maybe Class 2 is not adequately measuring level of service, and you need to even go beyond Class 2 and then continue the measurement. I can't say that would be the case, but maybe an issue of introducing another factor to measure, to deal with the other level of service."

McCarron raised the point of trip purpose by saying, "Some of those functions at different points in time have different classes. Like during the working week you know it's a commuter road but on the weekend it's a scenic highway. In our region, we've got a large national forest where they're trying to designate scenic highways that on a lot of the roads during the week are used as commuter roads."

During the second half of the meeting, video clips of two-lane highways taken during the field review were shown to gather the opinion from participants about each roadway. During this portion of the discussion, participants pointed out the role of geometry in roadway classification. Escalante noted, "…with better geometry there's more opportunity to pass. Geometry can constrain you from having an opportunity to pass relative to a relatively 'fly down the street.'"

This comment and the earlier comment made by Escalante regarding whether a driver is constrained from passing due to geometry, for example, versus traffic demand, raises the point of whether it is reasonable to base level of service on percent time-spent-following for roadways where the driver does not expect to be able to pass, such as on geometrically constrained roads and roads in developed areas. The following comment by Escalante further illustrated this point, "…the terrain meant for the yellow striping, which is a forced percent time following condition, not voluntary. So given that condition, if you are zipping along at 55, then why isn't that a high LOS? In other words…if you were at 70% time spent following, and came up with LOS D, I'd say, but you're going the speed limit. How can you have such high travel speed and be in that condition?

McCarron also raised the issue of pavement quality. Escalante gave an example by saying, "You get out into a region like Dixie County or Taylor County – where you've got logging trucks. The difference between the pavement condition on one lane versus the other where the trucks are going back empty and coming back full. They actually drive two sides of the road when there's no traffic coming just to make the ride less bumpy." McCarron added, "There are two county roads in Tallahassee (Leon County) where they put a rough coat on there intentionally to slow travel speeds."

Participants once again raised the point that speed, rather than percent time-spent following, should be the primary service measure. Escalante noted, "If everybody's going the speed limit, how can it be D? You'd be going the posted speed limit, but because the percentage time following is 70% you're in D. Why can't I understand that logic? If you are moving down the road at the legal limit, even though let's say you can go 70 on that road if you chose to step on the gas, then how can it be D?"

Gabbay added, "I think basically the underlying way that I would take is that I would try to adjust my speed to the one that is posted. So if your question is which one matters more by adjustment or credibility, I would say that my target is to look at what the posted speed is and I will try to by-pass that, but if I'm interrupted, then I'm not going right, then my level of service is not acceptable. Then the platoon and the trucks and all those other elements come into play. The real thing is that if the road is designed for a speed limit of 55 in a rural area or in urban area, whichever it was designed for, and it's posted 50 and I'm driving 55 – I'm doing good. If it's posted 50 and I'm driving 45, then I'm not reaching my flow, my driving ability." Gabbay also noted, "…if the speed limit is 55, then my level of service A is based on that speed limit because the road is designed to achieving speed limit for the safety, for design, for geometry, for whatever. So I'm measuring it based on that and I go a little faster 'cause I want to always do better. That's life. But my measurement of A will be that 55. If I go below then I'm not A."

In a follow-up discussion with Ms. Gabbay, after the roundtable meeting , she indicated that her proximity to other vehicles in the traffic stream is a secondary consideration for level of service, with her speed relative to the posted speed still being the primary consideration.

Charles Houston and Keith McCarron generally agreed with the concept of percent free-flow speed as a service measure in developed areas. Houston stated, "I think if you're doing 55 on a 55, that should be a better level of service." When Washburn responded, "What about if you do 35 on a 35?", Houston replied, "I think it should be a better level of service…that'll be all right. You're doing what you're expected to do. You're doing the best you can do." Washburn then said, "So you're saying that matches the driver expectation? Drivers go through these areas and their expectation changes…not whether they're going fast…" McCarron responded, "I agree. I think it's rational. It makes sense. It seems like the land use surrounding the roadway might be a way to distinguish between these rural roads you showed versus these others constrained, urban, or coastal roads."

Based on the different input from the participants, McLeod raised the point of whether it is better to use a combination of service measures as opposed to just one or two. He said, "…is it better to work with one service measure, so you can go out there and measure and monitor it and hopefully can make the best one, or is it better to have a function where there may be 50% because of speed, 20% because of volume, 10% because of the pavement surface, all measurable. Are we better off, when we determine the level of service, to use just one measure, is it all or nothing, but it's cleaner, or are we better off with a primary measure adjusted by others?"

There was a fair amount of discussion on this topic, but no clear consensus. The participants of course agreed that the chosen method for assessing level of service should be as accurate as possible, but some participants expressed concern that the use of multiple factors for evaluation would give analysts too much room to "maneuver" with regard to LOS results. If this issue could be controlled, and variables were all relatively easy to measure, the participants generally indicated that they would not have any objections to a multi-factor LOS evaluation approach.

Advance Material Provided to Roundtable Discussion Meeting Participants

Two-Lane Highway Analysis

Chapter 12 of the HCM2000 offers the following definitions for Class I and Class II two-lane highways:

- Class I—These are 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—These are 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 generally are assigned to Class II. Class II facilities most often serve relatively short trips, the beginning and ending portions of longer trips, or trips for which sightseeing plays a significant role.

Based on these definitions, the HCM uses two measures of effectiveness (MOE) for Class I LOS—percent time spent following (PTSF), and average travel speed (ATS), and just one measure for Class II—percent time spent following.

Some users (particularly FDOT staff) have questioned whether just these two definitions of two-lane highway classes cover the entire range of two-lane highways. In particular, it has been suggested that these two class definitions do not apply to two-lane highways that run through developed areas (such as small towns) and along coastal roads. FDOT staff and UF researchers have previously suggested the implementation of a third class of two-lane highway to account for these situations, with 'percent of free-flow speed' being the performance measure upon which to base level of service.

Many of the state's two-lane highways are in areas that would be considered scenic in nature (e.g., along the coasts, the Florida Keys route), implying a Class II classification, yet many of these highways also serve well-developed areas, which would imply a Class I classification. Quoting from Chapter 12 of the HCM, it is stated, "*…the primary determinant of a facility's classification in an operational analysis is the motorist's expectations, which might not agree with the functional classification.*" This statement sums up very well the crux of the issue for the FDOT as neither classification appears to be appropriate for these types of two-lane highways. It has been suggested that the most important LOS measure for motorists on these types of highways is the ability to maintain a "reasonable" speed. Drivers in a small, developed area which is posted for 55 mph would primarily like to travel near that speed. Similarly, along a beach road posted at 45 mph or in a community posted at 40 mph, drivers probably accept that they need to slow down and are quite satisfied to proceed through these areas close to those speeds. Based on this reasoning, PTSF is not a relevant level of service measure. Thus, Class II can be removed from consideration as a performance measure applicable for these types of roadways, as PTSF is the only performance measure for this Class. That leaves Class I for consideration, which includes a speed-based performance measure, as well as PTSF.

On Class I highways, the LOS is determined by the most critical of the two performance measures (ATS or PTSF). This raises the question of which measure controls under what conditions. The ATS is heavily influenced by the free flow speed and the PTSF is not. On the other hand, PTSF is much more sensitive to the traffic volume than ATS, whose relationship to the demand volume is fairly flat. So, it should be expected that the PTSF will govern at high speed and high volume while the ATS will govern at low speed and low volume. Figure 1 confirms this premise. Keeping all parameters except free flow speed and AADT at their default values for two lane highways, a "crossover volume" was determined for each free flow speed. The crossover volume represents the point at which PTSF becomes the critical determinant of the LOS. The volume is represented by the v/c ratio to give a normalized perspective on the numbers. It can be seen that ATS never governs at v/c ratios above 0.3, or at free flow speeds above 55 mph.

While free-flow speeds at or below 55 mph are the condition on a very large percentage of these two-lane highways, the volumes can encompass a large range, with v/c ratios frequently exceeding 0.3. However, even for facilities in which the ATS would govern, the FDOT has difficulty with the concept that a facility that has an average travel speed the same as a posted speed of 50 mph, for example, would only have a level of service of C (see Table 1). They felt these ATS LOS thresholds were unreasonably pessimistic for these types of roadways in developed areas. Thus, 'percent of free flow speed' has been suggested as the level of service measure for these types of two-lane highways as it best represents the concept of "reasonable" speed.

The concept of a third class of two-lane highway, and the 'percent of free flow speed' as its level of service measure have been adopted for use in the FDOT's Highway Planning (HIGHPLAN) level of service estimating software. Overall, the FDOT Systems Planning Office strives to maintain fidelity with the methods of the Highway Capacity Manual, so this issue is of considerable concern to the FDOT. Consequently, FDOT has funded a research project through the University of Florida to further investigate this issue. One of the expected outcomes is a recommendation to TRB's Highway Capacity and Quality of Service Committee (which oversees development of the HCM) for how to address two-lane highways in developed areas.

One of the tasks for this project is to obtain critical input from practitioners on the HCM2000's two-lane highway analysis methodology as applied to Florida's two-lane highways. Thus, UF research personnel would like to conduct a focus group/roundtable style discussion with regional planning council staff and FDOT district staff about experiences in applying the two-lane highways analysis procedures of the HCM2000 to the various two-lane highways in Florida.

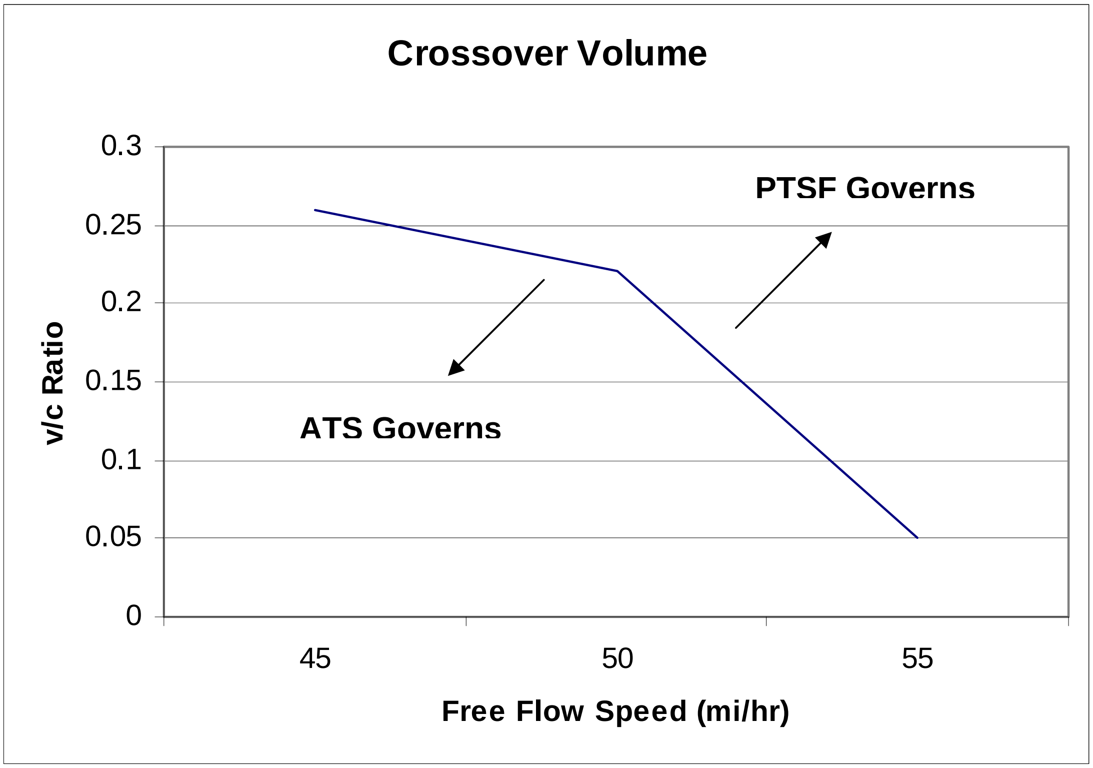

FIGURE 1 Effect of Free-Flow Speed on Crossover Volume.

TABLE 1 LOS Criteria for the Three Classes of Two-Lane Highways.

	Class I[1]		**Class II[1]**	**Class III**
LOS	**PTSF[2]**	**ATS[3]**	**PTSF**	**% of FFS[4]**
A	≤ 35	> 55	≤ 40	> 0.917
B	> 35-50	> 50-55	> 40-55	> 0.833
C	> 50-65	> 45-50	> 55-70	> 0.750
D	> 65-80	> 40-45	> 70-85	> 0.667
E	> 80	≤ 40	> 85	> 0.583

[1] Values are directly from the HCM
[2] PTS – Percent Time Spent Following
[3] ATS – Average Travel Speed
[4] FFS – Free Flow Speed

Transcript of Roundtable Discussion Meeting

Initials used in the following transcription:

DM – Doug McLeod, FDOT, Systems Planning Office

GB – Gina Bonyani, FDOT, Systems Planning Office

ME – Mike Escalante, North Central Florida Regional Planning Council

LG – Lea Gabbay, FDOT District 2

CH – Charles Houston, FDOT District 2

KM – Keith McCarron, Apalachee Regional Planning Council

SW – Scott Washburn, University of Florida

BC – Brad Choi, University of Florida

SW - Basically, the two-lane issue kind of started to develop when I was working on a project for Central Office for HIGHPLAN - highway planning methodology software. That would be incorporating multi-lane highways, two-lane highways – there was a new methodology for the 2000 edition of the Highway Capacity Manual. There's a two-lane methodology that's been in the Highway Capacity Manual that's been there since 1985. It was unchanged from 1985 to the 1997 edition. So then there was an NCHRP project to do a new two-lane highway methodology 2000 edition of the Highway Capacity Manual. Midwest Research Institute was the prime contractor on this project.

One of the significant changes to the methodology was that a directional analysis methodology was added – with the previous methodology it was always a two-way analysis. That's the only option you had was the two-way analysis. Now we have both a two-way and a directional methodology. When we did HIGHPLAN, we decided to implement just the directional methodology because that's the way we do the other things – arterial, freeway – it's always the directional methodology. And additionally, one of the other significant changes was that the 2000 introduced two different classes for a two-lane highways and the service measures depended upon (that is the performance measures the level of service depended upon) which class you were in – whether you were Class 1 or Class 2. If you look at that hand-out, I can bring it up on the screen. That's Exhibit 1 here. It gives the description of what Class 1 and Class 2 is. And if you are in a Class 1 facility – the service measures (there's two actually – there's percent time-spent following and average travel speed) and then if you are in Class 2 the service measure's only percent time-spent following. When we did the methodology for the two-lane highway for HIGHPLAN we found that the level of the service that we were getting now for two-lane highways in the state of Florida was coming out much worse than what it was with the '97 methodology with the same input conditions. That kind of raised a 'red flag' that this is probably a major issue that all of a sudden the two-lane highways in the state of Florida are performing much worse than they were just because the methodology changed, even though volumes were the same. That issue was kind of initiated through Central Office, FDOT – Highway Capacity

Quality and Service Committee and also, kind of simultaneously, the issue of whether the two classes really fully accounted for all the different two-lane highways that one might encounter was raised as well. And that's actually more the focus right now with this project. The issue with the level of the service coming out much worse with this new methodology was really related to the directional methodology and in particularly the percent time spent following service measure. Basically, the equation that's in the HCM2000 right now greatly over-estimates percent time spent following, at least until you get up to near capacity values.

The bottom line is the curve was nothing like this. The curve is very steep - percent time-spent following - you didn't have to get much volume for that percent time-spent following, so it gets way up there. The curve is supposed to look more like – something like that. That was essentially addressed in a kind of emergency NCHRP project. That was January or something like that and finished in July, that again was conducted by Midwest Research Institute. So, they made some corrections. They developed a new curve. It looks a little more reasonable. So that basically it correlates fairly well with the two-way analysis methodology.

What they did was basically said we feel that the two-way methodology is giving us reasonable numbers. They looked at the '97 two-way methodology, did some calculations there, compared that with the two-way calculations with the HTM 2000 methodology and there was pretty good agreement there. So they said the two-way is probably reasonable. So essentially what they did was look at one direction of the two-way analysis and see if they could get the directional analysis methodology to correspond with that. So basically, they started with the two-way data point and said, well let's take out one direction of the two-way and plot the curve for that. They basically developed some new data points, redid their regression equation and came up with this new curve. The problem is there's sort of a discrepancy between … The two-way was developed – well most of this was developed with a simulation model, but I don't remember all the details on this, but there's some difference between how they initially arrived at the two-way versus the directional and so there was a disconnect there and ideally one would fall out from the other. But they did them a little bit on separate tracks and then didn't realize "Oh! They don't correspond very well." Because you can do that, you can do the two-way analysis and then you can try and split out the two directions. If you do that, you find out that if you split out a direction and then do a directional methodology analysis, the numbers don't match at all. It's sort of a patch. I was on the panel reviewing the emergency project report and Gina was as well, but she left town conveniently when she had to review the report, so Doug ended up reviewing the report. But that was one of the recommendations that I made, was that we need another project, eventually, to hopefully address both two-way and directional at the same time and have one relate directly to the other.

LG: What I want to understand is that once the correction was made, the adjustments now reflect consistently the directional analysis?

SW: The adjustments were made such that the directional now matches better with the two-way.

SW: When they first started this, they essentially had the two-way methodology that they carried over from the '97 edition and then essentially did the directional methodology independently of the two-way analysis, so they got these curves and then they just said all right, we're good to go. They never really did a reality check on this. They never ran numbers and said what if we do the two-way and then split out the two directions and compare results. They never did that, otherwise they would have caught it. It wasn't until we started implementing this in HIGHPLAN. We said "Whoa. Something's not right here." That was a major goof. Now it's in the Manual. So what they did when they went back, they said "All right. Well let's just start with the two-way and extract it from that." But again, there's kind of a disconnect – the fact that they've extracted the directional from the two-way. It would be nice to be able to do research on the two-way, do research on the directional and see if they match up. So that's hopefully something that will happen in the future, but what MRI has done is essentially a patch. But this still has to go through the Highway Capacity and Quality of Service committee. I don't know where things are at right now with review comments on that.

DM: I think their final report is due at the end of this month. See what we get out of it.

SW: I think there were 5 people on the panel, maybe. And there were 3 that gave some significant comments and there were a lot of issues to be addressed, so they've got to work through those first and then it will probably come back up in January, TRB meeting. What will we do with this stuff? The two-lane subcommittee will have to probably - assuming that it gets approved by the NCHRP panel - then the two-lane subcommittee will have to approve it and it will be at least another year.

DM: Maybe by the mid-year meeting, next year TRB you may decide O.K. that can go into the Manual.

SW: The main issue for us right now is whether the existing two classes that are defined in Chapters 12 and 20 (those are the two chapters that deal with two-lane highways) adequately cover two-lane highways that we have nationwide and in particularly here in the state of Florida. So that's where we're looking for feedback from people who have used the methodology and ever tried to apply it to different two-lane highways in the state, what their sense is. And to review, in your Exhibit 1, Class 1 basically is like a major two-lane highway that connects the major destinations, the idea is that this is supposed to be a high-speed facility and generally a more long-distance type of trip. Class 2 right now is like it says there in the first sentence 'two-lane highways where the motorist doesn't necessarily expect to travel at high speeds, access routes to Class 1, recreational and scenic routes, maybe shorter trips, maybe not connecting to any major destinations, possibly connecting to Class 1 facilities.' And again for Class 1, there's two service measures – percent time spent following and average travel speed - Class 2 just uses the percent time spent following.

Go to that third page at the bottom there – see for Class 1 you've got percent time spent following, average travel speed. So if you decide that a two-lane highway is a Class 1 highway, then you calculate both percent time spent following and average travel speed and then see where the level of service falls for both of those and then you choose the worse of the two. So, for example, if you had percent time spent following in the 40s percent, that puts you in the LOS B category, but if your average travel speed is, say 47 mph, that's level service C, so then you say its level service C. Class 2 facilities says the idea is that travel speed is not that important or that high speed is not that important, you just use the percent time spent following service measure and that's the only thing that dictates the level of service. Another interesting point is that when we were doing some calculations with HIGHPLAN, it became apparent that average travel speed really never governs anyway with a Class 1 facility. You're talking about high-speed routes, and if you look at the chart right above, what you see there is what we're calling crossover volume here, basically increasing volumes for a given set of conditions would be when the service measures which you want… see which one governs but it switches between the average travel speed governing the level of service versus the percent time spent following. Basically stated, percent time spent following always governs at high-speed/high-volume. So it's only when you get into lower speeds and lower volume that average travel speed governs, but that's usually not the case anyway for a Class 1 facility. The average travel speed is rarely applicable here.

LG: I'm just thinking about two different routes comparing Class 1 or Class 2 and two-lane roads. I would say, for example, A1A along all the beaches in Florida is a Class 2 two-lane road. Speeds on A1A will be lower even though people drive faster. You look at a two-lane road (if you live down here, 121, or whatever it is, a two-lane road) and it has a higher speed, so if I'm understanding what you are trying to convey is that the speed really doesn't have that much of impact on it – but it does.

SW: Yeah. All I'm saying right now is basically is what's in the Highway Capacity Manual and when you go to the calculations – if you have a Class 1 facility and you do the calculations you're going to find that the average travel speed basically never determined what the level of service is. Its always PTSF, but part of the purpose for today's meeting is to talk about some of these issues -- is this really reasonable and do we really only have two classes of two-lane highways, and even if we really do only have two classes of two-lane highways, are the current service measures really applicable? Is that really what's determining the level of service in the eyes of the traveler?

LG: You think there is another measure?

SW: Well, yeah. And this is where we've got to be a little bit careful because – that's why Doug can't open his mouth too much because he's got pretty strong feelings on this and I have some opinions but it just may be that Doug and I (and Gina as well to some extent) see things one way but other people out there are not seeing it the same way.

LG: Sorry to interrupt, I just wanted to know.

SW: The purpose of today is not too much talking by me, but more talking by the rest of us, because ultimately what we want to do is to go back to the Highway Capacity and Quality of Service committee, to the two-lane subcommittee, and say we've looked into this a little bit, talked about it, we talked with some others that have some experience with two-lane highways, at least in the state of Florida, and either say "Yeah, we feel good with the two classes you've got in there and the service measures that are chosen. We think that covers the whole deal." or say "No, we don't think this really covers the whole situation."

SW: You've got the Class 1/Class 2 definitions right now, there's percent time spent following, average travel speed and the service measures for Class 1 and percent time spent following for Class 2 and I was talking about basically when we've done the calculations the average travel speed never really ends up dictating level service for Class 1 anyway and if you look at this figure here in the Exhibit, it kind of illustrates that what we were looking at here is - What is the crossover? What is the point when you have a certain set of conditions and you start increasing the volume? At what point does the PTSF start to govern the level service versus the average travel speed? Basically, when you get the high-speed, high-volume conditions, the percent time spent following always dictates level service, which is what you have anyway for Class 1. For Class 1 the average travel speed really never is a factor anyway and so one of the reasons for this meeting today is that we want to talk about 1) The current definitions for these two classes of highways – Do those really account for all the two-lane highways that we have in this state and 2) Are the service measures that are defined for these classes of highways really the most applicable service measures? And Doug wants to listen to what's going on, but he's with the Office, and so is Gina, who's with the project that I'm working on here. He's got very strong feelings about whether Chapter 20 really covers things accurately or not, and he tries not to say too much on that. He doesn't want to bias people too much but the bottom line is that we feel that there's some issues here in Chapter 20 and we felt it involved… we probably wouldn't be here today but we're trying to get feedback right now from folks who have some familiarity with trying to use the methodology. Lea was just bringing up the example of A1A along …

LG: Anywhere in Jacksonville or anywhere you go on A1A. The scenic routes, the speed limit is lower, people expect to drive slower and they don't want more lanes, they don't want more capacity, they object to any changes. But, in order to measure the level of service on that kind of a road is a really hard thing to do because it's really a small space for how many cars are on the road or basically on the street either. I just don't know if … I don't know where we're going with this – I'm waiting for what you're considering but I don't know yet where we're going with this.

SW: Well, I don't want to try and lead the discussion too much. If at the end of this we sort of get some consensus about some of the things we're thinking about already on this project, that's great, but if not, that's fine too. We may just decide that I'm out in left field or Doug is out in left field or whatever.

LG: Well, let me just start off with another thought. Are we still measuring everything by direction?

SW: For the purposes of the state of Florida, and the whole LOSPLAN thing, everything's a directional analysis.

Lea: O.K., and when talking about Class 2 roadways, everything is directional and Class 2 is basically measured only by PTSF, not by speed.

SW: If you say I have a scenic roadway or something along the coast there, let's say, right now by the current HCM definitions that's probably a Class 2, not a Class 1, and the percent time spent following is what's going to govern. So, does that seem reasonable? Does it seem reasonable that you're cruising down A1A and you're following a couple people, and that's really a bad level of service, or is there something else that you think that people are thinking about in terms of what's making for a good trip or what makes for a bad trip?

LG: My experience – the time I spend on viewing the sideways, the stores and everything else. It's not going to bother me how much time I spent following somebody else. How close am I to my destination? And speed does have something to say. If it's 30 or 40 or 50 I will always try to beat that speed – I don't care what it is. That's human nature.

SW: So you're saying that when you're talking about the speed, you're talking about the posted speed (Right.) and so if the posted speed is 30, you're thinking if I can do that or a little bit better I'm feeling good. (feeling good, right) O.K. But that's always relative to what the posted speed is so … (right) If it's 50, then I've got to be doing 50 or a little bit better. If it's posted at 25 and I'm doing that or a little more, then I'm feeling good.

ME: The classifications seem to be organized to what you can do on the roadway itself as a means of trying to deal with what level of development is around these roadways? Is that a fair assumption?

Because my impression is whether two classes is adequate or maybe you need a third or even a fourth, fifth or whatever. To me, is magnitude of development driven with the component being how many access points are along this roadway? Meaning how many potential conflicts can occur on this stretch of roadway between point A and point B? The fewer there are, obviously the faster travel speed everybody would enjoy, and if percent time spent following was 90%, if you're going 70 mph is that LOS D or is the whole platoon going A? You know what I'm saying? If somebody wanted to go 90 in a 65 mph zone, is he feeling he's at LOS D? I think most of us would say we don't think so. He's just unreasonable.

And compatible with that is how much development is along. We're talking like 129 through Suwannee County, you can go pretty fast with the not much around, but A1A is obviously more attractions and ability to pull off the road and get on which affects the speeds.

SW: In the methodology, you make adjustments to the (depending upon access) frequency and the combination of lane/shoulder width. We don't require that with HIGHPLAN, but that's the way it's treated in Chapter 20. That's how you factor in access and frequency if you just make an adjustment to the frequency and again now I want you to look at Class 1. Say you've got a Class 1 and you've got a lot of accesses, you're going to make some adjustments to FFS, maybe now the average travel speed might start to be a factor in LOS, probably a good chance the percent time spent following… Really what's wrong with access frequency? But if I hear you, it sounds like you're maybe making a little bit of an argument that you have a lot of accesses on the roadways and so maybe it's not really Class 1. Are you implying that?

ME: In other words I think when we travel in a more accessible facility and limited access facility our comfort level is if we could just get going and just not really have to pay attention to other traffic coming to get on the facility.

SW: The issue here is it's continual, and the question I guess would be is the two class continuum adequate, or with the adjustments that could be made within each class, or can an argument be made for more stratification?

LG: I kind of disagree with the issue on the access, it's signals where you stall. That's when there's an interruption. If you had a two-lane road going to Waldo, to Lawty, wherever, with two main roads and there are many accesses for single homes but they don't interfere with flow. Unless you live there, you really don't make that turn. So actually on a two-lane road, in rural areas in particular, it makes no difference. It's just if there is an intersection. Signalized or not, if there is an intersection that you physically use or stop, then you have an interaction with the flow. That's one instance and it's obvious to me that the two classes are very different. Class 1, that's what you expect – to flow a little faster, drive a little faster whatever is around. In Class 2, you do expect more development, slower speeds, more interruptions and adjustments to what come from the outside of the road. If you're looking for a store, if you're looking for an apartment, or whatever. To me, those two are two different things, but speed is secondary to my decision in measure of level of service. Because I'm driving on a two-lane road and I know I can't go anywhere else, I can't turn anywhere so whatever is the posted speed that's what it's going to be … when you come down here on 16 – two-lane road. What can you do?

SW: Are you saying again … I think kind of like what you were saying before. It's the following thing I want to clarify. If you're going at the speed limit, or a little bit above but you're following other cars, you'll feel like you got a good level of service?

LG: Yes, I don't expect anything else on a two-lane road. I think my perception as a driver is that in a two-lane road if I can pass him fine; if not it's O.K. I don't expect anything else. If you do 65 with no policemen around, right? Just my perception as a driver.

ME: I think that's a reasonable expectation, that is, if everybody's going at the speed limit and there's no tractor on the road to aggravate everybody, then regardless of how long you spend following, you should have a high level of service. I mean, if for some reason you ran into the tractor and there are a lot of cars coming behind and you can't pass, then it's an issue of discomfort and therefore lower LOS.

SW: At that point the PTSF becomes an issue because now your speed is impacted.

LG: But overall, how much of that occurs? It's very wrong. Is it worth changing and having another class or another concept put into the analysis step for that condition?

SW: I'm not sure we've hit on all the conditions yet, but …

ME: Lea disagrees with me because – at least I think I heard that the issue of signalization as far as preventing conflicts and I'll disagree with that because I think conditions where there may be a lot of turning movements to access roads that have not yet met signal warrants, which interrupt free-flow is an issue.

SW: I think there might be a distinction because Lea was talking more about minor driveways (single family residences) versus major driveways.

LG: Or to another facility is like what I'm talking about.

SW: If it's really minor (if they're homes) I don't even really think it has to be counted as accesses because you could get one person coming out of that home or somebody pulling in, but that's pretty rare.

ME: So I'm talking about what you would call a significant side street or …

LG: Well, if you have a "7-11", then yes you have an interruption. People may come out of there but I'm trying to figure out what we're trying to accomplish here with regard to this. We have two classes. We have two measurements. We have one way of analyzing, also how the adjustments are done. And what is the best way to improve this? Am I interpreting OK? Is that what you're trying to…

SW: Well, Doug, do you want to talk specifically about the issue? This was put into a letter to TRB in addition to the PTSF issue. That was supposed to be addressed in the NCHRP report. Another issue that was raised.

DM: After further discussion today, Mike might like the idea of redefining the classes. I mean what facilities are like. What I've heard from Lea today, maybe the 2 classes are sufficient, and it may vary either by significant access points, what the development goes by, which road, etc. It's like this general claim that if there's more than one class, there's at least two, and somewhere between 2 and 5 depending on which factors come up. The other question, what I've heard today is, most of the discussion is not on the open road much. The question is once we get into the other roads where the speed limit is slower, the development is higher, what's the appropriate service measure? Is it going close to the speed limit, or the percent time spent following versus average travel speed? And really those are the issues that Scott's bringing up here – how many classes of roadways are there and what should be the relevant measures.

KM: We have a situation with the Coastal group – Federal Highway US-98 to Wakulla, Franklin County and Gulf County and there's going to be a lot of pressure on that road and it's very constrained in terms of the proximity to water and very vulnerable road and segments of it have become urbanized – developments concentrated create a longer corridor because of a lot of public acquisition in this county and we're probably lagging behind some of the other regions in the state in terms of difficulties coming up in a timeframe of 10-year period. Around Tallahassee we have a lot of two-lane commuter roads, where following time is a concern and in some of the little, what you would might call traditionally rural, agricultural areas around Tallahassee, sometimes has difficulty in their development of LOS issues because of the way that the numbers work out. But the people there don't necessarily have a concern.

SW: Roadways like the first one you're talking about are getting somewhat urbanized. You would see that as a Class 2 right now?

KM: Right.

SW: So it'll just be percent time spent following?

KM: Right.

LG: Is there a possibility of considering a transitional Class 2? Let me just explain this – you have a clear Class 1 which is obvious to us. Where speed is higher, where you have some interruption but they're not as difficult to overcome. Then you have the extreme Class 2, which is really already built, you constantly stop and you have to (and sometimes it's constrained, you can't do anything – you cannot add lanes or anything). So maybe there's a transition because before you get to this the category of Class 2, that is, the final, you have developable land along a Class 1 that is not on the coast but will become as critical maybe as the coast.

SW: Yes. Now we're getting into one of the key issues the DOT has. The issue with developed areas that was basically one of the things that was put forth by MRI research. Does the 2 classes definition really accommodate all two-lane highways, but particularly two-lane highways in developed areas? You apply Class 2 in that situation and then use PTSF, you're probably getting pretty crummy levels of service because everybody's going slower, they're all bunched up, but is that reasonable? Mike saying earlier - even though the speed is slow, if you're going along average or a little bit above that you don't necessarily think it's that bad even if you're in a big platoon.

LG: You don't really care if you're along the beach and you are on A1A and you're doing that all along Florida. But if you are in Tallahassee, maybe, and you are not far from the shopping center and you're trying to go to work and this place is going to be jammed, eventually, and you still have two lanes, then the level of service is critical because then you are measuring from all capacity and you are anticipating more delays so then the key word that he said to me, what made it clear, is that during the constrained facility on A1A, but there isn't one on other roads that are taking you from one point to the other to go to work that are two-lane. And there are two lanes, so maybe that measure is not … maybe at that point is the speed and the amount of time you spend following somebody else.

SW: It's almost like you're saying (there's a transition) we have the Class 1, which is actually PTSF and speed, but maybe Class 2 really should be PTSF and speed, or not necessarily speed, but the speed relative to posted speed.

LG: I don't know where my Tallahassee people are standing on this issue 'cause they didn't get any directions, but right now I'm not even speaking from somebody who knows anything about level of service – I'm just speaking from being delayed, driving along the coast, driving to Waldo, Lawty or whatever, and driving to Tallahassee. So I can see myself doing exactly what I'm telling you I would be doing when I'm driving. So to measure the level of service, then I will be more a DOT person saying, well you know, I really should recommended more roads. But the mayor in Lawty or in Dixie County, I would say, well additional lanes here are impossible and we just follow this donkey along this road and I'll get there. And if I'm on A1A, I'll say, hey let me look at the city road and say I know that we can't add any more lanes if it costs billions of dollars, so I'll just follow and enjoy the world. You have the extreme and the middle way.

ME: It's a continuum. She also introduced the fact that maybe somebody needs to fill in between Class 1 and Class 2 and our offer is - like you would see Class 1 as an extreme for the free open road measurement, so to speak, but the question is Class 2 at the other end. Is that the other pole and you're trying to figure out what's in between. Maybe there are developments to a level that's not really urban but to a level that maybe Class 2 is not adequately measuring level of service, and you need to even go beyond Class 2 and then continue the measurement. I can't say that would be the case, but maybe an issue of introducing another factor to measure, to deal with the other level of service.

SW: Yeah. Getting into the next section we've got some brief video clips of different two-lane highways that we'll look at. See – what do you think about this and what do you think about that? So we'll get into that a little later on. I'm still in a mode of free-for-all right now, before I start looking for exactly how you might rate the roadway. That is coming up. If you have a two-lane highway that has geometric constraints (now we don't have too many in the state of Florida, but you can imagine yourself in the mountains of Montana…) but anyway. Let's say you've got some pretty good grades – that is another thing we kind of have to keep in mind – that ultimately we want to make some recommendations to the HCM committee too. It would be nice if we could account for the country as a whole, even though we are definitely comparing to the state of Florida. We don't have too many geometrically constrained roadways, but if you had mountainous two-lane highway – major vertical grades, major horizontal curvature—what do you think about that? Would that fit in Class 2, or something different?

LG: I think that will fall with your analysis of direction. If I had a problem measuring all of this two-lane road based on the directional volume. I have got to do whatever I have to on two lanes. So whichever direction I have to analyze, and it's not if it's in the morning or in the evening or whenever. So conflict of directions will be then affected by your geometry. If you have a geometric problem in that you actually see the problem. In mountainous areas there's really nothing you can do because of the geometry. You are more constrained than if you are on a rural road and you're just going in that direction. That's my perception. And for measuring LOS, its more critical if I'm in the mountains than if I am on the farm somewhere driving from one place to the other.

SW: I'm not sure I follow you completely but -- you've got that kind of road and we call it Class 2 -- if it is Class 2, then would you say that part of what might be the service measure how you would go about classifying level of service.

LG: Well, then you measure up the two measures, then it is following, the speed doesn't matter, who you're following the percentage and the other one would be the geometry because you are constrained with the geometry and the direction. When I was riding in the mountains in Switzerland, the Alps, you are blocked. You can't go anywhere. You are either falling down or are you just hugging a wall. I can physically see and the direction makes a big difference. If all the other directions you may feel less secure that you are just going to fall or if you are by the wall. I don't know how to explain it. It's more the geometry then that really makes a big difference.

GB: I think what she's saying is that the criteria or the service measure should be different for mountainous terrain than on level terrain.

ME: But it depends on the articulation of the steepness of the grade and how much curvature there is too because… My experience is less European, although I've seen some, but mostly Appalachian, where there are opportunities where they allow passing on the hills.

GB: Decisions are different too when you are on a mountain. On a mountain terrain she just described, you don't want to think about passing anybody. As long as you're going, you're fine. Why? The expectations are different.

SW: Does it make sense to you to be able to call this kind of roadway the same class as your A1A along the beach?

LG: Well, you know, because both of them have constraints, physical constraints. They will fall in the same category?

ME: I don't know because in the mountains they usually have your average – the posted speeds are usually lower. When you're dealing with grades they lower the speeds so they don't have trucks running away.

LG: A1A is lower speeds 30, 35.

SW: This is an issue I do want to explore some more eventually, but you mention the term constrained, but it's really two different kinds of constraints because there are geometric constraints, which are potentially limiting the performance of your vehicle and how you can travel on that roadway, and then there are further development constraints. Whether it affects your perception, or the driver's perception, in the same way I'm not sure. If I'm geometrically constrained or developmentally constrained, I do want to explore that more, whether that is one or two classes. Are they separate classes, should the service measure be something different for developmentally constrained areas? Because the travelers' perception might be a little bit different, their expectation that is.

ME: Every perception is different, so therefore, the expectations are probably different too. We're just a very small example. We all have our own expectations/perceptions. Ultimately we may get to that point too, depending on wherever this goes, but it may go to where we're going to try to do more interviews, survey-type of stuff with a large number of lay travelers out there to try to find out what their perceptions or expectations are for LOS on two-lane highways.

LG: It bothers me that we are constantly bringing back the concept of expectations/perceptions because up to now all our measurements are actual measurements based on numerical values that can be measured and concretely shown and all these fuzzy feeling-type things will change everything we see. So you may have a hundred classes. You've got to limit where you are and which direction you really want to go eventually. If we are going to bring in the concept of perceptions, expectations, and all these things, then we may have another book.

SW: You raise a good point and it's really all kind of relevant here I guess, but some of it is a little out of scope and so I'll try and keep it a little more focused. There is a quality of service task force now, which is part of the Highway Capacity and Quality Service Committee, and I've been participating in that. The language in the Highway Capacity Manual says that – for any roadway you could mention there are a variety of different performance measures. You can measure speed, you can measure density, vehicle occupancy, measure volume, measure percentage of time spent following, whatever, but of all these different performance measures, which are the ones that are really relevant to travelers' deciding if this is a good trip or this is a bad trip? The HCM states something to the effect that the performance measure we choose to base LOS on (which we term the service measure) should reflect traveler's perception. That's a little bit of the debate right now, but you guys were right that we still have to base this upon measures that we can actually go out and quantify, so we have to make the connection between what's driving their feeling, their perception of a good trip or bad trip, and relate that to things that we can quantify because if they're looking out and say the trees here are really nice. Yeah, but what can we do with that? But if somehow we can still make the connection between these other things that are out there like lane width and all that, to what travelers are perceiving to be the level of service experience. That's a little bit of the debate because some people within the committee feel like well, we said that it should be based on traveler perception but we still feel like we should be the ones deciding what the travelers are really perceiving in terms of level of service and therefore we'll choose the level of service measure. And then there's others, particularly within the Quality of Service task force, that think maybe it's time we actually go find out from the actual travelers if density on a freeway is really what's making them decide whether its LOS A, B, C, D or whatever. If it's not, and it's other things, that's great, and if you can quantify it and maybe even come up with a level of service function per se -- it's a little bit of density, a little bit of speed, and it's a little bit of the number of big trucks that I'm next to and so forth. As long as this is stuff that we can quantify, even something like non-traditional measures, maybe like pavement quality. We can still measure that – the pavement guys have ways to measure that – we do still have to keep it reined in though. That is something that is getting major discussion right now within the Highway Capacity and Quality of Service committee and some people are a little nervous about doing this kind of social research and asking people what they really feel.

ME: I'd like to get back to the two measures we were looking at before. My concern about using the term 'percent time spent following' -- it sounds like you're trapped behind the vehicle in front of you, you can't get around and I think actually following somebody at a reasonable speed like we were talking about before is a choice and therefore I have absolutely no problem following somebody for 90% of the time of each trip. So a factor in measuring LOS is to identify whether the driver spending all that time following was a choice or a constraint, over the length of this facility, were there opportunities to pass. In other words, how much of that facility was striped "no passing" or striped to allow passing, regardless of the oncoming traffic. So if he had an opportunity to pass and there are no cars coming, he can pass, but if it's a double yellow line then that person is trapped, and being trapped may be an issue in the comfort of their ride. It's not just an issue of --- it's an issue of the opportunity to pass or the choice not to. Given that you're traveling at an adequate speed.

SW: I think that the way it's set up now, percent time spent following is over the length of segment that you're defining what percentage of the vehicles were traveling at a headway of 3 seconds or less, or it might be also relative to the travel time over that length. But that is certainly an issue, about the assumption of somebody traveling at 3 seconds or less, are they really being constrained or are they just comfortable doing that even though they have the opportunity to pass, they just don't pass?

ME: That would be my point and I guess you'd have to do it by survey.

SW: If a vehicle is approaching a slower vehicle, they will generally do what they can to pass. If they can't pass, then they get into this 3 second range and therefore that's a negative.

But not necessarily for all drivers. Some drivers may just say, this isn't so bad, I'd rather do this than take the risk of trying to pass somebody.

LG: I think it's a function of age - if you're 17 you're going to do anything to get there. If your not, you just sit there and say O.K. I'll look at the scenery.

SW: You raised another good point about this idea of trying to relate factors to traveler's perception and level of service. I think one of the things we're going to find is that socio-economic and demographic characteristics play a big role. You may find that if we're given a set of conditions, the younger crowd is all giving this a certain level of service and the middle-aged crowd and the older crowd are giving theirs. The problem is that's hard to measure -- you can't go out there and necessarily measure the age of the people in the vehicle, but these are definitely issues that have to be dealt with if this kind of approach is ever going to be viable.

We're close to a break. Let's look at videos. Keith or Charles, you got anything. You haven't had too much discussion on this whole idea of the two classes. What's your gut feeling? The two classes have it covered, or maybe not? If you haven't made a decision yet, that's fine too. Maybe after we look at some of these videos, then that will help a little bit.

KM: Well, some of those functions at different points in time have different classes. Like during the working week you know it's a commuter road but on the weekend it's a scenic highway. In our region, we've got a large national forest where they're trying to designate scenic highways that on a lot of the roads during the week are used as commuter roads. So any time you try to fit something into categories there's always some outliers…

SW: You raise a good point. Because again one of the things that's in the Class 2 definition is sort of the trip's purpose. You're saying that really you can have the same route and the trip's purpose is changed by the time of the day, or day of the week, or something like that.

LG: Now on a scenic road, if you're going to work you don't care or if there are other people on the road – you just want to get to work.

SW: I don't think that's out of the realm of what could be accommodated -- a road maybe could be classified as Class 1 for analyzing a week day commute but a Class 2 for a weekend recreational trip time period. Is that pretty near?

KM: Pretty good. The counts are down here on a week day, but we use the state highway system. We use that officially in determining level of service for planning purposes.

ME: Isn't most of the analysis used for peak conditions, so if you were a resort area you might be trying to design the facility for weekend high travel volumes as opposed to commuter volumes. The resort calendar might be negligible versus a more developed area where you'd be designing for commuter traffic, not vacationers.

SW: I don't know. I guess it depends on the agency. Maybe in some respects it's like A1A, sort of like the commuter out there at certain periods, but I guess you have to decide whether it's a critical period - recreational people on the weekend. What's the peak period out there?

LG: On A1A? 1 a.m.
Those people, they don't even go to work, they play golf all day or they go to the beach. So there is no peak period to speak of and there is no percentage. Maybe a small percentage should be considered in the peak period going to work because it's a different kind of population and if you're in Miami it's different and if you are on A1A in some other non-resort areas, it's different so we're kind of bordering. We're dabbing here and there, different context – population, age, type of work and all that. I don't think that's what we're trying to do. We're looking at the car, the traveler in the car and the kind of road we have and what's adjacent. What kind of land use adjacent to that road and how can we measure what we have on that road. There is a variable that you can go forever into this. We need to be realistic and kind of nail them down to what we're trying to achieve. The way I'm seeing what you're trying to achieve is to find a class that's most reasonable and it's two-lane road…different kind of two-lane road you have.

SW: I think the bottom line right now is feeling that the two classes do not adequately cover at least the combination of the two classes, and the service measures that are devised for those two classes really do not accommodate the different types of two-lane highways that are out there. So you end up with unrealistic levels of service for certain kinds of two-lane highways. That's the thing. Whether that's right or wrong, we're still trying to determine that.

ME: Is driver behavior and driver vehicle choice an issue in dealing with this? Way back when it used to be cars and trucks and many, many cars and some trucks. Now you have many trucks, many cars, pick-up trucks, SUVs towing Seadoos and God knows what else.

SW: It's not an issue necessarily for looking at the need to expand the methodology. That certainly comes into play again with the whole traveler's perception issue.

ME: I'm talking about how the roadway is populated now compared to back then and there are many different vehicle types on the road than before.

LG: It's going to make a big difference if you are behind an SUV where you can't see anything or you're behind a car.

You know, Doug, do you remember that we had an issue, a paper some time ago I think 3 or 4 years on the FIHS two lanes and we allowed a standard of C or we didn't allow standard of C for two-lane roads for FIHS? What was the reasoning behind that? Maybe that's something that – I mean, the standards that we allowed for the two-lane road. Does that have anything to do with the kind of measurements which we are now talking about in this conference?

DM: It could, Lea, in the sense that if so given the current Highway Capacity Manual it is so hard to obtain the level of C on a two-lane roadway. (Right.) That we felt like we needed a level of service C for a two-lane roadway and yet our standard would be for rural areas. I think this is wrapped into the discussion that you all are having here in that maybe progress in rural areas and two-lane roadways – we're seeing things a little differently in that FDOT has this patch of putting C on all two-lane roadways to accommodate these different circumstances. Maybe there are other performance measures that would get us more realistic results rather than the patch they arbitrarily put. (Right.) I think it is relevant.

LG: Yes, I remember we made that change on purpose because we had this problem. Not being able to achieve the level of service B which is the perfect world when we kind of fly through the two-lane roads and you have no problems. Well, we have all kinds of problems. Maybe that's associated also with the class, that this extreme class we're talking about, that 2 and that 1 and we have to make some adjustments with our standards. With our standards so we didn't have a different way of looking at that two-lane road.

SW: The vehicle population may factor into the whole traveler's perception. You may find out if you research the modeling, that the percentage of large passenger vehicles to the percentage of trucks heavily impacts levels of service. That may be something built-in that you could measure. You could measure SUVs, or mini-vans, or trucks and that would be one of your variables in an LOS function, along with volume or speed or something like that. Let's take a quick break now.

SW: Let's begin first with our discussion and maybe get specific input on certain two-lane highways. Say yeah, I think it's this or I think it's that, or whatever. Doug and Brad and Gina and I went out and drove around for half the day. Doesn't sound like fun for most people? We drove a lot of two-lane highways here in North Central Florida with the video camera rolling and had a lot of discussion about what we thought was going on in these two-lane highways and what might be important to people for the level of service.

SW: So what we have here is several clips. Like we said, we drove around for hours, but we've got ample clips that kind of have a variety of different things at least within the state of Florida. We don't have any mountainous roads here. When we play the clip, I'll point out specific things to pay attention to – most of it probably will be obvious. I'll be looking for a little bit of your input on these. The first clip – I won't tell you which road it is initially, but maybe wait until after we've looked at it and discussed it.

So here we have a two-lane highway. Pretty narrow lanes. I don't remember what we thought these were – 10, 11 ft max – probably 10½ , no shoulders, pretty frequent driveways. I think the posted speed here is 55.

What do you think? Anybody think this is a Class 1?

LG: I think it's Class 1. Because I'm driving comfortably, I'm not stopping, I'm following somebody in front of me without any interruptions. It doesn't really bother me that there's no shoulders or sidewalks or bikeways or anything…As a driver, I'm interested in one direction and I'm doing O.K.

SW: You don't feel that maybe the allowable passing, from the striping standpoint, may be a factor in it being Class 1 or not?

LG: I'm one person. I'm just telling you. But to me a road like this with narrow lanes and no shoulder, I would not think you could go…

ME: If the geometry limits the ability to be striped for passing, I don't think that's a negative towards perception on the left because the driver can see from the terrain that there are passing limitations. Now if you have a double stripe …

SW: The geometry is constraining your ability to pass. Would it still be a Class 1?

ME: Yeah. It'll still be Class 1. Given motorists expect to travel at relatively high speeds, then it can't be Class 1 if terrain's limiting the ability to travel at high speeds. To me, when the terrain becomes a speed factor, then you're stepping away from Class 1. At what point is terrain affecting the ability to travel at high speeds, however you define high speeds, that's an issue that's debatable too. But if you're saying it's like 60… mountains with slower moving vehicles, that doesn't mean it's not Class 1.

SW: The methodology says there's nothing wrong with saying outside of town it's 55, when you get into town it's this class, when you get back out of town it's this class.

LG: Am I understanding what you're saying that the traffic would change based on the area type? Is that what you're trying to say? I thought the speed as the determining factor would be set by the area type.

SW: Speed could potentially be one of a few factors that you base segmentation on…

LG: Yeah, but that is not the issue. The class is not based on the area type. The class is based on what you are doing on the two-lane road?

SW: Maybe area type does indicate the type of class. Like whether it's a scenic area or whether it's a developed area. Do you have any thoughts on that one, Keith, the first one?

KM: Yeah, I was wondering what kind of area it was in?

SW: CR-326? East-west route going away from Ocala.

KM: Yes, would that be something that was functioning as an access route to a Class 1 and then could that meet the definition of a Class 2 because of that?

ME: Yes, it's kind of a rural collector.

KM: Sometimes those areas are used for recreational driving or cycling and that kind of thing. I might call it Class 2.

DM: I changed it around a little bit. Let me add – clearly my intent here was just to listen to everybody else. I think I am still counting my words so that I'm not redirecting anything. Do you want me to participate or not, Scott? (Yes)

I'm not sure if it's Class 1, which is the wide open, easy to pass, first percent or less predominately passing zone – I think maybe that's what Scott and I typically think of as Class 1 – wide open, good geometry. Listening to Lea though was also kind of Class 1 because it was 55 mph, still kind of open, but I almost kind of want to go 1 and 1A here – there's a high level facility then there's also the facility that is still kind of wide open. There may be some geometric constraint. So, maybe there's two types of Class 1, if you will. To follow-up on what Keith was saying, going by the HCM though, that thing was a Class 2 even though it was posted 55. I personally think that thing is more of a Class 1 than a Class 2 just because you can go 55 mph.

ME: It looks like it fits the definition…of Class 1 if it's connecting I-75 and 27.

SW: One of the issues I have here is the issue of the design of the roadway. If this was really meant to be a high-speed facility, would you design it with narrow lanes and no shoulders? This does not ...

LG: I don't think it was designed for high-speeds. It was designed as a two-lane road and we then posted the speed on it which became high-speed. We have to remember that those collectors, when they were built as two-lane roads, especially in the area of Ocala, they were just connectors. They were not…

SW: You're saying it's basically serving a different purpose than originally intended. You should base the classification on how its really functioning.

I still kind of see this wide-open, wide lanes, wide shoulders, it's a straight shot, plenty of passing opportunities, it's a no-brainer Class 1. Start getting into more of these restricted designs, why I'm not convinced.

ME: You can describe it as being, now given it's posted speed, sub-standard as far as current design standards and Alachua County …

SW: Let's go to the next one. We've got a few more of these.

DM: Maybe there are more than 2, maybe there are 3 or 5. And I thought FIVE classes? But all of a sudden I thought this was a geometrically constrained high-speed roadway. Maybe there is a different class there. Whether it's 1 and 1A, or whether it's a new class or something else.

ME: I think the issue is whether geometry is constraining, or driver behavior is constraining for level of service.

Next Clip Played

SW: This is entering a small town… that, I'm sure you will agree is not Class 1.

LG: I'm sorry. I'm still looking at it as a Class 1 (a Class 1 sub-category) because the area-type you will call it a community area or whatever you call it. But it's still a two-lane road where the speed is pretty reasonable, people can still drive, there are not as many interactions. As a driver, I'm getting to where I want to go, I don't need more lanes, I don't need anything else. So…

ME: Do you have a paved shoulder there now? In that developed area, you're not expecting high speeds in that area are you? (No.) Approaching stop light or sign or whatever.

LG: Maybe really the differences between the area type.

SW: If I hear Lea correctly, there is no reason why you still couldn't have level service A as you go into this small town, but for the purpose of classification you've got to have different classifications. Most likely you'd have a different way of defining levels of service between those two classes.

DM: Percent time spent following, is it close to the speed limit, is it going an average speed, is it a combination of this, is it the number of trucks that were on the other side – in that situation?

GB: As a driver, as long as I'm proceeding ... I would ask to mix in the number of trucks. If you are following or passing or on the other side or something, because that's a factor and it always slows you down.

Vehicle population is a factor. Go back to what you said earlier with speed as a potential service measure? If we go out and measure the average speed on that road and it's 35 and the posted speed limit is 35, that would probably be level service A. So it's not the magnitude of the speed per se, but magnitude of the speed relative to the posted speed.

ME: I think so. I think people have this perception of LOS being based on how comfortable you feel driving in the wide-open spaces of Montana and developing congestion in that environment and then translating that to New York City and applying the same measures is not realistic. People stop their cars and drive home in commuter traffic 90% of the time, but what do the car ads show? You're up in the Rockies, zooming … They sell that, but that's not what you end up purchasing it for. And that's my point – this perception of some nice LOS out there versus the realities you get here where people are 'conditioned' and since this is all qualitative based on perception…I think… we're stuck in this commuter traffic, this is what it is and I think the standard needs to really reflect the reality of our conditioning to traffic. It's like getting LOS A-plus when you get out into that wide-open space conditions. But for measuring workday commuter traffic, I think the standards and evaluations and measures should be reflective of that condition.

BC: Going back to Doug's question on LOS - they go into an area like that, what's important, for me, I think travel speed or percent time spent following is kind of – I can forget about those for a second when I'm driving on a two-lane road, going through a small town. It's probably a mile and a half – 2 miles at the most. I know it's going to pass soon. The only thing that would bother me is maybe the volume. If I'm expecting a traffic light, I don't mind stopping, but if there's heavy traffic volume and I get stuck in it, maybe I have to wait like 2 cycles before I can get through the light, that might irritate me a little bit. But being that there are gas stations and post offices and things like that, I don't think stopping or following somebody would really be an issue since you kind of expect that when you're driving through a town.

Next Clip Played

SW: This one has no shoulders – similar to the first one. We thought it was a Class 2…looked a little wider than the first one.

Yeah that's coming up, the passing opportunity is much more than in the first clip. This is a little bit wider but still no shoulder. What's different here between this one and the first one? (Better geometry.) Yeah, a little better geometry…

ME: And the point is – with better geometry there's more opportunity to pass. (Right.)

SW: Is that one of the distinctions between this one and the first one?

ME: I think so. That has to do with my discussion earlier about how geometry can constrain you from having an opportunity to pass relative to a relatively 'fly down the street.' In other words, you're trapped in a condition of percent time following as opposed to eternally following somebody.

KM: Did the road surface seem smoother there? Looked like the first one had a more rough…

SW: There's some other research for rural freeways where pavement quality has been indicated. A survey of many, many travelers – pavement quality was definitely a factor for them on LOS – something that we normally don't account for.

ME: You get out into a region like Dixie County or Taylor County – where you've got logging trucks. The difference between the pavement condition on one lane versus the other where the trucks are going back empty and coming back full. They actually drive two sides of the road when there's no traffic coming just to make the ride less bumpy.

SW: I tell you, I would take 20th /24th street home every day from school/work, but the fact is that it's a nightmare with the pavement there and all the pot-holes. I usually go down Archer even though it's littered with signals. The pavement beats the living daylights out of my car. If the pavement was nice there, it would be a no-brainer taking that route home.

KM: There are two county roads in Tallahassee (Leon County) where they put a rough coat on there intentionally to slow travel speeds. Like that first clip seemed to have that – more aggregate in the asphalt or something. Central Florida, around Marion County. They seem to have a wider appearance and they seem to have that rough coat. They seem to be out in the agricultural areas and I would associate it more with Class 2.

SW: Good point.

Next Clip Played

SW: 30 mph, two-lane roadway, you've got parking on the sides, Doug's driving 32 mph. Do you think it's a pretty good level of service on this section, Lea?

LG: Yes. I'm coming to more and more conclusions that the function of that level of service is based on the speed and the speed's set wherever it is. My perception, or how the geometry…but if the speed limit's at 30 or 35 or 55 because of the area type, or whatever it is. My driving ability and the level of service that I would perceive is based on that speed.

If there are trucks there on the opposite side and they're loaded, there are SUVs or if there is no way for me to pass or if the road is very narrow of if there are cars parked on the sides – I think some of those things interrupt my thinking. They kind of break my flow – I'm just driving. And that's what causes me to slow down and my speed changes. From my perspective, the speed was set up for reasons for why it was set up.

SW: The geometry may have factored into that as well.

LG: Of course it does. So my reaction to it is to hold that speed and my goal is always to go beyond that speed.

SW: You're almost making a case of measuring on your ability to maintain your speed relative to the posted speed…could maybe be service measure for any class of highway.

LG: And that's what I'm coming to, because I was looking at the first example, the second example and the third example. Whichever, if the first one was a 1 and if the second one was a 1A and the third one was a Class 2, in all three cases when I was driving with Doug in this car, I was just looking at how am I going to really reach over there, the faster I can get there without being interrupted. That's my goal and so I'm thinking about the speed.

SW: I think one potential glitch could be…but I'm not sure it applies as much to two lanes as it does, say, to the freeway. When you can't have multiple-lane freeway flow, speed is somewhat essential to flow but you start getting these closer headways and that's why density increases.

I think that would still impact your speed to some extent. Let's say you were doing close to 65, you're doing 55 but you're the only one on the road as you opposed to you doing 55 but you're in a group. Again, maybe really you wouldn't be doing that same speed if you're in a group.

LG: If I'm in a group I would be driving 45 but if I'm not in a group and the speed limit is 55, I'm driving 65.

SW: You're thinking that the platoon is still going to have a negative impact on your speed?

LG: Yeah, because I depend on what they're doing.

SW: Is that realistic to think that Lea would still go as fast as she wanted to by herself, as opposed to …

LG: If there was a truck in front or if there's an SUV or whatever, I will be reacting to that.

ME: So, the ratio of travel speed to posted speed … measurement is what you suggested?

SW: Basically what she's saying is – yeah, what is your speed relative to the posted speed. I don't know if you can measure…

ME: If everybody's going the speed limit, how can it be D? You'd be going the posted speed limit, but because the percentage time following is 70% you're in D. Why can't I understand that logic? If you are moving down the road at the legal limit, even though let's say you can go 70 on that road if you chose to step on the gas, then how can it be D?

SW: We did some examples for HIGHPLAN, where we set it up that the average travel speed was governing the level of service for Class 1, and the LOS was C or something even though the average travel speed was actually right around the posted speed. It's understandable. I would have issues with that.

DM: You wanted to tie your actual speed to the posted speed. (Right) Is it the posted speed limit you want to tie it to or do you want to tie it to your 65 mph? If it's posted 55, but your free-flow speed is 65, would you rather tie it to the posted speed limit or what you would normally drive at?

LG: Let me try to figure out what I would do. I think basically the underlying way that I would take is that I would try to adjust my speed to the one that is posted. So if your question is which one matters more by adjustment or credibility, I would say that my target is to look at what the posted speed is and I will try to by-pass that, but if I'm interrupted, then I'm not going right, then my level of service is not acceptable. Then the platoon and the trucks and all those other elements come into play. The real thing is that if the road is designed for a speed limit of 55 in a rural area or in urban area, whichever it was designed for, and it's posted 50 and I'm driving 55 – I'm doing good. If it's posted 50 and I'm driving 45, then I'm not reaching my flow, my driving ability.

SW: The posted speed may be 55 and let's say you and everybody else that drives that roadway feels like 60 is the speed they can do and should do. You feel at 60 your level of service is better than if you're doing 55?

LG: No.

GB: She's saying it's still the same. Whether she's going at the free-flow speed or right at the speed limit, she's doing fine.

SW: You wouldn't say that your level of service is a little bit worse?

LG: No. My best mark – if the speed limit is 55, then my level of service A is based on that speed limit because the road is designed to achieving speed limit for the safety, for design, for geometry, for whatever. So I'm measuring it based on that and I go a little faster 'cause I want to always do better. That's life. But my measurement of A will be that 55. If I go below then I'm not A. For example if you drive on Blanding, there are signals all over the place and a constant 35 miles or 45 in certain areas. We know Blanding Boulevard?

SW: No.

LG: Blanding Blvd. is that corridor that goes all the way to Orange Park. Have you taken that one? There are gas stations and Taco Bells and McDonalds and there are driveways every inch and everything. But there is a progression of signals and I'm always driving the 45 mph and you know what, I'm driving at level service A. I'm explaining it O.K.?

END OF TAPE 1

BEGINNING OF TAPE 2

SW: That's good stuff. I'll want to get some other opinions from the others on that.

DM: But being able to hit the signal progression is a very big deal for LOS for you.

LG: In a congested urban area, I guess.

ME: I'll be glad when signal progression comes to Gainesville.

SW: Yeah, I've been reluctant to bring up that issue yet.

Next Clip Played

BC: This one is, if you sort of ignore the construction, new pavement and…

SW: Wide lanes, shoulders. Let's skip to the next one.

BC: This is just driving through Micanopy.

LG: What's wrong, you're driving ten miles per hour here.

ME: I think the speed limit is 25.

ME: …And then they put in a speed hump. I just laugh at that condition. I'm sorry.

SW: I'm not sure we intended to show this one.

DM: Is your concern following other cars?

KM: Looks like a certain neighborhood or something.

ME: Well, I think what is happening in this condition, for those who are familiar, is basically when they laid that county road bypass to connect 441 to the interstate, to me this became a local collector at best. Because the function it previously served was to connect 441 to the interstate. And when they built that bypass, you pretty much want to go to Micanopy to go on that road, otherwise you're taking the bypass. So I think its functional classification is much different now than what it was. The fact that there's a speed hump on it should tell you something about that.

KM: Is that their main street? Kind of a main street with some antique shops on it.

ME: yeah

DM: According to the Highway Capacity Manual, it is still an uninterrupted, 2-lane highway.

DM: How do you evaluate that roadway?

ME: I don't know…it's in our region…I'm glad they hired consultants to do that. I'd be interested to see what the functional classification is now and then ????. Like I said, I'm almost inclined to relegate it to a local road as opposed to a rural collector.

Next Clip Played

SW: Let's go to this next one. OK, this is a scenic highway. Speed limit's set at 55. Maybe 11 foot lanes, no shoulders. And supposed to be lots of scenery to look at.

ME: Maybe just the absence of billboards makes it a scenic road.

SW: Yeah, I'm not quite sure how the scenic designation came about.

KM: Maybe it's the national forest?

ME: There are some canopy trees. We've seen some canopy. I was trying to see if it was a local scenic road. Ok, down around by Cross Creek, so this is east of Micanopy. Down by Evanston or something like that?

LG: You know I wouldn't call this a Class II scenic highway. I would call this a Class I, because I can drive here 55, 45, depending how much I want to enjoy the scenery. But, you know we need to go beyond the universe of Gainesville and look at what each corridor looks like. A1A, or US-1, or areas that have 2-lane roads that are different. And then see how to classify them. This is very similar to Class I.

ME: I think so.

DM: So is the wide-openness of the general free-flow traffic that was relevant here and not the scenery or something else?

ME: I would still say if you can do the speed limit or better, I just don't understand how it would be a bad LOS, even if you have 80 cars going.

SW: Did you say this would be different still from A1A?

LG: Yeah this one certainly is different from A1A. You need to look at different universe of classification.

ME: Well, different scenery and the number of access points that would be off A1A, as opposed to this are extreme.

Next Clip Played

ME: Somebody just pulled onto the shoulder.

DM: Narrow lanes.

LG: I'll tell you a big measurement we're ignoring, which is coming up right now, is the school crossing. Anywhere you have a school crossing…and have been ignored in Florida. But there is no other stronger element than a school crossing for slowing down or reducing speed, which disturbs the level of service at peak hours certain times of the day. That's one measure; did you see the school crossing? If it were there, I don't care if there were trucks, or 10 cars, a platoon, or if you were by yourself. As long as there's a crossing there and the light is flashing or there's a school bus, the whole universe stops and you have to slow down. Then it's not a measure of level of service and it does make an effect on the level of service.

SW: We're looking at down the road, a little bit, how we can accommodate different interruptions of 2-lane highways because it's becoming more and more common, whether it's a school zone or signal or something else.

ME: I think a factor you have to consider, and I'm sorry you didn't get it on your sampling, was passing or a bicycling lane because on that Evanston clip you had before, that's a popular bicycling route. There were some discussions years ago about having it resurfaced and adding paved shoulders. Some cyclists didn't want to have the paved shoulders because they associated adding paved shoulders to accommodating even higher vehicle speed. And as a vehicle comes around and clips the shoulder…they'll take out the cyclist worse than if the cyclist had stayed on a narrow lane. And I don't know how this factors into what you're evaluating, but…

ME: Well, geometry!

BC: The last one was pretty much the same as the other scenic routes, except we passed the truck.

SW: Go ahead and show the other one.

ME: Call it non-motorized vehicle accommodation …

Next Clip Played

BC: I think this was the most geometry we saw all day.

SW: We had a couple of horizontal curves but this is the only vertical…

ME: There's so much undulation that there's no real break in it.

SW: Here are some driveways again…

ME: And once again, given the conditions, I think proximity to the posted speed is a great factor. To me, that would be the most important factor for LOS perception.

ME: 55, looks like going up to Worthington Springs or something?

DM: This is old US-27, south towards Ocala.

SW: Terrain…Mike, you still think that the speed relative to posted speed is…

ME: Yeah, because obviously the terrain meant for the yellow striping, which is a forced percent time following condition, not voluntary. So given that condition, if you are zipping along at 55, then why isn't that a high LOS? In other words…if you were at 70% time spent following, and came up with LOS D, I'd say, but you're going the speed limit. How can you have such high travel speed and be in that condition?

LG: You know what? Personal conclusion…in all those 2-lane roads, all those samples that you drove, the factor of the volume of cars didn't come into play at all. The second most important factor…the other third factor is the factor of geometry. How much time you spend following and all of that, is almost at the end of the line.

SW: Say it again, you said speed was number two?

LG: Right, what I was saying is volume was not a factor. Number two factor was speed. How fast can I go past the speed limit? Geometry is the next one, because if I have to curve on a narrow road, and somebody's car, or wall, or bike, or whatever, some constraint of some sort whether physical or non-physical. That is the third element that'll affect my driving, and the level of service. The last of all these was following someone as a measure. Because I can always take the opportunity to pass or slow down or stop somewhere. Sometime, if there is a dump truck in front of me, I'll go to the gas station and get a cup of coffee, so I don't have to see him. I mean…

DM: Clarification Lea…your speed is not average travel speed; your speed is how close I am to the speed limit?

LG: Right, I'm not doing 75 mph because it's open. I'm trying to always obey the law, with 5 miles more.

ME: Just like in ARTPLAN, with 5 mph over the posted speed.

LG: And I may not be the example; everybody's got their own way of doing things. A 17-year old, in an SUV or BMW, and they're zooming through that 2-lane road; they're getting there 5 minutes before me. I don't know if that's the goal. They're not going to work, I may be going to work. Five minutes may not be important to them. Five minutes may be more important to me, but I'm willing to give that for safety. So, the trade-off, the difference.

SW: We have one more clip. Let's do that one and then we can wrap up the final discussion.

Next Clip Played

BC: This one is just right after the last one with the terrain. This one goes back to a flat geometry…same road.

LG: Scott, I think we need to make a note that if it's an FIHS facility, to consider it differently. I don't know the wording, maybe I don't have the right expression, but if it's an FIHS facility and it's connecting major … it has a different function. Then I would look at the classification and all these decisions a different way, even the speed. Because on an FIHS facility, the speed should be relative to the function of the road, not just the design of it.

LG: We have the other FIHS in the state that are 2-lane.

DM: Lea, what I want to say is those FIHS routes are the classic Class I…

LG: Yeah that's right.

SW: That's SR-40, right?

DM: Right. The other routes that are posted 55 and maybe have geometric constraints are a little bit different. They're still open roads, but they're not the same as the 12-ft lanes with the 4-ft shoulders with as much passing zone as we can get.

SW: Yeah, we didn't have a video, SR 40 probably would have been a good one. There's usually pretty heavy volume on that. We would be able to see the relative difference. Everything we were driving…there were few other cars out there.

GB: I think that's a reason…volume did not really affect…wasn't a factor. You were the only car on the road.

LG: If you look at an FIHS facility, then volume is an issue. Level of service is measured by the volume, and the number of trucks and all that.

SW: Charlie? Any thoughts on what Lea said or other things? Haven't decided yet? Or speed relative to speed limit?

CH: I think if you're doing 55 on a 55, that should be a better level of service.

SW: What about if you do 35 on a 35?

CH: I think it should be a better level of service…that'll be all right. You're doing what you're expected to do. You're doing the best you can do.

SW: So you're saying that matches the driver expectation? Drivers go through these areas and their expectation changes…not whether they're going fast…

KM: I agree. I think it's rational. It makes sense. It seems like the land use surrounding the roadway might be a way to distinguish between these rural roads you showed versus these others constrained, urban, or coastal roads.

SW: You think that would make a case for different classification?

KM: Yeah, maybe whether the density…whether you might base it on population, or census, distinguish it, defines urban versus rural, or you actually have a land use classification system or something like that.

DM: Keith, what about the possibility of using driveways? Is that another one? Or it could be non-residential driveways. What I heard earlier was…number of access points, which you differentiated between whether they were residential…I thought you were grouping commercial and streets, that was one type of access point, and then just kind of discarding residential. I want to get at your land use point of view.

KM: Right, I thought maybe the DOT tracks or permits…you have a count on that right?

LG: Some of them we do because we permit the access points, but some of them, you know, there are some that are grandfathered. We don't have a database that tracks all the driveways and the geometry. But I want to respond to and emphasize what you just said, because he's got a very good point. Classification is more likely to be based on the area type, if it's urban or transitioning or… It's not so much the function of how many driveways. You have driveways and you have signals and if there's a progression, then that's not so much a problem. But if you have an urban area with a lot of development, then your speed limit is lower; your expectation is different as you're driving. The interruption when people come to driveways or cut to roads is to slow down, then you measure slowing the speed limit. The speed is what lowers the level of service. And the volume of course is part of that equation. In classification of Class II, and anything beyond that, or in between Class I and II, would be based on area type.

SW: But I still get the sense that you're thinking that we don't necessarily need different service measures for different classifications, am I correct? I've been hearing the speed relative to posted speed, and I've been hearing that across the different classifications.

LG: Yeah, I agree. That is an umbrella to all of it, but if you want to go beyond that and classify…

SW: You're saying maybe we can have secondary…that'll be a primary service measure but there could be different secondary service measures for the different classifications.

LG: Right. I'm not the TRB or anything. Now you know how I feel as a driver.

KM: We were discussing earlier about what goes on in the coast versus what you might find out in a traditional commuter pattern. In the coast, there seems to be a seasonal peak, where certain times of the year, you're in St. Augustine where you have constrained bridges and constrained highways, it's really frustrating to be there at the wrong time. I don't know if there's a way to factor that, the seasonal issue. The way they try to address that is providing alternative routes with bridges of greater capacity, interspersed along the coast. But I think along the coast, if there are sections of highway, of A1A…have they been fixed at 2-lanes. The scenic highway designation, has that fixed the lane width by local government decision?

LG: Most of the time they are. And the speed is adjusted to that. And as it grows more vertically, the population is requesting even lower speed limit. They want to absolutely slow this movement. So what's happening is that, you were talking about alternative routes, or alternative bridges, there's also the concept about alternative motor conservation to alleviate some of that. There are other ways…we're talking about measuring the LOS as a driver. But on A1A, you're right, the season makes a big factor, in the summer or December, depending where you are.

DM: We're constantly narrowing in on these clues…Do you think the HCM is...is it better to work with one service measure, so you can go out there and measure and monitor it and hopefully can make the best one, or is it better to have a function where there may be 50% because of speed, 20% because of volume, 10% because of the pavement surface, all measurable. Are we better off, when we determine the level of service, to use just one measure, is it all or nothing, but it's cleaner, or are we better off with a primary measure adjusted by others? Understand the question?

LG: Yeah, very good question Doug. If I was a consultant, I would say give me all those opportunities. Let me measure it this way, this way, this way and come up with a good level of service. But if I'm being practical about setting some standards and being able to measure it one way across the board, it's better to have one measure. From DOT perspective, for us, it's better to have one measure than to have five little element s to try to conquer in order get level of service.

SW: Let me see if I can clarify a little bit on what Doug's talking about. Right now, you have two service measures that are sort of independent; I think I can see what you're talking about, you've got percent time spent following and average travel speed; and if you leave it to the consultant, they look at them and say this one comes out, and this one, this one, let's go re-measure, this one's now here…But maybe what Doug was getting at was that maybe we can have a very defined, basically like a function, where we have a coefficient times the volume, plus a coefficient times the speed, plus a coefficient times a geometry factor, and so on, but there wouldn't be room for the consultants to play games. They measure these three things, plug them into the equation, function, and calculate the level of service … granted, they can go back out to re-measure. At least there wouldn't be the independent relationships, they're all related, you just plug in the numbers and calculate an answer…then reference this answer to one LOS threshold table…

LG: I think if it's done correctly, and your coefficients are proper and don't have room for jiggling, then one measure is a better measure for it; but it has to be realistic, that's the key to it, no room for question.

ME: You're saying you may be inclined to use the function to come out with one single value…because I don't think there's a magic bullet, one single thing that says that's what LOS is, that can be applied everywhere. You will offer great economy, but I don't know if it's realistic.

SW: We did some preliminary research on rural freeways and found that…that was one of the conclusions I made, was people think multi-dimensionally about this, multiple factors. There are some that are definitely more important than others, but it's not like they don't consider anything else. This is for rural freeways, but it may be applicable to other facilities. But speed was definitely, what you were talking about, the ability to travel at or above the posted speed limit. I don't remember…that might be number one, but there are a couple of other things, like pavement quality, that was definitely a strong thing, not as strong, but that was a factor, and there were a couple of others. So there's a dominating factor, but there are others that can shift it a little bit one way or another.

LG: There's certainly correlation between all those factors. There is a measure of all of them…and maybe the best way to handle all of them under one formula; but really, you cannot allow much room for jiggling, that's the most dangerous thing, to move in all directions. To answer that, I think one formula is better than ten little ways to look at.

ME: Scott would love to do the studies to able to weigh each one of those components.

DM: Actually along those lines, what some of us on the Highway Capacity Committee are doing is suggesting a national study. $500,000 or a million dollars throughout the United States to do the research of what are the factors. So it wouldn't be just Florida, it'd be a nationwide study, so for the nation as a whole, that is not an unreasonable cost. It may come to that if it's a good idea. But other people on the Highway Capacity Committee liked…you don't go out to measure a function, you don't go out there and, you know, here are the 14 factors and you get a value of 2.6, and that means LOS C. It's much easier for us to go out there and measure a speed; you measure a density of vehicles…

ME: Yeah, but that speed is a result of the driving conditions, which may have accounted for 85% of the …

DM: But there's only one thing the person has to go out there and measure and determine. Some of the group like that one thing only; but others like the idea of as long as we can keep it down to one function, you don't get the wiggle room. But again, the major factors, so that we can account for 90% of what they experience. There are two thoughts there.

SW: In the case of a rural freeway again, speed is the major factor; but again, speed should be relatively constant. The increase of volume is when you really start to…when you get the volume up there is when it starts to drop. But we saw that density was still the concern because of the comfort level. Even though they may be doing 75 -- 75 by themselves versus 75 with several cars around them. The comfort level comes down a little bit, they still feel like well maybe it's not LOS A+, maybe it's LOS A-. Sort of tempering it a little bit.

ME: I suggest they'll feel even less comfortable if the vehicles surrounding them are trucks.

SW: Right. And so again...

ME: I like the point about vehicle population being a factor before.

SW: We put that in the survey, I just don't remember if people indicated that was significant or not, it may have been to some extent.

ME: Not so much on two lanes because they are either in front or behind you, or in the opposite direction. But if they are next to you, the comfort level drops.

SW: Keith, was there any specific thing that you want to bring up?

KM: Just talking to some other people in the office, we generally agree with some of the statements made that two classifications sometimes don't result in…that they do not apply to developed areas such as small towns.

SW: Felt like that is kind of falling through the cracks right now?

KM: Right, we kind of agree with the comment there, also with the average travel speed LOS thresholds being unreasonably pessimistic for these types of roadways through developed areas.

END OF TAPE 2

Task 2b

Identification of Preferred Performance Measures for the Assessment of Level of Service on Two-Lane Highways

IDENTIFICATION OF PREFERRED PERFORMANCE MEASURES
FOR THE ASSESSMENT OF LEVEL OF SERVICE
ON TWO-LANE HIGHWAYS

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ABSTRACT

The concept of level of service (LOS) is central to the *Highway Capacity Manual* (HCM) [1] and is used to assess the performance of all types of roadway facilities. Many transportation infrastructure funding decisions are based on LOS analyses and the resulting LOS designations are intended to represent user perceived quality of service.

This paper provides an overview of the evolution of the two-lane highway LOS analysis methodology and identifies weaknesses in the methodology as perceived by the Florida Department of Transportation (FDOT), as well as other HCM users. In particular, this study focuses on deficiencies in the methodology (in terms of performance measures, LOS thresholds and service volumes) with respect to rural developed two-lane highways, such as those facilities through small towns or developed coastal areas.

Although the HCM intends for LOS designations to correlate with user perceived quality of service, little research has been done to ascertain what those perceptions are. Therefore, the objective of this study was to determine what performance measures appear to be most appropriate (i.e., consistent with traveler perceptions and expectations) for assessing LOS on different types of two-lane highways. This objective was facilitated primarily through direct input from non-transportation specialist travelers in a series of three focus group sessions. Focus group participants watched a series of video clips depicting different two-lane highway driving situations. Audio recordings of focus group discussions and data collected from survey forms were analyzed.

Based on the data collected in this study, it is apparent that motorists consider several factors in their assessment of trip quality on a two-lane highway. The function and/or development setting of the facility also appears to dictate what their quality of service expectations are. At this time, two-lane highway classifications are largely based on expectations of travel speed. However, from this study, it appears that expectations for passing should also be considered, in addition to travel speed, when distinguishing among facilities. Also, the current classifications do not address rural developed two-lane highways (e.g., facilities through small towns, developed coastal areas, etc.). These types of facilities should receive their own classification (Class III) and their own specific performance measure.

Ultimately, the development of a more comprehensive LOS methodology should be pursued. The outcome of such research might be a level of service function, defined in terms of a series of variables (performance measures) and corresponding coefficients that could be applied to all categories of two-lane highways.

CHAPTER 1
INTRODUCTION

Background

The *Highway Capacity Manual* (HCM) [1] is widely accepted among governmental agencies in the United States as the definitive tool for level of service (LOS) analysis on all types of roadway facilities. The Florida Department of Transportation (FDOT) is no exception, and has committed itself to implementing the principles outlined in the HCM when evaluating the LOS for transportation facilities found within the state.

The HCM 2000 defines LOS as a "qualitative measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience" [1]. It also states that "each LOS designation (A through F) represents a range of operating conditions and the *driver's perception* of those conditions" [1]. In other words, the concept of LOS serves primarily as a means of evaluating the operating conditions and quality of service of a roadway as perceived by the traveling public.

Because decisions regarding transportation infrastructure investment are largely based on LOS analyses, roadways with poor LOS designations typically receive higher priority for funding. Therefore, LOS methodologies that accurately reflect the roadway user's perception of operating conditions are necessary to avoid spending taxpayer money where it is not necessary.

With this in mind, transportation researchers are continually trying to develop new or improved methods for accurately estimating roadway performance measures and translating those into LOS values that hopefully correlate well with the quality of service as perceived by the traveling public. Again, with better LOS analysis methodologies, transportation practitioners and funding decision makers will be able to make better infrastructure investment decisions in the eyes of the public.

Problem Statement

One area of special concern to the FDOT since the early 1990s has been the LOS analysis of two-lane highways in rural developed areas. Since the publication of the 1985 HCM, FDOT has questioned the applicability of the two-lane highway methodology to two-lane highways in rural developed areas.

This issue came very much into focus when officials in Monroe County, Florida had difficulty accepting the results of HCM LOS analyses for US-1 (Overseas Highway) from the Florida mainland to the Florida Keys. After applying the 1985 HCM methodology, state transportation officials felt that the resulting LOS determinations along this highway were unrealistically low and did not reflect actual user perceived quality of service. US-1, like many other two-lane highways in the United States, features uninterrupted flow with alternating sections of undeveloped and developed surrounding land use. However, as some transportation officials would later come to believe, the 1985 HCM two-lane highway methodology was not designed to account for developed sections of two-lane highway with uninterrupted flow.

These concerns did not apply only to US-1 however. In addition to FDOT officials, other HCM users were expressing dissatisfaction with the 1985 HCM two-lane highway methodology with respect to these types of facilities. Prior to the release of the

HCM 2000, the National Cooperative Highway Research Program (NCHRP) sponsored Project 3-55 Task 3 [2] to identify the strengths and weaknesses of the 1985 HCM two-lane highway chapter. As part of this project, a survey was conducted that asked HCM users to identify ways in which they would like to see the two-lane highway LOS methodologies improved. Among the responses, several comments were made regarding the lack of an explicit methodology for uninterrupted flow two-lane highways in rural developed areas as well as two-lane highways with reduced design speeds. One user stated, "There is a need to develop a consistent level of service measure to address situations where a rural two-lane road passes through 'village' areas where posted speeds are less than those considered in the current methodology. In many cases, these areas cannot be considered urban or suburban and, thus, there is not an appropriate method to assess level of service" [2]. Another comment was, "The procedure should address levels of service for roads with design speeds down to 25 mi/h" [2]. The project report also noted that several agencies felt inclined to invent their own procedures to deal with these types of facilities.

While the two-lane highway analysis methodology in the HCM 2000 was more robust than the previous methodology, transportation officials at the FDOT still felt that this revised methodology fell short of adequately addressing LOS analysis issues for two-lane highways in rural developed areas. Despite the introduction of two different classes and corresponding service measures, which allowed more flexibility in two-lane highway analyses, the FDOT still felt that traveler expectations on two-lane highways in rural developed areas were not consistent with the service measures, LOS thresholds, or roadway travel functions defined for either of these two classes. This is essentially the core of the problem for the FDOT.

Although the HCM intends for LOS designations to correlate with user perceived quality of service, little research has been done to ascertain what those user perceptions are and rarely have user perceptions been compared to the current LOS designations assigned to a facility.

Research Objectives and Tasks

The objective of this study was to determine what performance measures appear to be most appropriate (i.e., consistent with traveler perceptions and expectations) for assessing LOS on different types of two-lane highways. This objective was facilitated primarily through direct input from non-transportation specialist travelers in a series of three focus group sessions. The following tasks were carried out in support of this research objective:

- Determine suitable two-lane highway segments from which to collect field data,
- Collect video footage of roadway and traffic conditions from these chosen two-lane highway segments,
- Produce short video clips to be shown to focus group participants,
- Recruit focus group participants,
- Conduct focus group sessions to solicit traveler opinions and perceptions about the factors most important to them for assessing trip quality on two-lane highways
- Perform an analysis of focus group participant responses, and
- Recommend performance measures for use in two-lane highway LOS analyses based upon the analysis of the focus group participant responses.

Chapter Organization

Chapter 2 includes an overview of existing literature relevant to this topic as well as a timeline describing the sequence of events that led up to the current research detailed in this paper. Chapter 3 is an extension of chapter 2 in that it provides a more comprehensive look at the methodology in terms of service measures, LOS thresholds and service volumes. This is achieved through a series of example LOS calculations. Chapter 4 describes the research approach used in this study, including the selection of two-lane highways, equipment setup, collection of video footage, video clip production, focus group participant recruitment and selection, and focus group implementation. Chapter 5 describes the analysis method as well as the results. Chapter 6 is comprised of conclusions and recommendations. Several appendices are also included with supporting data and information.

CHAPTER 2
METHODOLOGY REVIEW

This chapter provides an overview of the historical development of the two-lane highway analysis methodology in the HCM, deliberations by the Highway Capacity and Quality of Service (HCQS) committee on the topic, as well as other relevant literature. The material in this chapter is organized chronologically and traces the development of the methodology over approximately the last 20 years, as well as the related issues that ultimately motivated this research study.

Highway Capacity Manual (1985)

The 1985 publication of the HCM introduced the concept of percent time delay as the primary service measure to be used in the assessment of LOS for two-lane highways. Percent time delay is essentially a measure of decreased mobility as a result of traffic platooning, or more precisely, "the average percent of time that all vehicles are delayed while traveling in platoons due to the inability to pass" [3]. Average travel speed (ATS) and capacity utilization were named as secondary measures.

Also introduced in this edition was the concept of capacity as a function of the directional split of traffic. However, the capacity analysis procedure still only estimated capacity for both directions combined (two-way), such as in the 1965 HCM. Also discussed in this edition are several measures that can be implemented to improve operations by reducing platooning. One of the measures discussed is the usage of passing lanes; however, no corresponding procedure accounting for their effect on operations is incorporated into the methodology.

Another aspect of the methodology was that it appeared to focus mainly on uninterrupted flow two-lane highways with high design speeds and undeveloped surrounding land use. Under the methodology, two-lane highways with "design speeds greater than or equal to 60 mi/h" were considered ideal, and quality of service representative of LOS A would consist of "motorists being able to drive their desired speed" with "average travel speeds approaching 60 mi/h" [3]. However, many two-lane highways are not designed for high speed travel, either because of terrain, surrounding development, or other conditions. As discussed in the following sections, many users of this methodology came to believe that it did not adequately address these types of facilities.

Methodology to Assess Level of Service on US-1 in the Florida Keys (1993)

One such example, as described in a 1993 paper by De Arazoza and McLeod [4], was US-1 in the Florida Keys (Monroe County). US-1, the sole roadway connecting mainland Florida to the Florida Keys, is primarily an uninterrupted flow, two-lane facility with rural developed and suburban land use. US-1 passes through several small communities and developed areas, with alternating stretches of rural, open highway. When trying to assess the LOS on US-1 using the 1985 HCM, state of Florida and Monroe County transportation officials felt that the methodology presented in the HCM did not adequately address the unique aspects of US-1, nor did it produce LOS designations that realistically reflected user perceived quality of service.

Largely in response to this finding, the State of Florida and Monroe County formed the US-1 LOS Task Force in 1990, of which the authors, De Arazoza and McLeod, were members. Around the same time, the FDOT formed a subcommittee, comprised of members from the previously established Florida LOS Task Team (1988), to deal specifically with issues regarding two-lane highways in developed areas.

As explained in the De Arazoza and McLeod paper, the Monroe County Task Force, as well as the Florida LOS Task Team, held the belief that on two-lane highways in developed areas “most drivers were more concerned with maintaining a decent travel speed under uninterrupted flow conditions than trying to pass.” In other words, both task teams did not believe that the 1985 HCM LOS service measure of percent time delay was appropriate for this situation. As a result, the Monroe County US-1 LOS Task Force developed an alternative LOS methodology in which average travel speed (ATS) was used as the service measure, which they believed would reflect user expectations more effectively. The task force then developed LOS thresholds relative to the roadway’s posted speed limit (weighted by segment length).

In 1991, and then again in 1992, the Monroe County Planning Department conducted a travel speed and delay study of US-1. The alternative methodology, using ATS as the service measure, was applied to the study data to assess the LOS on different segments of US-1, as well as the overall facility. Based on knowledge of the local area and the supporting travel speed and delay data, De Arazoza and McLeod found that using ATS as a means to determine the LOS on US-1 produced results that “accurately reflected traffic operations and perceived levels of congestion.” Therefore, the authors recommended that ATS be used as the primary service measure in the assessment of LOS for uninterrupted flow two-lane highways in developed areas.

Level of Service of Two-Lane Rural Highways with Low Design Speeds (1994)

A 1994 paper by Botha et al. [5] also expressed concern with the two-lane highway chapter of the 1985 HCM. The authors noted the lack of an explicit methodology to assess two-lane highways with lower design speeds (less than 60 mi/h) and questioned the appropriateness of percent time delay as a service measure. These concerns were brought about when the authors observed discrepancies in the LOS results after applying both the 1965 and the 1985 HCM methodologies to two-lane highways with design speeds less than 60 mi/h.

While this paper recognized the need to address two-lane highways with low design speeds, the authors do not refer specifically to two-lane highways through developed areas (small towns, coastal areas, etc.). Instead, the focus of the research described in this paper was on the "evaluation of methodological alternatives for defining the LOS for two-lane highways with 50 mi/h design speeds" [5]. The methodological alternatives, other than percent time delay as used in the 1985 HCM, included other service measures and concepts such as density (two-way), functional classification of the roadway, limitation on achievable LOS range for low design speeds, and a combination of percent time delay and density.

Ultimately, the authors did not recommend any specific service measure or methodology. However, one of the main points that can be deduced from this paper is that the 1985 two-lane highway analysis methodology was insufficient in terms of evaluating two-lane highways with low design speeds and that further research needed to be conducted in an effort to remedy this issue.

Highway Capacity Manual (2000)

In 1994 and 1997, the Transportation Research Board (TRB) released updated editions of the HCM. However, there were no changes to the two-lane highway methodology introduced in either of these updates. In 1999, research conducted as part of NCHRP 3-55 Task 3 [2] resulted in the development of a new two-lane highway analysis methodology for the HCM. This methodology was incorporated into the 2000 edition of the HCM and with it came many significant changes. The two most significant changes involved the introduction of a directional procedure for capacity analysis and the introduction of a classification scheme defined in terms of user expectations of travel speed and roadway function. The classification scheme and the corresponding service measures outlined in the HCM 2000 are the focus of this section.

When following the current HCM methodology, the first step in determining the LOS of a two-lane highway is to classify the roadway. There are presently two classifications, which are defined below (directly from the HCM 2000):

- Class I highways are defined as two-lane highways in which drivers 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. These highways are often used in long-distance trips or as links between highways that serve long-distance trips.
- Class II highways are defined as two-lane highways in which drivers do not 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 generally are assigned to Class II. These roadways are often used for relatively short trips, the beginning and ending portions of longer trips, or for trips that include sightseeing, such as trips along scenic routes.

Once the classification is selected, the LOS can be determined by calculating the appropriate service measure(s) and applying the corresponding thresholds. Two service measures are used to determine the LOS of a Class I highway: percent time spent following (PTSF) and ATS. The definition of PTSF is essentially the same as that for percent time delay. The term was changed to percent time spent following to more clearly communicate the meaning of the service measure [2]. However, only PTSF is used to determine the LOS of a Class II highway.

While the two-lane highway analysis methodology in the HCM 2000 was more robust than the previous methodology, transportation officials at the FDOT still felt that this revised methodology fell short of adequately addressing LOS analysis issues for two-lane highways in rural developed areas. Despite the introduction of two different classes and corresponding service measures, which allowed more flexibility in two-lane highway analyses, the FDOT still felt that traveler expectations on two-lane highways in rural developed areas were not consistent with the service measures or LOS thresholds for either of these two classes.

More specifically, the FDOT felt that these types of facilities did not seem to easily fit into the new classification scheme. In accordance with the HCM's intent that LOS methodologies, and corresponding service measures, reflect user perceived quality of service, the two classifications (Class I and Class II) are defined in terms of user expectations of travel speed. Class I facilities are those in which motorists expect to travel at high speeds, while on Class II facilities motorists do not necessarily have this expectation.

User expectations are in large part tied to roadway function. Roadways that function as major intercity routes or primary arterials are often synonymous with high speed travel, and are therefore usually designated Class I facilities. Local collectors, scenic or recreational routes, and mountainous roadways often do not carry the same expectations for high speed travel and are therefore usually designated as Class II facilities.

However, the primary travel function of the roadway is not always consistent with user expectations of travel speed. In fact, Chapter 12 of the HCM 2000 states, "The classes of two-lane roads 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 facility's classification in an operational analysis is the motorist's expectations, which might not agree with the functional classification" [1]. This discrepancy between traveler expectation and roadway travel function formed the basis of the FDOT's concern with the two-lane highway analysis methodology.

Adaptation of the HCM2000 for Planning Level Analysis of Two-Lane and Multilane Highways in Florida (2002)

A 2002 paper by Washburn et al. [6] further explained this sentiment and outlined the FDOT's attempt to remedy it by revising the LOS determination aspect of the HCM 2000 two-lane highway methodology. The authors note, "Many of the state's two-lane highways are in areas that would be considered scenic in nature (e.g., along the coasts, the Florida Keys route), implying a Class II classification, yet many of these highways also serve well-developed areas, which would imply a Class I classification" [6]. As a result, FDOT LOS Task Team members "had to decide if either one of these classifications would be appropriate for these types of highways, or if a new classification needed to be developed" [6].

As mentioned previously, FDOT's LOS Task Team members believed that the primary concern of drivers on rural developed two-lane highways was the ability to maintain a decent travel speed rather than the ability to pass. Consequently, the FDOT decided to revise the two-lane highway LOS methodology of the HCM 2000, based on recommendations from researchers at the University of Florida Transportation Research Center, to more adequately address their needs. These revisions were ultimately incorporated into the FDOT's two-lane and multilane highway level of service analysis software package (HIGHPLAN).

One of the principal changes dealt with the addition of a third class of two-lane highway that used percent of free flow speed (PFFS) as its primary service measure. The third class of two-lane highway was intended to represent those roadways in rural developed areas (e.g., along the coasts, through small communities/towns). The proposed service measure, PFFS, gives the average travel speed relative to the free flow speed. The authors note that the use of relative speed, as opposed to an absolute speed, provides a more accurate gauge of LOS than the ATS measure recommended in the US-1 methodology. Additionally, the authors proposed that the LOS thresholds also be based on PFFS.

Ultimately, the authors concluded that there is great need for the HCM to recognize that a third class of two-lane highway exists and they recommended the use of PFFS as the corresponding service measure to be used in LOS analyses.

NCHRP Project 20-7 Task 160 (2003)

In April of 2002, the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Traffic Engineering issued an emergency contract[1] to the Midwest Research Institute (MRI) to address issues regarding the two-lane highway LOS methodology in the HCM 2000. The prime contractor, MRI, was to deal with two main concerns, initially raised by the FDOT, but also echoed by some other HCM users. The first concern involved the overestimation of PTSF in the directional segment methodology. The second concern (which is relevant to this methodology

[1] NCHRP Project 20-7 Task 160: Two-Lane Highway Analysis Methodology in the Highway Capacity Manual: Final Report. Midwest Research Institute. Kansas City, Missouri, 2003.

review) dealt with the fact that the HCM 2000 methodology did not appear to address two-lane highways in developed areas. Appendix A contains copies of letters from representatives of FDOT and the North Central Florida Regional Planning Council (NCFRPC) regarding this concern.

The project report identified three scenarios not directly addressed by the HCM's two-lane highway methodology:

1. a two-lane highway with continuous urban/suburban development but with no traffic signals or traffic signals spaced at intervals greater than 2 miles,
2. a two-lane highway through a small town with a reduced speed limit, located on a major road with speeds of 55 mi/h or more, and
3. a two-lane highway in a transition area between rural and urban/suburban development, with reduced speeds and low-to-medium density development.

Alternative conceptual methodologies were outlined in an attempt to address these three scenarios. The contractor also made recommendations as to where the new procedures should appear in the HCM. While reviewers of the report felt that the first issue regarding directional segment PTSF was addressed adequately by the contractor, there were still concerns with the second issue regarding two-lane highways in developed areas and questions still remained on how to proceed. Therefore, the final report was never officially published by the TRB. The correction to the PTSF estimation for the directional analysis methodology was incorporated into the official errata of the HCM, but the potential methodologies for analyzing two-lane highways in the situations listed above were not published.

Highway Capacity and Quality of Service Committee Workshop on Developed Two-Lane Highways (2004)

In January 2004, at the annual TRB Conference in Washington D.C., the HCQS committee held a workshop to discuss the results of NCHRP Project 20-7 Task 160. At the workshop, both Mr. Douglas Harwood of MRI and Mr. Doug McLeod of the FDOT presented their respective opinions and recommendations of how to handle LOS analysis for two-lane highways in rural developed areas. Dr. Scott Washburn of the University of Florida was the workshop moderator. The following sections summarize the presentations by Mr. Harwood and Mr. McLeod and the outcome of this workshop.

Mr. Douglas Harwood's Presentation

Mr. Harwood's presentation (refer to appendix B) summarized the results of NCHRP Project 20-7 Task 160 and addressed all three of the two-lane highway scenarios described above in which the current HCM methodology does not apply. For scenario 1 (two-lane highway with continuous suburban/urban development), Mr. Harwood argued that this type of facility was essentially the same as an urban street, except for the absence or wide spacing of signals. Therefore, he recommended that an approach similar to the urban street analysis methodology be used, with ATS as the service measure. An estimated (or measured) ATS was then to be compared to speed values representing percentages of the facility's FFS, such as in Chapter 15 (Urban Streets) of the HCM.

He recommended that ATS be calculated using procedures from either Chapter 15 or Chapter 20 (Two-Lane Highways), depending on the presence or spacing of signals. The proposed LOS threshold values were the same as those used in Chapter 15 to assess LOS for urban streets. Because the recommended service measure and threshold values were the same as those found in Chapter 15, Mr. Harwood also recommended that the procedure be incorporated into that chapter.

Because scenarios 2 (two-lane highway through a small town) and 3 (two-lane highway in a transition area) share similar characteristics, Mr. Harwood issued the same recommendations for each. The recommendations for these types of facilities were based on two factors: 1) the length of the developed area with reduced speeds and 2) the amount of through traffic versus locally circulating traffic. The extent of development and the amount of through and/or local traffic is reasoned to be important because of the differing user expectations involved.

If the developed area with reduced speeds extends for 2 miles or less and most traffic is through traffic, then Mr. Harwood argued that the roadway should be evaluated as a Class II two-lane highway. Through motorists on a Class I facility, who travel through a small town or transition area most likely expect to return to Class I conditions shortly. Therefore, Mr. Harwood contended that the reduced speed does not affect their perception of quality of service as much as the platooning that occurs as a result of it, which in turn hinders passing ability once Class I conditions are resumed.

If the developed area with reduced speeds extends for more than 2 miles, with mostly local circulating traffic, Mr. Harwood argued that the procedure described above for two-lane highways with continuous development (scenario 1) should be used. He contended that if the majority of users are local, traveler expectations may more closely relate to expectations of urban streets, thereby suggesting ATS be used as the service measure.

Mr. Doug McLeod's Presentation

Mr. Doug McLeod's presentation [refer to appendix B] consisted of recommendations in contrast to those outlined by Mr. Harwood. The recommendations presented were essentially those expressed by Washburn et al. in the paper described in a previous section. These recommendations included the introduction of a third classification of two-lane highway that applied to all uninterrupted flow two-lane highways in developed areas and the use of PFFS as both the service measure and basis of LOS threshold values. Mr. McLeod also argued that these types of facilities should be addressed in an uninterrupted flow chapter as opposed to Mr. Harwood's recommendation of addressing them in Chapter 15, an interrupted flow chapter.

Mr. McLeod suggested that the use of PFFS is more consistent with user expectations while traveling on a two-lane highway through a developed area. He explained that PFFS reflects the "desire to maintain a speed reflective of specific roadway/area circumstances, while PTSF "largely reflects the desire to pass," and ATS "largely reflects the desire to maintain a set speed." Mr. McLeod argued that motorists traveling through small towns or other developed areas do not have an expectation to pass, and in many cases are restricted from passing, thereby rendering PTSF inappropriate. By that same token he suggested that motorists "do not expect to go the same speed regardless of roadway/surrounding conditions," which is what the use of ATS implies.

Additionally, Mr. McLeod called attention to the differences between the current Class II two-lane highway methodology (as revised by the NCHRP 20-7 Task 160 results) and the FDOT's proposed methodology, in terms of service volumes on a rural developed two-lane highway. He argued that the resulting service volumes using the PTSF service measure were largely underestimated for this type of facility and are inconsistent with user expectations.

Workshop Outcome

In conclusion, workshop participants were unable to reach consensus on the best way to proceed. Some participants felt that the mixed use of Chapters 15 and 20 of the HCM, as recommended by Mr. Harwood, would potentially cause added confusion for users. Many workshop participants felt that more specific research should be conducted to address the issue, and that a long term solution should be sought and released in a future edition, rather than a temporary fix released as errata. Recognizing that a great deal of time would be required to perform additional research, the participants decided that some language be included in Chapter 20 cautioning users that the existing methodology does not address two-lane highways in developed areas.

In reaction to this workshop, the FDOT sponsored quality of service research to explore preliminarily what roadway performance measures are appropriate for assessing the level of service for two-lane highways. This research was performed by soliciting information from the travelers themselves. The details of this research are the subject of chapter 4.

The next chapter provides a more comprehensive look at the differences between the HCM 2000 Class II methodology and the FDOT's proposed methodology with respect to levels of service and service volumes. Numerical examples illustrating these differences are presented through a series of LOS calculations using both PTSF and PFFS service measures.

CHAPTER 3
LEVEL OF SERVICE EXAMPLES:
PERCENT TIME SPENT FOLLOWING VERSUS PERCENT FREE FLOW SPEED

This chapter provides a detailed review of the computational procedures and resulting level of service (LOS) determinations for the PTSF and PFFS service measures. Two-lane highways that travel through small towns or along the coast clearly do not fit the HCM Class I definition, as discussed previously. Thus, by default, they must be considered as Class II under the current HCM methodology. The service measure for Class II two-lane highways is PTSF. However, the FDOT does not believe that this service measure or the corresponding LOS thresholds are appropriate for these types of highways. In response, the FDOT has created a third classification (Class III) in which PFFS is used as the primary service measure.

The practical differences between the application of the PTSF service measure[1] and the PFFS service measure[2] to these types of highways can best be illustrated by an example LOS calculation and corresponding service volumes for a given set of input conditions.

Example LOS Calculations

The following example calculations utilize the input conditions outlined in Table 1. The LOS thresholds for Class II and Class III two-lane highways are included in Table 2.

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[1]Based on the revised methodology from NCHRP 20-7 Task 160

[2]As outlined in Washburn et al. [6]

Table 1. Input Roadway and Traffic Data

Roadway Variables	Traffic Variables
Area Type = Rural developed	AADT = 5,000 veh/day
Number of Lanes = 2	K factor = 0.097
Analysis Type = Segment	D factor = 0.55
Terrain = Level	PHF = 0.895
Posted Speed = 50 mph	% Heavy Vehicles = 4%
Presence of Median = No	Base Capacity = 1700
Presence of Left Turn Lanes = Yes	Local Adjustment Factor = 0.92
% No Passing Zone = 40%	Adjusted Capacity (calculated) = 1475
Presence of Passing Lanes = No	

Table 2. LOS Thresholds for Class II and Class III Two-Lane Highways

	Class II[a]	Class III
LOS	**PTSF**	**PFFS[b,c]**
A	≤ 40	> 91.7
B	> 40-55	> 83.3
C	> 55-70	> 75.0
D	> 70-85	> 66.7
E	> 85	> 58.3

[a] Values are directly from the HCM [1]

[b] Values are directly from Washburn et al. [6].

[c] PFFS Values derived by assuming a FFS of 60 mi/h and dividing into the Average Travel Speed thresholds in Exhibit 20-2 of the HCM 2000 [6]

Initial Computations

1. Calculate DDHV

$$DDHV = AADT \times K \times D$$

$$DDHV = 5000 \times 0.097 \times 0.55 = 266.75 \text{ veh/h}$$

2. Determine adjustment for the presence of a median and/or left turn lanes

Left Turn Lane Adjustment (LTadj) = 0.0

Median Adjustment (MedAdj) = 0.0

$$AdjMedLTL = 1 + LTadj + MedAdj$$

$$AdjMedLTL = 1 + 0.0 + 0.0 = 1.0$$

3. Determine Facility Adjustment Factor (FacAdj)

FacAdj = 1.0 for Analysis Type = Segment

4. Calculate Adjusted Volume (AdjVol)

AdjVol = DDHV / (PHF × LAF × AdjMedLTL × FacAdj)

AdjVol = 266.75 / (0.895 × 0.92 × 1.0 × 1.0) = 323.96veh/h

Calculations For PTSF

5. Determine E_T (Truck passenger car equivalency factor)

Look up value from HCM Exhibit 20-10 (no interpolation necessary)

Directional flow rate (323.96) > 300 - 600, terrain = level, $\therefore$ $E_T = 1.1$

6. Calculate f_{HV} (heavy vehicle factor)

$$f_{HV} = \frac{1}{1 + P_T\left(E_T - 1\right)}$$ HCM Equation 20-4

$$f_{HV} = \frac{1}{1 + 0.04(1.1 - 1)} = 0.9960159$$

7. Determine f_G (grade adjustment factor)

Look up value from HCM Exhibit 20-8 (no interpolation necessary)

Directional flow rate (323.96) > 300 - 600, terrain = level, $\therefore$ $f_G = 1.00$

8. Calculate forward direction volume (v_d)

$$v_d = \frac{V}{PHF * f_G * f_{HV}}$$ HCM Equation 20-12

Since the PHF was already accounted for in Step 4, the following equation is used:

$$v_d = \frac{AdjVol}{f_G * f_{HV}} \qquad v_d = \frac{323.96}{1.0 * 0.9960159} = 325.26 \text{ veh/h}$$

Check this value against flow range used for Exhibits 20-10 and 20-8, and repeat steps 6 through 9 as necessary. No further iterations are necessary

9. Calculate opposing direction volume (v_o)

$$v_o = \frac{v_p * (1 - D)}{D} \qquad v_o = \frac{325.26 * (1 - 0.55)}{0.55} = 266.12 \text{ veh/h}$$

10. Determine values of coefficients ‘a’ and ‘b’ for HCM equation 20-17

Look up values from HCM Exhibit 20-21 (linear interpolation if necessary).

v_o is rounded to nearest 10 veh/h, $\therefore$ 266.12 $\rightarrow$ 270.0 veh/h

From exhibit, for v_o = 200; a = -0.0014, b = 0.973

From exhibit, for v_o = 400; a = -0.0022, b = 0.923

For v_o = 270 veh/h,

$$a = -0.0014 + (270 - 200)\left(\frac{-0.0014 - (-0.0022)}{200 - 400}\right) = -0.00168$$

$$b = 0.973 + (270 - 200)\left(\frac{0.973 - (0.923)}{200 - 400}\right) = 0.9555$$

11. Calculate base percent time spent following (BPTSF)

$$BPTSF_d = 100\left(1 - e^{av_d^b}\right) \quad \text{HCM Equation 20-17}$$

$$BPTSF_d = 100\left(1 - e^{-0.00168*325.26^{0.9555}}\right) = 34.454$$

12. Determine value of f_{adj} for HCM equation 20-16

Determine f_{adj} value from HCM Exhibit 20-20 (linear interpolation if necessary, by % no passing zone, directional split and two-way flow rate).

For FFS = 55 (posted speed + 5), %NPZ = 40, v_o = 266.12 veh/h

This example only calls for interpolation by volume,

$$f_{adj} = 46.05521$$

13. Calculate percent time spent following (PTSF)

$$PTSF_d = BPTSF_d + f_{adj}\left(\frac{v_d}{v_d + v_o}\right)$$ HCM Equation 20-16

v_d = 325.26 from Step 9

v_o = 266.12 from Step 10

$BPTSF_d$ = 34.454 from Step 12

f_{np} = 46.05521 from Step 13

$$PTSF_d = 34.454 + 46.05521\left(\frac{325.26}{325.26 + 266.12}\right)$$

$PTSF_d$ = 34.454 + 25.330 = 59.78

14.Determine Level of Service (LOS)

LOS from Table 2 is C

Calculations For PFFS

5. Determine E_T (Truck passenger car equivalency factor)

Look up value from HCM Exhibit 20-9 (no interpolation necessary)

Directional flow rate (323.96) > 300 - 600, terrain = level, $\therefore$ $E_T = 1.2$

6. Calculate f_{HV} (heavy vehicle factor)

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)}$$ HCM Equation 20-4

$$f_{HV} = \frac{1}{1 + 0.04(1.2 - 1)} = 0.9920635$$

7. Determine f_G (grade adjustment factor)

Look up value from HCM Exhibit 20-7 (no interpolation necessary)

Directional flow rate (323.96) > 300 - 600, terrain = level, $\therefore$ $f_G = 1.0$

8. Calculate forward direction volume (v_d)

$$v_d = \frac{V}{PHF * f_G * f_{HV}} \qquad \text{HCM Equation 20-12}$$

Since the PHF was already accounted for in Step 4, the following equation is used:

$$v_d = \frac{AdjVol}{f_G * f_{HV}} \qquad v_d = \frac{323.96}{1.0 * 0.9920635} = 326.55 \text{ veh/h}$$

Check this value against flow range used for Exhibits 20-10 and 20-8, and repeat steps 6 through 9 as necessary. No further iterations necessary.

9. Calculate opposing direction volume (v_o)

$$v_o = \frac{v_p * (1 - D)}{D} \qquad v_o = \frac{326.55 * (1 - 0.55)}{0.55} = 267.18 \text{ veh/h}$$

10. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM equation 20-15

Look up value from HCM Exhibit 20-19 (linear interpolation if necessary, by both volume and % no passing zone).

For FFS = 55 (posted speed + 5), %NPZ = 40, v_o = 267.18 veh/h

This example only calls for interpolation by volume,

$$f_{np} = 2.4 + (267.18 - 200)\left(\frac{2.4 - 1.9}{200 - 400}\right) = 2.23$$

11. Calculate average travel speed (ATS)

$$ATS_d = FFS_d - 0.00776(v_d + v_o) - f_{np} \qquad \text{HCM Equation 20-15}$$

FFS_d = 55 from inputs

v_d = 326.55 from Step 9

v_o = 267.18 from Step 10

f_{np} = 2.23 from Step 11

$ATS_d = 55 - 0.00776(326.55 + 267.18) - 2.23 = 48.16$ mi/h

12. Calculate the Percent Free Flow Speed (PFFS)

$$PFFS = \frac{ATS_d}{FFS_d} \times 100$$

$$PFFS = \frac{48.16}{55} \times 100 = 87.56$$

13. Determine Level of Service (LOS)

LOS from Table 2 is B

Comparison of PTSF and PFFS Service Measures

The above example calculations (the results are also shown in the HIGHPLAN output in Figures 1 and 2) demonstrate the difference in LOS when evaluating the given input conditions as a Class II roadway with PTSF versus a Class III with PFFS. In the former case, the resulting LOS is C (PTSF = 59.8). However, the average travel speed is only 1.8 mi/h below the posted speed limit, which indicates that roadway users are maintaining a reasonable speed even though they are following nearly 60 percent of the time.

When evaluated with PFFS as the service measure, the resulting LOS is B (PFFS = 87.6), which seems to be a more accurate representation of operating conditions given that the ATS is so close to the posted speed limit. This example illustrates the FDOT belief that drivers on rural developed two-lane highways are primarily concerned with maintaining a reasonable travel speed and are not as concerned with following or passing other vehicles.. Thus, the LOS C designation that results from applying PTSF is considered to be overly penalizing, whereas the LOS B designation that results from

PFFS is thought to be more consistent with traveler perceptions. The LOS B result reflects that travelers are maintaining a speed close to the posted speed limit, but operational conditions are not representative of LOS A since they are traveling somewhat slower than the posted speed limit.

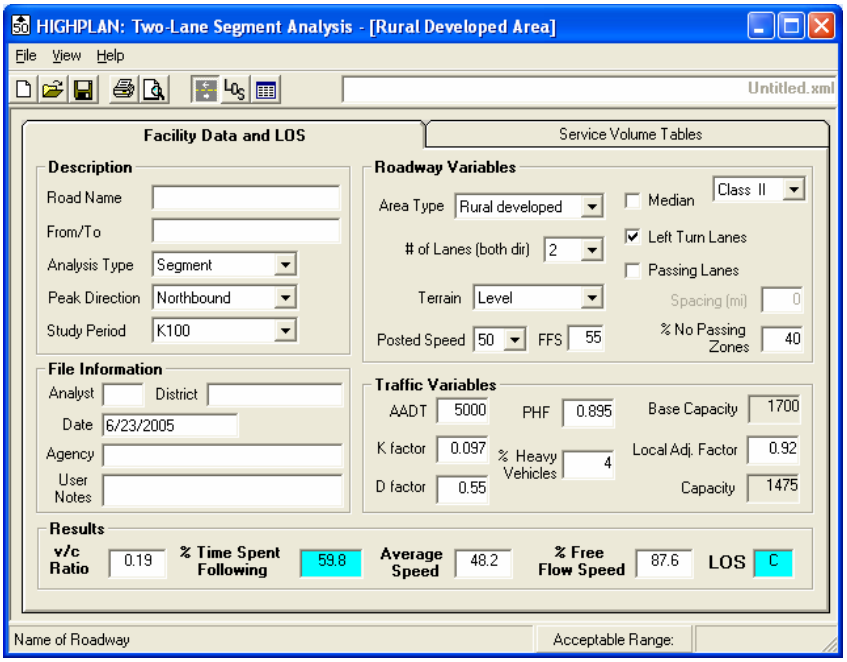


Figure 1. Class II LOS Calculation in HIGHPLAN

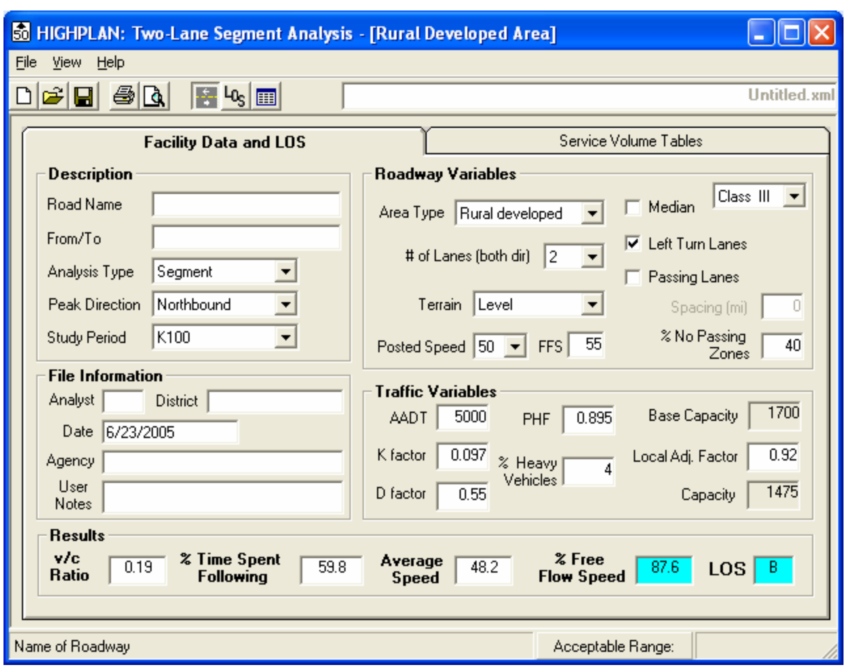


Figure 2. Class III LOS Calculation in HIGHPLAN

Comparison of Service Volumes

Service volumes indicate the maximum volume that can be accommodated for a given set of roadway, traffic, and control conditions, for a specified level of service. As can be seen in Table 3, the Class II service volumes are much lower than the Class III service volumes for the given input conditions used in the above example calculations. The volumes in this table represent the annual average daily traffic (AADT).

Many transportation agencies, such as the FDOT, use service volumes at LOS C to design and plan future facilities and to assess the operations of existing facilities. Facilities with flow rates in excess of the LOS C volume threshold would be considered operationally deficient and in need of improvement. In many cases, the design improvements required to bring a facility up to operational standards are of great expense. This reinforces the importance of accurately estimating roadway performance measures that translate into LOS threshold values which correlate well with the quality of service as perceived by the traveling public.

Table 3. Class II and Class III Service Volumes (AADT)

	Class II	**Class III**
LOS	**PTSF**	**PFFS**
A	2100	2800
B	4200	8000
C	8000	14100
D	14800	19300
E	26100	24300

CHAPTER 4
RESEARCH APPROACH

This chapter describes the research approach used in this study. The sections that follow will describe the method used for collecting example two-lane highway driving data as well as the process used to gather roadway user opinions and perceptions with regard to trip quality on two-lane highways.

Survey Method

This study used an approach that combined aspects of both a video survey and a focus group. Video surveys allow survey participants to watch pre-recorded video footage of actual two-lane highways. When video is taken from the driver's perspective, participants are presented with a reasonably realistic representation of two-lane highway travel. Because all participants view the same video footage, survey responses are based upon the same conditions, thereby establishing a baseline. Video data collection is less costly and involves no liability on the part of the researchers (with respect to survey participants).

Focus groups allow survey participants to engage in roundtable-like discussion. Discussion is usually led by a moderator, who attempts to solicit participant opinions in an unbiased way, while simultaneously attempting to keep the discussion focused on the topic. Focus groups offer a more flexible approach to data collection by allowing the participants to present issues of importance to them and to discuss their opinions in an open environment. They also give the researcher the opportunity to prompt further discussion about certain topics or ask for clarification if necessary.

In this study, survey participants watched a series of video clips depicting travel on two-lane highways (from a driver's perspective) and then participated in a group discussion facilitated by a moderator. This approach combined the control of a video survey with the flexibility of a focus group. The following sections describe the video data collection process and focus group implementation in more detail.

Video Data Collection

In this study, sample driving scenes from two-lane highways were viewed in a focus group setting to facilitate discussion on potentially important performance measures used in the assessment of trip quality. Video data collection included four specific tasks: selection of two-lane highways, equipment setup, collection of video footage, and video clip production.

Selection of Two-Lane Highways

The first step of the video data collection process involved the selection of several two-lane highways from which video footage were to be collected. The intent was to choose a representative sample of two-lane highways within reasonable proximity to the University of Florida. The 2003 Florida Highway Data (FHD) CD-ROM [7] as well as the 2003 Florida Traffic Information (FTI) CD-ROM [8], provided by the FDOT, were used in the preliminary stages of the two-lane highway selection process. Both CDs employ a Geographic Information Systems (GIS) based user interface in which users can access information on roadway characteristics and traffic data for nearly every roadway in the state of Florida.

The FHD CD-ROM provides roadway characteristic information including, but not limited to: functional classification, number of roadway lanes, median widths and types, shoulder widths and types, speed limits, and locations of intersecting roadways.

The FTI CD-ROM provides roadway traffic information collected through the use of traffic monitoring stations located throughout the state. Each traffic monitoring station uses Inductance Loop Detectors (ILD) to gather traffic data such as Average Annual Daily Traffic (AADT), truck percentage, K_{30} and D_{30}. K_{30} is defined as the proportion of AADT occurring during the 30^{th} highest hour of the design year. D_{30} is defined as the proportion of traffic in the 30^{th} highest hour of the year traveling in the peak direction.

Through the use of these two CD-ROMs, as well as the FDOT Roadway Characteristic Inventory (RCI) Field handbook [9], numerous two-lane highways within proximity to the University of Florida (approximately a 60 mile radius) were identified and selected for use in the collection of video footage. The selected two-lane highways consisted of a diverse range of roadway and traffic characteristics as well as functional characteristics.

Equipment Setup

The next step of the video collection process was the instrumentation of the data collection vehicle. A 4-door Chevrolet Cavalier was rented and outfitted with two video cameras, two portable VCRs, a microphone, a monitor, an A/V selector switch and two batteries used to power all of the equipment. The video camera setup was intended to portray two-lane highway travel from the driver's perspective. Therefore, one camera was set up to capture the windshield view, which also included a view of the interior rear-view mirror, while the second camera recorded the view of the speedometer. During a later step, images recorded from the two cameras would be combined into one image for the creation of the video clips.

The camera capturing the windshield view was attached to a pole which was secured between the floor and ceiling behind the driver's seat. The camera capturing the speedometer view was mounted to the steering column. See Figure 3 for photos of the in-vehicle camera setup. The two VCRs recorded the images captured by the two video cameras. A microphone was also connected to one of the VCRs, allowing the researcher to verbally identify which two-lane highway was being driven as well as changes in the posted speed limit. The monitor and A/V selector allowed the researcher to switch between VCRs to see if the cameras and other equipment were functioning properly. A schematic depicting the in-vehicle data collection equipment setup is shown in appendix C.

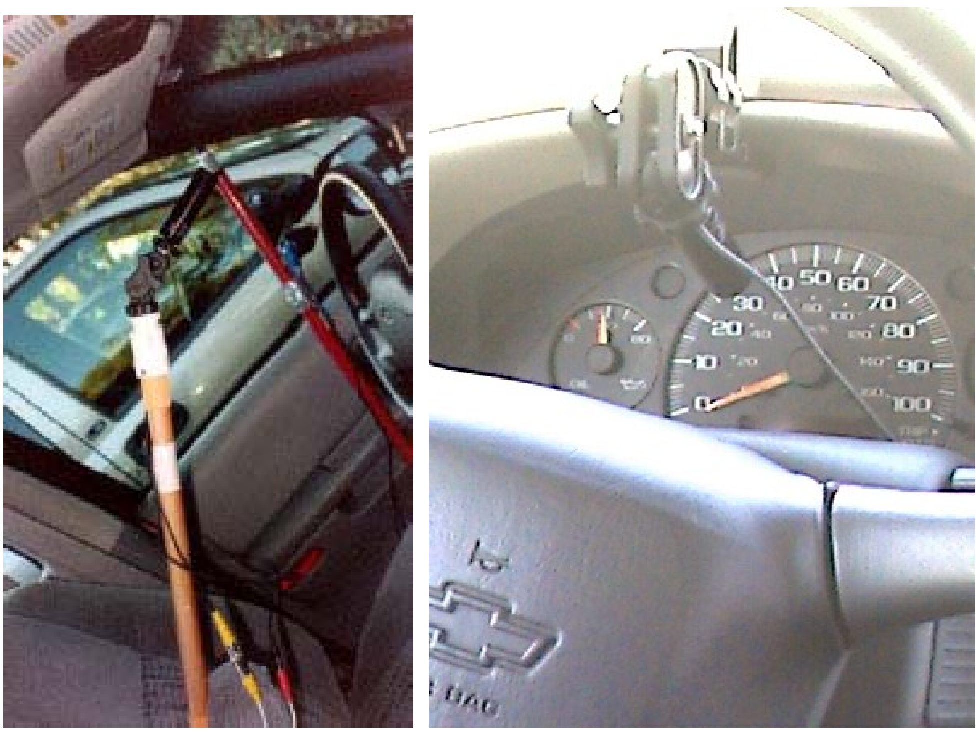


Figure 3. In-vehicle Video Camera Setup

Collection of Video Footage

Video footage was collected over three separate days between January 20th and January 23rd, 2005. Approximately 450 miles of two-lane highway were driven and about 9 to 10 hours of video footage were recorded over the three-day period. The weather on all three days was sunny and dry. Table 4 lists the route number, the county in which the two-lane highway is located, the direction of travel, and the approximate distance driven on each of the two-lane highways during the three day period. Appendix D contains maps of the driving routes.

The video footage was collected from a representative sample of two-lane highways throughout the north-central Florida area. These two-lane highway facilities can generally be divided into four categories which are described below:

- High Speed Roadways - generally used for inter-city travel.
- Medium to Lower Speed Roadways - generally connect to higher speed facilities or are used for intra-city travel.
- Lower Speed Roadways that are scenic - could be coastal, or with a tree canopy, etc.
- Lower Speed Roadways that go through a small town - either with or without the presence of a signal.

Video Clip Production

As mentioned previously, survey participants were to be shown a series of video clips depicting travel on two-lane highways from a driver's perspective. After all video footage was collected, the researcher reviewed all of the footage—entering specific roadway and traffic characteristic information for each roadway into a spreadsheet. This spreadsheet was then used to determine which footage would be edited into video clips.

In an attempt to more accurately portray the driver's perspective, video footage of the front windshield view and interior rear-view mirror, as well as the speedometer, was compiled into a single video display to be shown to survey participants. Also, a graphic display of the roadway's speed limit was included in the composite video image. This graphic changed as the roadway's speed limit changed during the progression of the video clip. A screenshot from one of the video clips is shown in Figure 4.

Table 4. Two-Lane Highway Driving Routes

Date of Travel	Route Number	County	Direction of Travel	Approximate Distance (mi)
January 20, 2005	SR 326	Marion	East	10
	SR 40	Marion, Lake, Volusia	East	65
	SR 19	Marion	North and South	16
	SR A1A	Volusia, Flagler	North	14
	SR 100	Flagler, Putnam	West	80
	SR 26	Putnam, Alachua	West	22
January 22, 2005	CR 219	Putnam	North	4
	SR 100	Bradford	East	16
	SR 16	Bradford, Clay, St. John's	East	40
	Int'l Golf Pkwy	St. John's	East	7
	SR 207	St. John's, Putnam	South	24
	SR 20	Putnam, Alachua	West	43
January 23, 2005	SR 121	Alachua, Union	North	12
	SR 18	Union, Bradford	East	7
	SR 231	Bradford, Union	North	10
	SR 238	Union, Columbia	West	15
	US 41	Columbia	South	5
	CR 18	Columbia	West	6
	SR 47	Columbia, Gilchrist	South	22
	CR 339	Gilchrist, Levy	South	15
	SR 24	Levy, Alachua	East	10
	US 27	Alachua	North	10

The video footage was then edited into 16 clips, with each clip being between 1.5 and 2 minutes in length. As a whole, the video clips were intended to showcase two things: 1) the four different categories of two-lane highway facilities described above, and 2) the various roadway and traffic conditions that one may typically experience while driving on a two-lane highway. However, a significant number of the video clips featured roadways in small towns and in coastal areas. This was done because it was felt that there were a larger number of questions about user perceptions with regard to these types of facilities.

Figure 4. Screenshot of Composite Video Image

Three separate focus group sessions were held in which the video clips were viewed. However, as a result of time limitations, each focus group was not able to view all 16 video clips. Therefore, the 16 video clips were divided into three separate groups, or blocks. Clip blocks 1 and 2 were each comprised of five video clips. Clip block 3 was comprised of six video clips. Focus group session 1 was shown a total of 10 clips (clip blocks 1 and 2). Focus group session 2 was shown a total of 11 clips (clip blocks 2 and 3). Focus group session 3 was shown a total of 11 clips (clip blocks 1 and 3). This system of viewing clips ensured that each clip block would be viewed by 2 separate focus groups. Table 5 describes the 16 video clips (by clip block) shown during the three focus group sessions.

Focus Group Implementation

As mentioned earlier, three focus group sessions were held in which participants watched a series of video clips depicting travel on two-lane highways. The following sections will discuss the participant recruitment process, the participant selection process, and the implementation of the focus group sessions.

Participant Recruitment

Participants were selected from those who responded to an advertisement placed in the *Local* section of the *Gainesville Sun* newspaper. The *Gainesville Sun* serves the local Gainesville area as well as the University of Florida and many of the surrounding counties. The advertisement ran for three consecutive days, between Friday, March 18th and Sunday, March 20th. This allowed those who receive only the Sunday paper, as well as those who receive the paper throughout the rest of the week to have the opportunity to view the advertisement. The newspaper is also available for purchase through coin-operated machines found at popular locations throughout the local area. In addition to appearing in print, the advertisement was also placed in the *Online Marketplace* section of the *Gainesville Sun's* website.

The advertisement solicited individuals interested in participating in a focus group as part of a University of Florida transportation study. The advertisement requested that individuals be over the age of 25 and have previous experience driving on two-lane highways. See appendix E for a copy of the advertisement. Interested individuals were to respond by contacting the Transportation Research Center of the Civil and Coastal

Table 5. Video Clip Descriptions

Clip Block	Clip #	Dir. Of Travel	Route #	County	Clip Length	Shoulder Type 1		Shoulder Type 2		Speed Limit (mi/h)	Description of Video Clip
						Type	Width (ft)	Type	Width (ft)		
1	Clip 1	North	SR 121	Alachua	1:40	Paved	4-5	Lawn	20-30	60	Open road, no traffic, many passing zones, wide shoulders.
	Clip 2	North	SR 121	Union	2:10	Paved	4-5	Lawn	15-20	60,55,45,35	Approaching small town, decreasing speed limit, passing and no passing zones, no traffic, side parking. No signals.
	Clip 3	East	Int'l Golf Pkwy	St. John's	1:30	Lawn	8-10	na	na	50	Designated scenic roadway, tree canopy, narrow lanes, little to no shoulder.
	Clip 4	East	SR 100	Bradford	2:00	Paved	4-5	Lawn	10-15	45,35,25	Approach medium sized town, decreasing speed limit, following large vehicle, no passing zone, driveways and roadside development, side parking.
	Clip 5	West	SR 100	Flagler	1:35	Paved	2-4	Lawn	5-6	60	Guardrail on right side, paved shoulder, passing zones, car following, pavement quality is poor.
2	Clip 6	North	CR 219	Putnam	1:50	Lawn	2-10	na	na	45	Rolling terrain, narrow lanes, alternating passing/no passing zones.
	Clip 7	East	SR 100	Clay	1:45	Paved	3-5	Lawn	10	45,35,45	Approaching small town, decreasing speed limit, traffic signal, moderate traffic, driveways and roadside development.
	Clip 8	North	SR A1A	Volusia	1:40	Paved	4-5	na	na	40,45	Atlantic ocean on right, view of water, moderate traffic, parking pullout areas on right, dunes, no passing zone, alternating shoulder/no shoulder, pedestrian crossing zones,some pedestrian
	Clip 9	East	SR 24	Levy	1:45	Lawn	20	na	na	35	Near small town, no traffic, lawn shoulder, low speed residential area. 35 mph for extended distance.
	Clip 10	East	SR 16	Bradford	1:45	Lawn	15-20	na	na	60	Following slower vehicle. Light traffic, passing zones.
3	Clip 11	North	SR A1A	Flagler	1:52	Lawn	3-4	na	na	45,35,30	Atlantic ocean on right, passing zone in beginning, lower roadside activity/development, transitions into higher activity/development, no passing, pedestrian activity. Traffic signal.
	Clip 12	East	SR 16	Clay, St. John's	1:50	Paved	3-4	Lawn	15-20	55	Following vehicles traveling at speed limit or above. Go over 2 lane bridge with guardrails and no shoulder. St. Johns river.
	Clip 13	West	SR 20	Putnam	2:00	Paved	3	Lawn	10-15	45,35,45	Approaching small town, decreasing speed limit, following slower vehicle, roadside development, moderate traffic, traffic signal.
	Clip 14	East	SR 18	Bradford	1:40	Lawn	20-30	na	na	50	No traffic, narrow lanes, no paved shoulder, passing zones.
	Clip 15	East	SR 40	Volusia	1:40	Paved	2-3	Lawn	4-10	45,55	Following vehicles, moderate opposing traffic, passing zones, ditch & trees on both sides, some roadside development.
	Clip 16	West	SR 100	Putnam	2:00	Park Ln	8	Curb		45,35,	Approaching medium sized town, decreasing speed limit, moderate traffic, following vehicles, side parking. Approaching traffic signal.

Engineering Department at the University of Florida. Approximately 60 responses were received within one week of the ad's placement.

A researcher then contacted all individuals who responded to the advertisement. Each person was given information about the study and the purpose of the focus group sessions. Also at that time, the researcher collected demographic information from each respondent, as well as information regarding their two-lane highway driving experience. Demographic information was requested in an attempt to secure a reasonably representative sample. Respondents were also asked about their availability and scheduling preferences. All information was recorded on a preliminary survey form. See appendix F for a copy of the preliminary survey form.

Participant Selection

Participant selection was based on the desire to obtain a representative sample for use in the three focus group sessions. A total of 36 individuals were invited to participate in the study, 12 for each session. Those chosen to participate were divided into the three sessions based upon their two-lane highway driving experience and demographic information collected in their preliminary survey form. This was done in an attempt to create a balance of personal backgrounds and driving experience between the 12 participants in each session. A special effort was made to accommodate scheduling preferences. Tables 6 and 7 summarize the demographic information and the two-lane highway driving characteristics respectively, for participants in each of the three focus group sessions, as well as the overall study.

The abundance of responses to the newspaper advertisement allowed for the selection of a demographically diverse group of participants. The majority of participants (17) were between the ages of 46 and 65, with an equal number of participants (8) over the age of 65 and between the ages of 26 and 45. Additionally, participants were asked to rate their typical driving style on a scale of 1 to 5 (1-very conservative, 5-very aggressive). As can be seen in Table 7, the results of this survey question indicate that most participants rated their driving style as more conservative. Therefore, it is possible that the higher number of "older" participants contributed to the high percentage of conservative driving styles. Thus, it is also possible that the opinions expressed in the focus group discussions and on the survey forms, may have a more conservative overtone than if there were a larger number of younger participants.

Table 6. Summary of Participant Demographic Characteristics

Participant Information	Focus Group 1	Focus Group 2	Focus Group 3	All
Total # of Participants	12	12	10	34
# Yrs. with Driver's Lic.	35.4	36.5	32.6	36
Gender				
Male	7	5	2	14
Female	5	7	8	20
Age Range				
16 to 25	0	0	1	1
26 to 45	3	4	1	8
46 to 65	7	4	6	17
Over 65	2	4	2	8
Marital Status				
Single	1	1	6	8
Married	8	7	2	17
Separated/Divorced	1	3	2	6
Widowed	2	1	0	3
Highest Education Level				
Some or no HS	0	0	0	0
HS diploma or equivalent	1	4	0	5
Tech. College (A.A.)	1	2	7	10
College Degree	5	3	1	9
Post-graduate Degree	5	3	2	10
Household Income				
No Income	0	1	1	2
Under $25,000	2	1	2	5
$25,000 - $49,999	3	8	6	17
$50,000 - $74,999	5	2	1	8
$75,000 - $99,999	1	0	0	1
$100,000 - $149,999	0	0	0	0
Over $150,000	1	0	0	1
Ethnicity				
White	9	11	8	28
Black	2	1	2	5
Other	1	0	0	1

Table 7. Summary of Participant Two-Lane Highway Driving Characteristics

Participant Information	Focus Group 1	Focus Group 2	Focus Group 3	All
Total # of Participants	12	12	10	34
Average Percentage of Trips as Driver	93.7	77.3	84.1	85
Vehicle Most Often Used	na	na	na	Sedan
Most Common Trip	na	na	na	Business & Personal
Driving Style (1-very conservative, 5-very aggressive)				
1	3	1	2	6
2	3	5	5	13
3	6	5	3	14
4	0	1	0	1
5	0	0	0	0
Typical # of Passengers for Two-Lane Highway Trips				
0	5	5	4	14
1	2	1	3	6
2	5	5	3	13
3	0	1	0	1
Typical # of Two-Lane Highway Round Trips Per Month				
1 to 2	0	0	1	1
3 to 4	0	1	1	2
5 to 6	1	1	0	2
7 to 8	2	1	0	3
9 to 10	3	1	1	5
11 to 12	1	0	0	1
Over 12	5	8	7	20
Typical One-Way Length of Trip (miles)				
less than 5	1	1	1	3
6 to 10	4	2	3	9
11 to 20	2	7	3	12
21-40	3	1	2	6
41-60	0	0	1	1
Over 60	2	1	0	3

All respondents were contacted within one week of initial contact and told whether or not they had been selected to participate in the study. Those who had been selected to participate were told when and where their focus group session was to be held. The selected participants were also sent a letter of confirmation with more detailed information. Those who had not been selected were thanked for their interest and were told that their contact information would be kept on file if there were any cancellations.

Focus Group Implementation

The two main objectives for conducting the focus group sessions were: 1) to identify the factors (e.g., roadway and/or traffic conditions) that are important in the assessment of trip quality provided on a two-lane highway, and 2) to identify the relative differences, if any, between the importance of these factors in the assessment of trip quality for different types of two-lane highways (i.e., the four categories discussed previously).

All three focus group sessions were held on Saturday April 23, 2005 on the University of Florida campus in the Civil and Coastal Engineering Department's main conference room. The room was equipped with a video projector and large screen for viewing the video clips. All focus groups sessions were audio recorded with the permission of the participants. Focus groups sessions 1 and 2 had twelve participants. Focus group session 3 had ten participants (two persons failed to show and did not previously cancel). Each session was approximately 1.5 to 2 hours in length and was audio recorded. The duration of each focus group session provided ample time for the moderator to engage the members in meaningful discussion and obtain the information sought for this research study. Dr. Scott Washburn, the principal investigator, was the moderator of each focus group to ensure consistency across each of the three sessions.

A one page written instruction sheet was developed and given to participants upon arrival. The instruction sheet described the purpose, objectives, and format of the focus group session. See appendix G for a copy of the instruction sheet. Participants were also given a survey form (Form 1) that was comprised of two sections. The first section was similar to that of the preliminary survey conducted over the phone during the participant selection process. In this section, participants were to provide information about their personal background and two-lane highway travel habits. Examples of this information include income level, education level, marital status, typical number of two-lane highway trips taken per month, typical number of passengers for two-lane highway trips, etc. This information was summarized previously in Tables 6 and 7. The second section of the survey form was used by participants to write down their responses to each of the video clips. See appendix G for a copy of the survey form.

Each focus group session began with some brief introductory statements by the moderator pertaining to the purpose and objectives of the focus group. Prior to viewing the video clips, the moderator verbally reviewed the instruction sheet and survey form for each session of focus group participants. After reviewing all instructions and answering questions, the participants began watching the video clips.

Each video clip was between 1.5 and 2 minutes in length. Immediately following the conclusion of the video clip, the moderator facilitated group discussion about the conditions observed in the clip and what the important factors are for the assessment of trip quality. Approximately 5 minutes of discussion time was allotted for each clip. After the group discussion, participants wrote down their opinions on the survey form. The above steps were repeated for all of the video clips.

After watching all of the video clips, there was an additional 10 to 15 minute discussion about the overall performance measures, or factors, that group members felt were important in their assessment of trip quality on a two-lane highway. This discussion served more as a summary, and was not in reference to any particular video clip.

Finally, the session moderator facilitated a short group discussion about the different types of two-lane highway classifications, or categories. Participants were given a second survey form (Form 2), asking them to rank the importance of certain factors to the assessment of their trip quality on different types of two-lane highways. Examples of these factors include: the ability to consistently maintain desired travel speed, ability to travel at a speed no less than the posted speed limit, frequent passing zones, wide travel lanes, wide shoulders, etc. Refer to appendix G for a copy of the second survey form.

CHAPTER 5
ANALYSIS AND RESULTS

As discussed in the previous chapter, the two main objectives for conducting the focus group sessions were: 1) to identify the factors (e.g., roadway and/or traffic conditions) that are important in the assessment of trip quality provided on a two-lane highway, and 2) to identify the relative differences, if any between the importance of these factors in the assessment of trip quality for different types of two-lane highways.

This information was obtained from focus groups, where participants engaged in a roundtable-like discussion led by a moderator and recorded written responses on survey forms. The following sections describe the methodology used to analyze the focus group discussion and survey form data, as well as the results of these analyses.

Analysis Method

Focus Group Discussions

Audio recordings from each focus group session were reviewed thoroughly and all relevant discussion material was transcribed to a word processor. As is the case with most group discussions, there is a natural tendency for discussion to get side-tracked. Discussion that was not relevant to the topic was not transcribed or analyzed.

The discussions were transcribed in sections, with each section corresponding to a different video clip. Resulting discussion could then be more easily interpreted by referring back to the video clips. Important themes from each video clip discussion were identified and direct quotations supporting those themes were extracted.

Some common focus group analyses include the usage of computer software programs that determine the frequency in which certain words, phrases or themes appear in discussion. While counting the frequency in which certain topics are discussed is sometimes an important component of qualitative analyses, it does not always accurately reflect the level of importance in which participants view these topics. For example, more discussions pertaining to lane width than the presence of SUVs, does not necessarily mean that participants consider lane width to be a more important factor in their assessment of trip quality. In fact, in this study, certain topics were sometimes raised by the moderator either because they didn’t arise naturally or because further discussion or elaboration was deemed necessary. Therefore, the frequency in which certain topics were raised was noted but not strictly counted.

Instead, the responses of the participants to the video clips and related questions posed by the moderator were judged solely on their own merit. Themes or points that were raised and received agreement (or disagreement) among participants were noted, as well as the emphasis participants placed on those themes. The results section of this chapter describes, on a clip-by-clip basis, the discussions and corresponding themes or points that emerged during each of the focus group sessions.

Survey Forms

As discussed previously, there were two different survey forms filled out by participants during the focus group sessions. The first form consisted of merely blank spaces, one for each video clip. On this form (Form 1), participants could write down what they felt were important factors in the assessment of trip quality for the roadway segments depicted in each clip. These written comments served as summaries and as further support of the verbal discussions. Comparisons between the written responses and corresponding dialogue contained in the transcripts helped to analyze and interpret the results. Refer to appendix F for a copy of this survey form.

The second form (Form 2) asked participants to rank the importance of certain factors to the assessment of their trip quality for different types of two-lane highways. As discussed previously, four different types, or categories, of two-lane highways were included on the form, ranging from high-speed, intercity facilities to low-speed facilities through small towns or scenic areas. For each type of two-lane highway, participants assigned numbers, from 1 to 7 (1-not at all important, 7-extremely important), to different items listed on the form, indicating how those items affect the quality of their trip. Examples of these items, or factors, include: the ability to consistently maintain desired travel speed, ability to travel at a speed no less than the posted speed limit, frequent passing zones, wide travel lanes, wide shoulders, etc. Refer to appendix F for a copy of this survey form. The data collected on this form served as quantitative reinforcement of the verbal discussions and was entered into a spreadsheet for further analysis. Results from these survey forms are discussed in the latter part of this chapter.

Results

Focus Group Discussions

Below are descriptions of the roadway and traffic conditions depicted in each video clip as well as the results of the focus group discussions. Each video clip was watched by two of the three focus groups.

Video clip 1

Description: A high-speed facility with a 60-mi/h speed limit and very little traffic in either direction. The roadway has well maintained pavement and markings, standard-width lanes (12 feet), paved shoulder (4-5 feet), large clearance zone between pavement and other obstacles, and many marked 'passing' zones (as indicated by a dashed-yellow center line).

Figure 5. Screenshot of Video Clip 1.

Discussion results: One of the major themes that emerged in the discussion about this clip was the importance of pavement quality and positive guidance through lane markings. Members of both focus groups made comments about the high quality of the pavement saying "pavement quality good" and "the road itself looked good, no pot holes or anything." Other comments focused on the lane markings, such as "the outside white lines are painted, which I think is real good so you know where you're at on the road" and "the markings on the outside of the lanes were great."

Another major theme, which was raised by the moderator, concerned the speed of the facility. The moderator asked both focus groups if they felt the posted speed limit was reasonable. Several participants from both groups seemed to agree that the speed was reasonable for this section of roadway, saying "60 mi/h was a good speed limit" and "it's rural out there, so yes."

Another issue that was raised by one person from each group concerned passing opportunities. One person said that one of the most important things in terms of trip quality was that there be "lots of places to pass." The other person only noted that the roadway depicted in the clip offered "good proviso for passing."

In summary, pavement quality and positive guidance were two issues initiated by members of both groups. Participants also seemed to agree that the posted speed was appropriate and was consistent with the rural context of the facility. The importance of passing opportunities was also raised by a couple of participants. Given the lack of traffic present in the video scene, there was little discussion about specific traffic factors.

Video clip 2

Description: The speed limit transitions from 60 to 35 mi/h (60-55-45-35) as the roadway approaches a small town. No traffic in either direction was present in the video scene. The roadway has well maintained pavement and markings, and standard-width lanes. Pavement markings in town area indicate 'no-passing' (solid-yellow center line). No traffic control is present on the mainline in town.

Discussion results: Two major themes emerged in the discussion following this video clip. One dealt with expectations of travel speed in a small town and the other dealt with expectations for passing.

In one session, members were asked if they felt the posted speed of 35 mi/h within the small town was acceptable and what speed would they go if they were traveling on that section of roadway. Several people agreed that they would travel at a speed around

35 mi/h. One person said, “The 35-mi/h [speed limit] seems consistent with the fact that it’s a smaller town, it’s a shorter span, and it’s only a two-lane road.”

Figure 6. Screenshot of Video Clip 2.

When asked how they felt about the speed reduction upon entering a small town area, two participants commented negatively about this type of situation. One person said, “Often times the speed reductions come too rapidly and you don’t have enough time to reduce to the posted speed.” Another person expressed frustration about having to constantly change speeds when traveling on these types of highways, saying “As soon as you get up to speed you’re having to slow down again.”

Members of this group were also prompted to discuss their expectations for passing in this situation. Several participants stated that they felt no expectation to pass in a small town area. One person said, “It just wouldn’t be safe, you might have people crossing the roadway, you may have cars coming in from the side." Another said frankly, "I don't feel compelled to pass anybody in those small towns."

In summary, many participants felt that the reduced speed in a small town was both acceptable and expected. For this particular video clip, only members from one group discussed their expectations for passing and most agreed that they would not feel compelled to pass in that type of situation.

Video clip 3

Description: A designated scenic roadway with extensive tree canopy and a 50-mi/h speed limit. The roadway has narrow lanes (10-11 feet), no paved shoulder and very little clearance zone between pavement and trees. Light traffic was present in the video scene.

Figure 7. Screenshot of Video Clip 3.

Discussion results: Members of both focus groups spoke positively about the scenic nature of this tree canopy roadway, referring to the beauty of the surrounding trees. However, in one session, several participants mentioned that the lack of a shoulder or clearance zone was of concern to them. One person stated that there were “no paved shoulders, not much right-of-way, and tree and brush growth was close to the road.” Others said that there was no “escape route” or “breakdown area,” illustrating a desire for increased shoulder space or clearance between the roadway and the trees.

For members of the other focus group, the main topic of discussion centered on their expectations for passing other vehicles on a roadway such as this. When asked if passing restrictions on the roadway, as indicated by lane markings, decrease their perception of the trip quality, a few group members said “no” with one person saying, “No, not if it is for a short length.” Another person stated that, “There should be no passing on a road like this because people do not have a good enough sense of speed and distance.”

Most members of this group expressed that they would not feel compelled to pass, as long as the surrounding cars were going the speed limit or above. One person said that someone would have to be going “15 or 20 below” for them to want to pass in that situation. For this reason, one member expressed that passing should not be restricted by saying, “Sometimes you’ll be behind someone who’s going very slow and if it is safe to pass [then you should be able to].”

Another interesting comment that was made dealt with the different perspectives of local travelers versus through travelers. One person stated, “I think all of us enjoyed the scenic part, but if you drove it everyday going back and forth to work or whatever, you're not thinking 'oh this is a beautiful road' because you're late to work or whatever."

In summary, many participants enjoyed the scenic nature of the roadway in the video clip however they did not feel comfortable with the lack of shoulder or clearance area. Additionally, most participants (with the exception of a few) felt that passing restrictions on a roadway such as the one depicted in the video clip did not lower the trip quality because they had no expectation for passing in that situation.

Video clip 4

Description: The speed limit transitions from 45 to 25 mi/h (45-35-25) as the roadway approaches a medium-sized town. A significant amount of roadside development and many driveways are present in the town area. The pavement markings in this area also indicate 'no-passing' (solid-yellow center line). Moderate opposing traffic is present in the video scene. The video vehicle is following a large vehicle traveling approximately 5 mi/h under the speed limit and is also being followed. There are two traffic signals present in town.

Discussion results: Two major themes emerged in the discussion following this video clip. One dealt with expectations of travel speed in a small town, such as with video clip 2, and the other dealt with the relative importance between travel speed and following or being followed by other cars.

While most people agreed that a slower speed was appropriate while traveling through the developed town area, there was some disagreement as to what that travel speed should be. Many participants, from both groups, remarked that the posted speed limit, including transitions, was appropriate. However, one person from each group said that the 25-mi/h speed limit through the busiest part of the town was too slow. One person commented that in that situation, a "constant speed" was the most important thing to them. When asked "What speed?", they replied, "30 mi/h in a small town like that." When asked "If it were posted 40 mi/h what speed would you go?", the same individual said, "Still slower, 30 mi/h."

Figure 8. Screenshot of Video Clip 4.

In one session, the moderator posed a hypothetical question involving the relative importance between speed and following. He asked, "For example, with the speed limit at 35 mi/h, would you prefer to be doing maybe 25 mi/h and not be following anybody or having anybody follow you, than to be doing 35 mi/h and be following other people?" A few participants said that they preferred the former situation, with a few mentioning tailgating and the high number of vehicles as reasons.

Also, many members of both groups stated that they had no expectation for passing in this situation, saying “there was too much traffic” and “there’s no way you’re going to be able to pass in town like that, you’ll have to wait until you get back onto the rural part.”

When asked if the presence of the occasional traffic signal influenced their perception of the trip quality, several members of one group said that it did not and that it was “no big deal.” However, one person said, “I think it depends on how long you know your overall trip is going to be. For example, traveling on [US] 301 up toward Jacksonville, you feel like you’re stopping and going. The presence of more of those I think decreases the value of your trip.”

In summary, members from both groups felt that a slower travel speed was appropriate and that there was no expectation for passing due to the high level of development and surrounding vehicular activity depicted in the video clip. This sentiment is consistent with the discussions from video clip 2. It also seemed that the occasional or rare presence of a traffic signal was not a large factor in their perceived trip quality, but for a couple of people, the “stop and go” on long trips is frustrating and lowers the trip quality. In reference to the discussion about speed and following, it appears that a few participants in one of the focus groups do not feel comfortable having to follow or be followed by other vehicles and that in this case speed is a secondary consideration. However, this may be attributable to tailgating fears and the generally conservative driving style of many of the participants.

Video clip 5

Description: A high-speed facility with a 60-mi/h speed limit. The roadway has standard-width lanes with a 5-6 foot grass shoulder bordered by a guardrail, and many marked 'passing' zones (indicated by a dashed-yellow center line). The pavement quality is poor with visible rutting and degradation. Minimal opposing traffic was present in the video scene. The video vehicle is traveling 5 mi/h over speed limit with two cars following closely. The second car back passes both the video vehicle and the vehicle behind it.

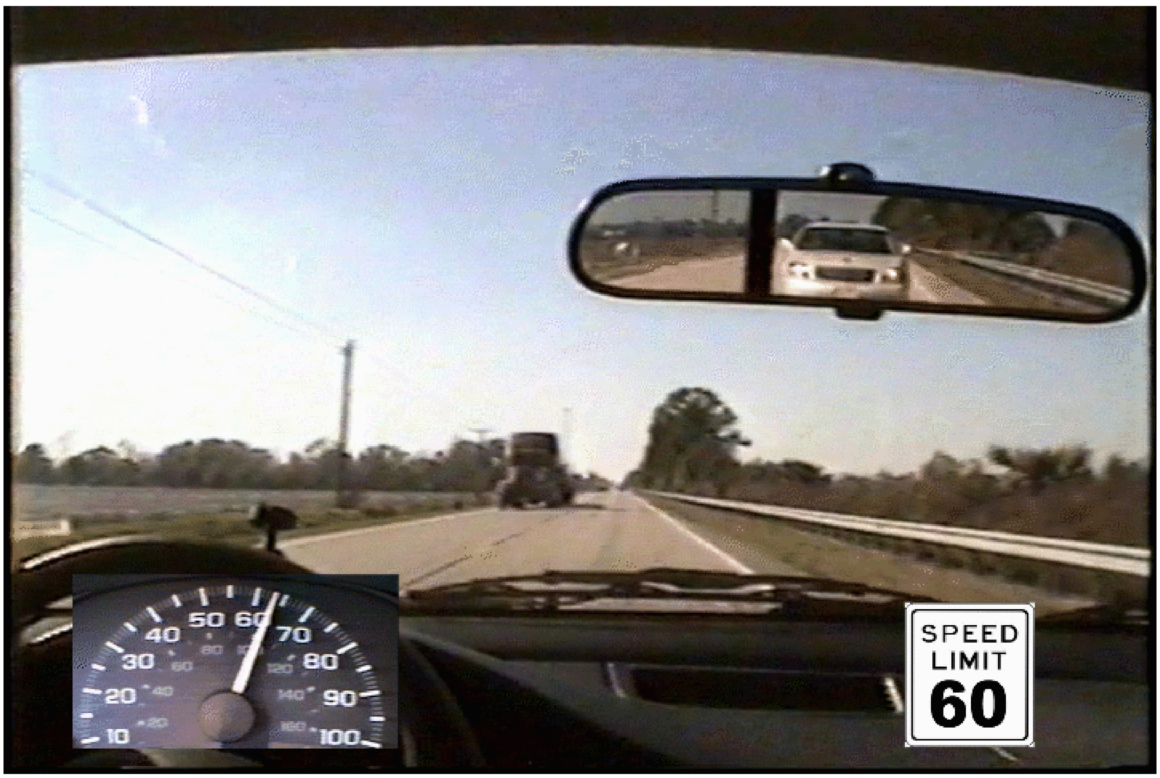


Figure 9. Screenshot of Video Clip 5.

Discussion results: One major theme that arose again was the importance of pavement quality. Members of both groups remarked about the poor pavement quality of the roadway depicted in this video clip. When asked about the significance of pavement quality, the majority of participants stated that it was "very important."

Another major theme dealt with the passing situation shown in the video clip. Members of one group were asked to express their feelings about passing. Several people said that it does not bother them to get passed by other vehicles and that they have no problem passing other vehicles themselves. However, in reference to the scenario in the clip, one person said "I am fearful of passing, especially two cars and if they are at least going in that 5-mi/h range of the speed limit, then I'm not going to pass." When asked how much slower than the speed limit would someone have to be going for them to consider passing, several people say "10 mi/h."

Another comment that was made dealt with the use of cruise control, a common feature on cars that allows the driver to set a nearly-constant vehicle travel speed. This issue arose when one person remarked that they liked the conditions depicted in the video clip because "you could set your cruise control." The moderator prompted further discussion by asking about the use of this feature on a two-lane highway. Many participants said that they do not expect to be able to use it on a two-lane road. However a couple of people said that they use it sometimes, if there is no traffic.

A minor theme that was discussed involved the presence of the guardrail. The majority of participants liked the guardrail, saying that they would rather the guardrail be there to prevent them from running into the trees along the roadway. A couple of people did not like it, however.

In summary, the importance of high quality pavement was reiterated. This was one of the first things that the participants noticed when viewing the clip, and these feelings are consistent with the discussion about pavement quality for video clip 1. Many people do not seem to be bothered by passing maneuvers; however they do not feel compelled to pass unless they are following a vehicle going approximately 5-10 mi/h under the speed limit.

Video clip 6

Description: The speed limit is 45 mi/h with rolling terrain. The roadway has narrow lanes (10-11 feet), no paved shoulder, and alternating 'passing' and 'no-passing' zones. In the video scene, there is moderate residential development present, driveways on both sides of the roadway, and minimal traffic in either direction.

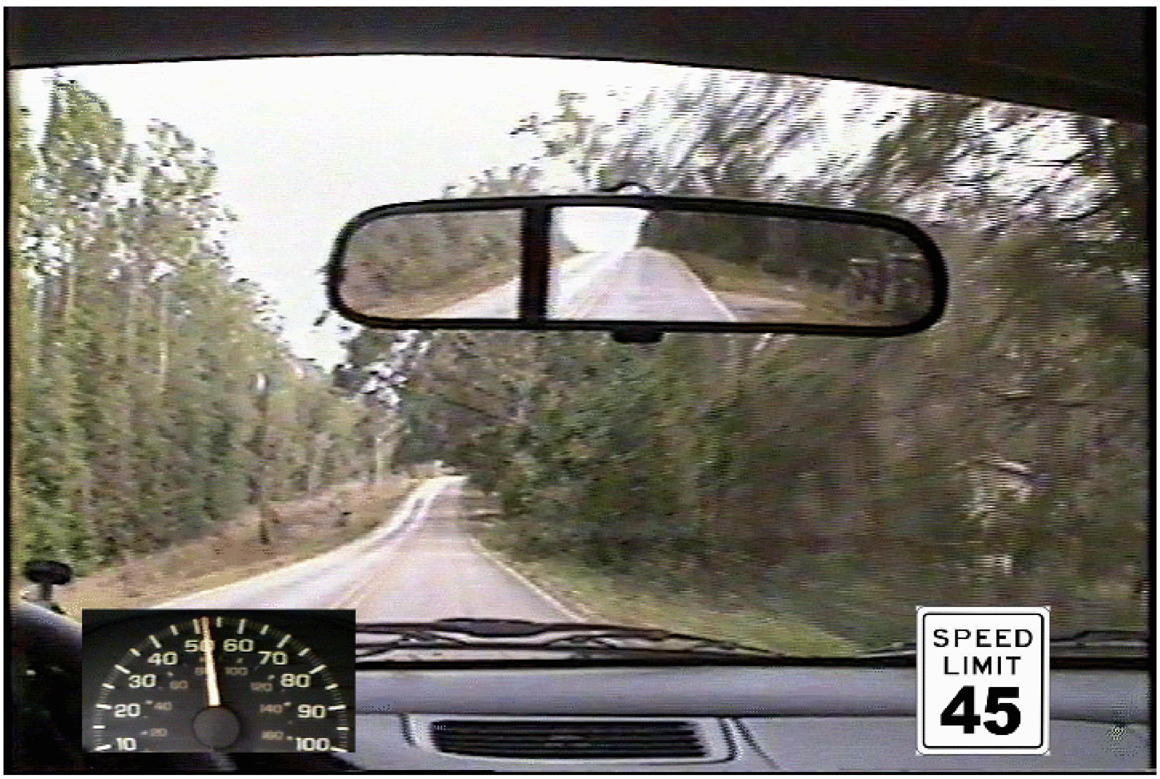


Figure 10. Screenshot of Video Clip 6.

Discussion results: One major topic that was discussed in both of the focus groups was the relationship between lane width, shoulder area, terrain and speed. Several members of one group expressed concern with the narrow lanes and lack of shoulder area. A few people agreed that they "wouldn't go faster than the speed limit" due to the rolling terrain. Another group member stated that they "wouldn't feel comfortable going faster [than the speed limit]" because "there are a lot of houses." However a couple of people felt that the speed limit was too low because there was "no traffic" and "good visibility." Further discussion was prompted when the moderator asked one group of participants, "If there were no posted speed limit, or even if there was one posted, would you be wanting to drive faster if there was a wider lane and more shoulder area?" Several people said, "Yes, of course." One person added however, that if they "were unfamiliar with the road, they would drive more conservatively, but if they were used to it then their speed would pick up."

Another issue that was discussed in reference to this clip was the effect of overhanging tree limbs on the drivers. Although this roadway was not a "tree canopy" roadway such as the one depicted in video clip 3, there were several overhanging tree limbs present. One person said that they are "very distracting" and that they affect visibility. Someone else continued by saying, "I think the psychological aspect of the tree canopy is key. I believe that when you travel through an area that has a tree canopy, traffic slows down much more."

In summary, lane width, shoulder area, terrain, and level of roadside development are factors that appear to influence the choice in travel speed for many of the participants. Also, some members of one group felt that presence of overhanging tree limbs or a tree canopy affected visibility and travel speed.

Video clip 7

Description: The speed limit decreases from 45 to 35 mi/h as the roadway approaches a small town with moderate roadside development, many driveways and a traffic signal. After the traffic signal, the speed limit returns to 45 mi/h. The roadway has well maintained pavement and markings. In the video scene, there is moderate traffic in both directions and the video vehicle is following other vehicles and is being followed.

Figure 11. Screenshot of Video Clip 7.

Discussion results: As in the discussions about similar video clips, such as clip 2 and clip 4, where there were small or medium-sized towns with reduced speed limits, the two major themes that were discussed dealt with expectations of travel speed and passing.

Again, members of both groups seemed to agree that the speed limit reduction approaching the small town and signal was appropriate for the situation. Several people in one of the groups said that it was fine because of the surrounding "commercial development." In the other group, most people felt that the posted speed limit, including transitions, was appropriate, with one person saying, "When you're going through a town it's fine to slow down, unless you've got a tornado behind you." When asked if going below the posted speed limit was bad, there were some audible groans of discontent, indicating agreement with the statement, but no one elaborated.

Additionally, members of both groups reiterated that they had no expectation to be able to pass in a town area such as the one in the video clip, citing “too much traffic” and the “urban context with the strip development…and the exits and entrances (driveways)” as reasons. To clarify responses, the moderator asked one group of participants, “If you’re going about the speed limit, are you going to be happy, whether you’re following cars or not?” A few people confirmed the moderator’s assessment and one person said, “Yes, there’s nothing you can do, you just accept it.”

In summary, the discussions resulting from this video clip seem to be consistent with those from other similar clips, in that most people accept the fact that they will have to reduce their speed and do not expect to be able to pass in a town or developed area.

Video clip 8

Description: Coastal roadway with a speed limit that increases from 40 to 45 mi/h and a view of the ocean. There are dunes and pull-over parking areas on the edge of the roadway, however there is no paved shoulder. Moderate traffic in both directions, some pedestrian activity, and continuous roadside development was present in the video scene.

Discussion results: The main topic of discussion for both groups about this clip was speed. A majority felt that the speed limit of 40-45 mi/h was appropriate. Members of both groups also commented on the “recreational” character of the roadway, and took this into consideration when assessing the speed. For instance, one person said “I don’t mind going a slower speed here because half the time people are looking at the ocean.” A person from the other group commented on speed, following, and passing implications by saying, "If I were following and being followed and [the person in front of me] was going below the speed limit, I could appreciate that [that person] was trying to enjoy the scenery and I wouldn't be trying to pass them."

Figure 12. Screenshot of Video Clip 8.

However, a couple people did not agree with the prospect of having to travel at a slower speed just because of the "recreational" context of the facility. Their comments included, "I don't mind going 40 mi/h (the posted speed limit), but I don't want to have to follow someone [going] 20 mi/h" and "In terms of speed limit, I'm trying to get from point A to point B. So ultimately, I'm either going to exceed the speed limit or at least definitely go the speed limit. That would be my desired goal." In relation to this topic, someone else stated, "If I were going on a recreational trip, I wouldn't be as concerned with speed. But if it was a business type trip I would be more concerned."

The lack of shoulder area was another key concern for members of one group, stating that "having someplace to go is important" and that "when you add the fact that there is no shoulder, coupled with the dunes, that makes me feel like I have to be more cautious cause I really don't have anywhere to go." Additionally, when asked if passing was a concern and if they had and expectation to pass on this type of roadway, members of this group said "no."

In summary, a majority of participants felt that the posted speed of the facility was appropriate. The recreational nature of the roadway also seemed to be a factor in their assessment of speed in relation to trip quality, with some members being more tolerant of slower vehicles, and others not. The importance of a shoulder area was also reiterated.

Video clip 9

Description: The roadway has a speed limit of 35 mi/h, standard-width lanes, well maintained pavement and markings, and a wide grass shoulder (15-20 feet). In the video scene, there is minimal residential development on both sides of roadway and minimal traffic in either direction present.

Discussion results: The main topic of discussion, which was initiated by both groups after viewing this video clip, was speed. A majority of the participants seemed to feel that the posted speed of 35 mi/h was "too low" or "too slow." However a few people felt that the presence of residences along the roadway (although set back at a significant distance) warranted the lower speed limit. When asked how much higher the speed limit should be if the roadway could accommodate a higher speed, many people in one group said "45 mi/h." Additionally, a few group members said that they would not restrict their speed based on the posted speed. However an equal number said they would.

Figure 13. Screenshot of Video Clip 9.

With regard to these feelings, the moderator asked one group of participants to describe how much of a factor law enforcement (getting a ticket) would play in their speed choice and perceived trip quality. One person said, "I follow the posted speeds, but in that situation I would be frustrated because I thought the speed was too low." Several other people agreed with this sentiment by saying that they would have gone faster "if they didn't have to worry about getting a ticket."

In summary, the majority of participants felt the posted speed limit was unreasonably low for the segment of roadway depicted in the video clip. While some said that the posted speed would not cause them to restrict their speed, others said that it would, however many of these same individuals expressed that they would feel uncomfortable and frustrated traveling at such a slow speed.

Video clip 10

Description: A high-speed facility with a speed limit of 60 mi/h. The roadway has standard-width lanes, a 15-20 foot grass shoulder, well maintained pavement and markings, and many marked 'passing' zones (indicated by a dashed-yellow center line). The video vehicle is following a vehicle traveling approximately 5 mi/h under the speed limit and there is minimal opposing traffic present in the video scene.

Figure 14. Screenshot of Video Clip 10.

Discussion results: After viewing this video clip, the vast majority of participants from both focus groups expressed "frustration" and "irritation" with the situation depicted in the video clip, where the video vehicle was following a pickup truck traveling under the speed limit. The moderator asked one group of participants, "Given that the speed limit was 60 mi/h and he was going about 5 mi/h under, how many of you would have wanted to pass that truck?" The moderator stated for the record that just about everyone raised their hand.

Both groups were asked if they would feel compelled to pass if the pickup truck was traveling at 65 mi/h (5 mi/h over the speed limit. Members of both groups said “no” with one person saying, “No, there’s no reason to, because he’d be going at least the speed limit.” One of the focus groups was asked if they would feel compelled to pass if the truck was going 60 mi/h (the speed limit) and several people stated that they would not. To follow up, the moderator said, “So the threshold seems to be the speed limit. As long as they’re doing the speed limit then you’re OK.” Several people said “yes.”

As an aside, the moderator asked if the presence of large semi-trucks was a big issue for members of one of the groups. The majority of the group acknowledged that they were uncomfortable around large semi-trucks and one person said, “They slow up your speed and limit your visibility.”

In summary, most participants felt frustrated and dissatisfied with the prospect of having to follow the slow-moving pickup truck. In this situation the threshold between feeling compelled and not compelled to pass seems to be the posted speed limit. This appears to be consistent with the discussions resulting from video clip 5, where several people said they would feel no desire to pass unless the vehicle in front of them was going approximately 5-10 mi/h under the speed limit. Also, large trucks seem to play a negative role in their perceived trip quality.

Video clip 11

Description: Coastal roadway with a speed limit that transitions from 45 to 30 mi/h (45-35-30) as the roadway approaches a moderate pedestrian/development activity area with a traffic signal and parking lot off to one side. The roadway also transitions from a ‘passing’ to a ‘no-passing’ zone near the more densely developed and active area. In the video scene, the ocean can be seen from the roadway and there is moderate traffic in both directions.

Figure 15. Screenshot of Video Clip 11.

Discussion results: In this discussion a couple of people from both focus groups mentioned that they thought the speed limit was appropriate but that it should have been lower in the area where there was higher density development, more pedestrian activity, and vehicle activity, such as near the parking lot.

Many members of one group remarked that even though the pavement markings indicated that passing was permitted, they would not do so because of the increased level of traffic and pedestrian activity. One person said, "I would be less likely [to pass] due to the fact that we were in a resort area and the activity is going to dictate."

When asked how the number of vehicles would influence their trip quality, a couple of people from one group said that the quality would "go down with lots of cars."

One person took a different stance by saying, “The number of cars would not be a problem if traffic was moving.”

In summary, although there was no lengthy discussion about any one of the topics mentioned above, it appears that most people expect to travel at slower speed because of the higher level of roadside development and activity. There also seems to be no expectation for passing for the same reasons. These discussions are generally consistent with those of other similar video clips, such as clip 2, clip 4, and clip 7, which all depicted travel through small or medium-sized towns.

Video clip 12

Description: Two-lane bridge with a speed limit of 55 mi/h and no shoulder, only a guardrail. The roadway has well maintained pavement and markings and standard-width lanes. The pavement markings on the bridge indicate ‘no-passing’ (solid-yellow center line). The video vehicle is following other vehicles (but not closely) traveling at the speed limit or above.

Discussion results: A few issues emerged in the discussion about this video clip. Members of both groups expressed concern with the lack of a shoulder or pull-off area for disabled vehicles or other incidents. Additionally, when asked about passing expectations in this situation, members of both groups resoundingly said that they would not feel compelled to do so.

Members of one group were asked if the following situation depicted in the video clip, where the video vehicle was traveling in a well-dispersed platoon at speeds at or above the speed limit, was an undesirable situation. The only audible responses were from a few who said “no.”

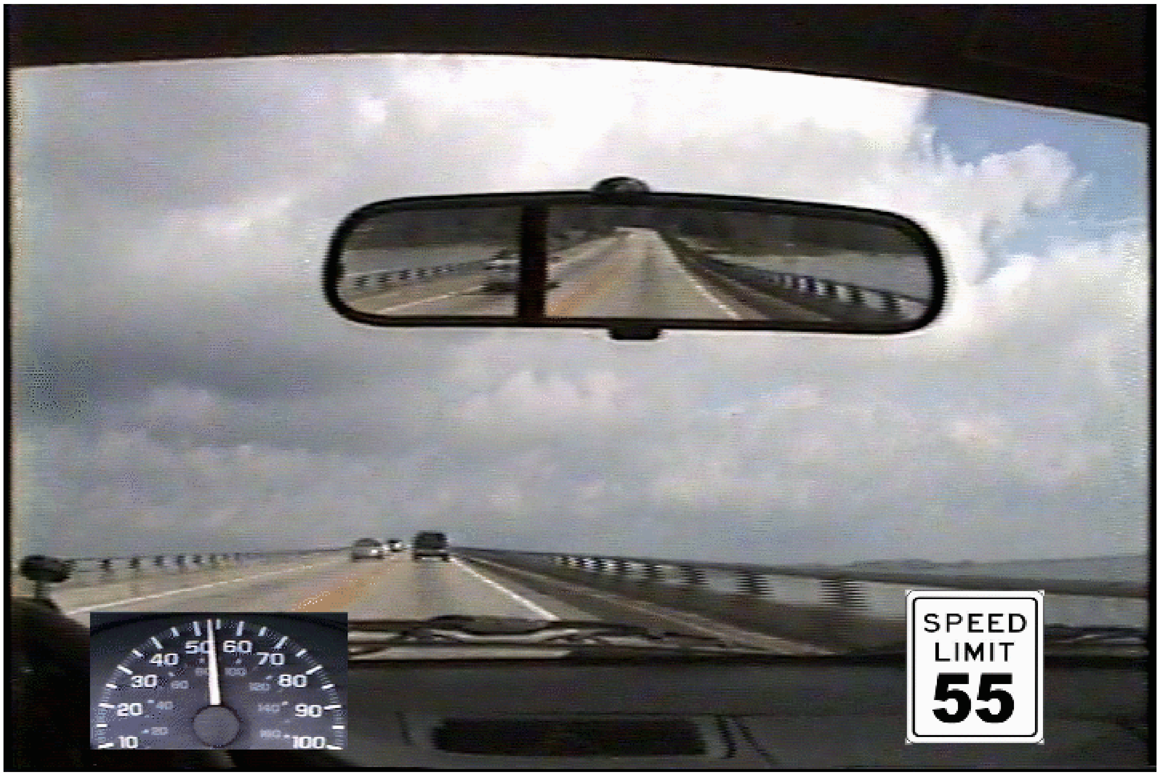


Figure 16. Screenshot of Video Clip 12.

Another issue involved the posted speed limit of the facility as well as the expected travel speed. In one group, several participants felt that the posted speed was too high for the type of bridge, citing safety concerns. However, many others felt that the posted speed limit was appropriate. When asked if the "primary thing in terms of delineating between poor and good trip quality would be maintaining a speed close to the posted speed limit", most members of one group said "yes" with one person saying "because you don't have to worry about people coming in and out."

In summary, the importance of a shoulder is once again reiterated. There also seems to be no expectation for passing on a facility such as this. Participants did not seem to be bothered that the video vehicle was following other vehicles because the other vehicles in the platoon were not closely spaced and were traveling at a reasonable speed. Participants also noted that a travel speed close to the speed limit was desired.

Video clip 13

Description: The speed limit transitions from 45 to 35 mi/h as the roadway approaches a small town with moderate roadside development, many driveways and a traffic signal. After the traffic signal, the speed limit returns to 45 mi/h. In the video scene, the video vehicle is following a vehicle traveling between the speed limit and 5 mi/h under and there is moderate traffic present in both directions.

Figure 17. Screenshot of Video Clip 13.

Discussion results: Two major themes emerged in the discussion following this clip. One dealt with perceptions of trip quality with respect to traffic signals on two-lane highways and the other dealt with the relationship between speed and following.

Members of both groups were prompted to discuss how the occasional presence of traffic signals (once every 5-10 miles) on two-lane highways impacts their perception of trip quality. The majority of member said that traffic signals “didn’t bother” them or that they were “not a big deal.” However, one person said that the presence of a traffic signal was a “big impact, negatively.” Another individual said that it was a “medium impact” and followed by saying, “If it was every 5 miles and the light was red it would start to become an issue. If it were a longer interval and half of them were green, that would be better.”

When asked if anyone would feel compelled to pass in the situation depicted in the video clip, several members of one group said “no.” One person said, “That person in front was going 35 in a 45-mi/h zone and that was getting me a little bit antsy, but I wouldn’t have passed either way.” A couple more people indicated that they too were frustrated with having to follow at a lower speed than the speed limit, as depicted in the video. When asked the same question, a member from the other group said, “It frustrates me. I would rather do what the speed limit says, and if [the speed limit] is slow, then fine, but I don’t want somebody in front of me going 15 miles below the speed limit.”

In summary, the occasional or rare presence of a traffic signal on two-lane highway trips does not seem to bother the majority of the participants. However, a couple of participants expressed that the presence of signals does downgrade the quality of their trip. Most group members agreed that they would not feel an expectation to pass in the small town area, however, several members were frustrated by having to follow a vehicle traveling well below the speed limit. These comments are consistent with those discussions for similar video clips.

Video clip 14

Description: A high-speed facility with a 50-mi/h speed limit. The roadway has narrow lanes (10-11 feet), no paved shoulder, well maintained pavement and markings, and many marked ‘passing’ zones (indicated by a dashed-yellow center line). In the video scene, there is minimal traffic present in either direction.

Figure 18. Screenshot of Video Clip 14.

Discussion results: The main topic of discussion for this video clip involved the impact of narrow lanes and lack of shoulders on the participants’ perceived trip quality and choice of travel speed.

As was the case with many of the other video clips, many people commented about the lack of shoulders, indicating that it may have some impact on perceived trip quality. However, as the moderator prompted further discussion, many of those participants began to acknowledge that their concerns were related more to safety than operations. When asked to consider a hypothetical situation in which the same road was being judged, but there was no chance of a ‘crisis situation’ occurring, thereby requiring the driver to pull over, many people said that the lack of shoulder would not lower their trip quality, calling it “a fine road” and “a good road.”

Furthering the conversation, the moderator attempted to get information about how roadway characteristics such as narrow lanes and lack of shoulder area impacts the participants choice of travel speed. To do so, the moderator, once again, described a hypothetical situation in which he asked participants to compare between a straight roadway with 12 foot lanes and a paved shoulder, and a straight roadway with 10 foot lanes and no paved shoulder. The moderator then asked, “Who would drive slower than that posted speed limit because of the narrower lane and lack of shoulder?” Several people said that they would, with two people saying “especially at night.” The moderator stated for the record that four people raised their hand to indicate that narrow lanes and lack of shoulders would not affect their speed.

In summary, it appears that narrow lanes and lack of shoulder do impact the choice of travel speed for some participants, but others claimed that it has no effect. However, previous discussion indicated that these characteristics did not necessarily lower their perceived trip quality.

Video clip 15

Description: A high-speed facility with a speed limit that increases from 45 to 55 mi/h, standard-width lanes, well maintained pavement and markings, and moderate roadside development. In the video scene there is moderate traffic present in both directions and the video vehicle is being followed by another vehicle (but not closely).

Figure 19. Screenshot of Video Clip 15.

Discussion results: While there was no lengthy discussion about any particular topic, a couple of issues were discussed briefly. Most people seemed to feel that the speed limit on the facility was appropriate and that the adjacent driveways were easy to see. Only one person seemed to be bothered that the video vehicle was being followed by another vehicle, and said that maybe this indicated that the speed limit was not high enough.

One person mentioned that the addition of deceleration lanes would be an improvement because "…there were so many driveways turning off, and having a lot of people slowing down in front of me to turn into driveways, they would have to slow down really slow and that would bother me."

In summary, most participants felt that the speed limit was appropriate given that there was some roadside development. The suggestion made by one participant regarding the addition of deceleration lanes indicates that having to slow down for vehicles exiting the roadway would lower the quality of the trip.

Video clip 16

Description: The speed limit transitions from 45 to 35 mi/h as the roadway approaches a medium-sized town. The roadway has standard-width lanes, well-maintained pavement and markings, moderate roadside development, and many driveways. In the video scene, there is moderate traffic present in both directions. Also, the video vehicle being followed closely and is following other vehicles traveling 5 to 10 mi/h under the speed limit.

Figure 20. Screenshot of Video Clip 16.

Discussion results: Both focus groups did not have much to say in reference to this clip. A couple of people mentioned that they did not like that the video vehicle had to travel so far under the speed limit due to the vehicles ahead of it. One person said, “If people were going the speed limit there would have been no problem, but the people were just going 10 mi/h under." Another group member said that they "wouldn't dare go over the speed limit" because there was a lot of "activity going on off to the sides." As a result of the activity and traffic volume, most people said that they would not feel the need to pass.

In summary, although there was little discussion about this clip, what was said, however, was consistent with previous statements about passing expectations within small to medium-sized towns. Also, the statements about expectations of travel speed are consistent in that most participants do not like having to travel at a reduced speed (relative to the posted speed limit) as a result of following other vehicles.

Survey Forms

Form 1

For Form 1, participants were asked to use the spaces provided on the form to: "Describe what you consider to be the primary indicators of the trip quality for each of the two-lane highway video clips. Please be specific as possible when describing what you feel are the important factors used in your assessment of trip quality. Factors you should consider include traffic conditions and/or characteristics of the roadway itself."

While the written comments proved useful in some situations, helping to interpret and back up the data collected from the focus group discussions, many of the comments were either vague, irrelevant, or sometimes illegible. In some cases, participants wrote down merely what they saw in the video clip. For instance, if there was a railroad crossing in the video clip, some people simply wrote "RRXing" or if there was a guardrail, they would write "guardrail." For this reason, some of the responses were difficult or impossible to interpret.

At times however, the written comments were more specific. For example, in reference to many of the video clips featuring a two-lane highway through a small or medium –sized town (clips 2, 4, 7, 13, and 16) , many participants wrote, “not compelled to pass” or “should not be able to pass”, indicating that they do not feel compelled or expect to pass in these situations. In reference to clip 10, in which the video vehicle was following a vehicle traveling slower than the speed limit, many participants wrote, “would have been frustrated with vehicle going too slow” or “would have passed” or “I would pass if a car was not doing the speed limit.” Comments such as these, when put into the context of the corresponding video clip, served as support to the verbal discussions.

An effort was made to quantitatively analyze the written comments provided on this survey form. A spreadsheet was created in which the comments for each video clip were entered. Irrelevant comments were discarded. The remaining comments were then separated into different categories. Examples of such include: “good visibility,” “pavement quality good,” “posted speed limit is good/adequate,” “not compelled to pass,” and “lane width not good.” The frequency of comments pertaining to a particular category (for each video clip) was then calculated. However, as discussed previously, the frequency in which a particular topic is discussed (or in this case written) does not necessarily reflect its importance. In fact, in this study, the frequency of certain written comments did not always correlate with the topics emphasized most heavily in the discussions. The spreadsheet detailing the frequency of comments is included in appendix H.

Form 2

Unfortunately, much of the results from this form were inconclusive. In many cases the results were inconsistent with the data collected from the focus group discussions and from the written responses on survey form 1. In fact, when analyzing the rankings, it appeared that many of the participants either did not understand what was being asked of them or did not want to take the time to properly fill out the form. Since the form was given to the participants at the end of the focus group session, it is possible that many participants were experiencing fatigue or were simply eager to leave.

In general, participants tended to say that all of the roadway and traffic factors listed on the form were of great importance to their perceived trip quality, rather than indicating the relative importance between them. In some cases, participants recorded 7's (indicating extreme importance) for all of the factors in all of the two-lane highway categories. While it is possible that these individuals felt that all of the roadway and traffic factors were of equal importance on all of the different types of two-lane highways, it is more probable that these individuals were eager to leave and therefore did not take the time to fill out the form in a way that truly represented their opinions.

However, some general trends were observed in the rankings. With respect to the four categories of two-lane highways listed on the form, a general downward shift in the frequency of higher numbered (5's,6's, and 7's) rankings occurred between the high and medium-speed facility categories and the low-speed categories. This indicates that the majority of participants consider the roadway and traffic characteristics listed on the form to factor more heavily in their assessment of trip quality for high and medium-speed facilities, and less heavily for lower-speed facilities such as those through small towns or coastal areas. The results of this form are included in appendix H.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to determine what performance measures appear to be most appropriate (i.e., consistent with traveler perceptions and expectations) for assessing LOS on different types of two-lane highways. As it stands, LOS methodologies can be improved by more accurately correlating the roadway performance measures used in analyses to the perceptions and expectations of the roadway users themselves. This will lead to better decision making about the allocation of resources to roadway infrastructure improvements.

Conclusions

Focus Group Implementation and Survey Forms

The recruitment of participants with the newspaper advertisement method was generally effective. The response rate exceeded expectations. Since many more people responded to the advertisement than the number needed for the three focus groups, it was possible to select participants such that each focus group consisted of a reasonably diverse sample of individuals. However, the one limitation with this method was that the majority of respondents were older[1]; thus, almost all of the few younger people (ages 25 – 45) that responded were selected to participate in the focus groups.

All three focus groups ran relatively smoothly and a significant amount of valuable information was obtained. As expected, however, the group discussion w as sometimes

[1] This is expected to be due to a large amount of retirees whose schedules are more often more flexible.

dominated by the more talkative or extroverted individuals, which consequently led to unequal representation in the audio recordings. However, the written survey form was intended to counter this, by giving all participants a forum in which to voice their opinions, although those opinions were limited to the space on the form.

While the written survey form (Form 1) proved useful in some situations, helping to interpret and back-up the data from the focus group discussions, many of the comments were either vague, irrelevant, or sometimes illegible. In many cases, the frequency of certain written comments did not always correlate with the topics emphasized most heavily in the discussions. The use of Form 2 ultimately did not have the desired outcome, in that the results were inconclusive and in some cases inconsistent with the data collected from the focus group discussions. It is suspected that participants either did not understand what was being asked of them or did not want to take the time to properly fill out the form. Therefore, it is felt that the audio data recorded from the focus group discussions is the most reliable set of data.

Focus Group Discussions

The focus group discussions proved to be an effective method of obtaining user perceptions about quality of service on two-lane highways. Based on the focus group discussions in this study, it is apparent that motorists consider several factors in their assessment of trip quality on a two-lane highway. The function and/or development setting of the of two-lane highway facility also appears to dictate what their trip quality expectations are.

In all three focus group sessions, there were many common themes or topics of discussion that arose repeatedly. For many of the study participants, safety was a primary concern, and was discussed heavily. Positive guidance, in the form of appropriate signage, clear lane markings and striping, reflectors, and in some cases lighting, was considered to be an important factor in their assessment of trip quality on all types of two-lane highways. While this is not necessarily a traffic operations issue, it nevertheless was a popular discussion topic and worthy of noting.

Another popular, but non-traffic operations, issue involved pavement quality. Participants stressed the importance of high quality, well maintained pavement repeatedly throughout the focus group discussions. For example, many participants immediately noticed and responded to the high quality pavement depicted in video clip 1 and the poor quality pavement depicted in video clip 5.

Another heavily repeated theme, that transcended all two-lane highway types, involved the presence or absence of shoulder area (paved or unpaved). While this is partly a safety issue in terms of having an “escape route” or “leeway” in the event of an incident, it can also be an operational issue. Some participants indicated that a lack of shoulder or adequate clearance zone decreases their comfort level and overall perception of trip quality. These participants felt that a lack of shoulder area also influences their choice of travel speed. Others, however, claimed that this had no impact on their travel speed or perceived trip quality.

In relation to shoulders, lane width was also discussed in reference to many video clips, including clips 3, 6, 12 and 14. Like shoulders, lane width appears to have an effect on the choice of travel speed and perceived trip quality for some study participants, but not others.

Speed and following/passing were also themes that arose repeatedly in all of the focus group sessions. The discussions about speed often centered around either an absolute speed, such as the posted speed of the roadway, or a relative speed, such as the desired travel speed or speed of the vehicles in the video in relation to the posted speed limit. The discussions about following/passing often focused on whether or not the participants felt compelled to pass in a given situation and how they felt about following or being followed by other vehicles. Based on the data collected in this study, motorists have different expectations of speed for different types of two-lane highways, as well as different expectations with regard to passing.

In reference to video clips 1, 5, 10, 14 and 15, most participants agreed that the posted speed limits on the facilities were appropriate given the context of the facilities. All six video clips featured two-lane highways through rural undeveloped areas with 50- to 60-mi/h posted speed limits. Study participants indicated a desire and an expectation to travel at high speeds on these facilities. In most cases this desired or expected travel speed was the speed limit or above by 5-10 mi/h. Most participants agreed that having to travel slower than the posted speed limit on these types of facilities resulted in a lower trip quality. Participants also indicated that passing opportunities were an important aspect of trip quality on a high-speed two-lane highway. However, many participants agreed that they would not feel compelled to pass unless they were following a vehicle going approximately 5-10 mi/h under the speed limit, such as with video clip 10.

Video clips 2, 4, 7, 13 and 16, all feature two-lane highways which travel through small-or medium sized towns. Based on the focus group discussions, many participants agreed that they would not feel compelled or have an expectation to pass in a town area. Participants appeared to feel similarly with respect to passing expectations for the coastal roadway depicted in video clips 8 and 11, which featured moderate surrounding development and pedestrian activity. Participant also felt this way about the two-lane highway segments depicted in video clips 3 and 12. Video clip 3, featured a scenic tree canopy roadway with narrow lanes and video clip 12 featured a narrow bridge with no shoulder. In all of the above situations, participants agreed that they would not have an expectation to pass, but that having to follow a vehicle traveling slower than the sped limit would negatively affect the trip quality, such as in video clips 13 and 16. Furthermore, participants acknowledged that their preferred travel speed was a speed at or above the speed limit

Video clips 6 and 9, the only two remaining video clips not discussed previously, both depicted two-lane highways with moderate residential development on both sides of the roadway. Both video clips received debate over the appropriate posted speed limit and passing expectations. For video clip 6, some participants felt that the 45 mi/h speed limit was appropriate due to the residences along the roadway. These participants also expressed that they would not feel compelled to pass for this reason. However, others felt that this speed limit was too low and that they would pass if it were safe to do so. For video clip 9, the majority of participants agreed that the posted speed limit of 35 mi/h was too low. Although they recognized the presence of residences, many felt that a speed limit of 45 mi/h would be more appropriate given that very little traffic would be using these private driveways. Again, some participants felt a reasonable expectation to pass in this situation, while others did not.

Based on the data collected from the participants in this study, there appears to be at least three categories of two-lane highways from a motorist’s perspective. There are two very definable categories of two-lane highways and the resultant traveler expectations. However, there were other two-lane highway situations that did not fit into either of those two categories and there was not a clear consensus on the preferred performance measures.

The first category includes high-speed (50 mi/h and above) two-lane highways, in generally rural undeveloped areas, in which motorists expect to travel at high speeds and have frequent passing opportunities. Therefore, the combination of speed- and passing opportunity-based performance measures seems appropriate for this category.

The current HCM service measures for a Class I two-lane highway include ATS and PTSF. The ATS service measure and corresponding thresholds for Class I are intended to reflect the motorist’s expectation for high-speed travel. However, the current thresholds for this class are somewhat restrictive given that the threshold for LOS A is 55 mi/h and, based on this study, motorists tend to perceive facilities with 50-60 mi/h speed limits as falling under this classification. Thus, PFFS may be more suitable than ATS in terms of a speed-based performance measure because it references a relative speed rather than an absolute speed. It is felt that the PTSF service measure is reasonable for this class because it accounts for passing opportunities. However, the implication with this measure is that vehicles traveling with headways of 3 seconds or less are compelled to pass, whereas this may not necessarily be the case. Therefore, this category of two-lane highway (high-speed, rural undeveloped) appears to be consistent, in terms of service measures, with the current Class I definition.

The second category consists of two-lane highways in which there is essentially no passing expectation, including roadways through small-or medium-sized towns, developed coastal areas, and certain scenic areas. While these types of facilities are certainly not Class I facilities, they do not fit under the Class II definition either. These types of two-lane highways therefore should be of a separate class, Class III for example. On these facilities, passing opportunities are not an issue, and in general, neither is the percent time-spent-following. While the participants stated that they would certainly rather be traveling with no other vehicles around them, they acknowledged that following is not much of a concern in these situations. Particularly in low-speed conditions, such as in small towns, following does not tend to be of much concern because there are fewer safety implications. On these two-lane highways, the clear consensus from the focus groups was that the motorist's primary desire is to travel at a speed at or slightly above the posted speed limit. Therefore, a speed-based measure, such as PFFS, appears to be more appropriate for these Class III two-lane highways than a following-based measure such as PTSF.

Based on the focus group results, it is clear that there are additional two-lane highway situations/configurations that do not fall into either of the above described categories. These two-lane highways essentially fall in between the two other categories in that passing expectations on these roadways do not appear to be as definitive. For example, with video clips 6 and 9, participants were essentially divided on the issue of passing. Given the moderate level of residential development depicted in both of the video clips, participants did not expect high-speed travel (such as on a rural undeveloped facility), which in terms of the current HCM classifications, would render this type of highway as Class II. The performance measure for a Class II two-lane highway in the HCM is PTSF, indicating that following is the primary determinant of level of service. However, this does not seem to be consistent with the expectations of some motorists.

Instead, for these types of two-lane highways, speed seemed to be a larger issue. While the participants did not have an expectation for high-speed travel, at the same time they did not feel that low speeds were warranted either (such as in a small town). In reference to video clip 9, most participants expressed frustration with what they perceived was an excessively and unnecessarily low posted speed limit, given the context of the facility. On these types of intermediate two-lane highways, an absolute travel speed appears to be just as important as a relative travel speed. In other words, while most motorists' primary desire is to travel at a speed which is at or above the speed limit, on these types of two-lane highways it is just as important (from the motorist's viewpoint) for the posted speed limit to be set appropriately within the context of the facility. Therefore, for these Class II-type facilities, an absolute-speed-based performance measure such as ATS should be considered. It is possible that, based on the context of the facility and motorist's expectations, a following based performance measure should also be used. However, for these types of two-lane highways, "engineering judgment" will have to dictate.

In summary, it is clear from this focus group effort that some improvements could be made to the current classification scheme and corresponding service measures. To begin with, the manner in which the current HCM classifies two-lane highways does not appear to be comprehensive, and for one of the classifications the chosen service measure is not necessarily appropriate. At this time, classifications are largely based on expectations of travel speed. From this study, it appears that expectations for passing should be considered, in addition to travel speed, when distinguishing among facilities. Also, the current classifications do not address two-lane highways through small towns or through coastal and scenic areas. These types of facilities should receive their own classification (Class III) and their own specific performance measure, the most logical choice being PFFS.

The current HCM Class I methodology is largely consistent with what was determined in this study. However, the use of PTSF does not account for the possibility that in some situations many people are content to not pass, even if following other vehicles closely. A passing opportunity-based performance measure, rather than a following-based performance measure may be more appropriate for these types of facilities. However, the development of such a measure should perhaps be pursued as part of a more long-term research effort.

The current HCM Class II definition, which includes all roadways in which motorists do not expect to travel at high speeds, is also largely consistent with what was determined in the study, except that two-lane highways in which there is no expectation for passing should be designated as Class III. Unlike the current Class II methodology though, the use of a speed-based performance measure should be considered, as well as a following-based measure. For these types of roadways, it appears that absolute travel speed (e.g., no less than 45 mi/h) is just as important as being able to travel at a certain speed relative to the posted speed limit. Therefore, ATS should be considered as a speed-based measure. Thus, a combination of ATS and PTSF, similar to Class I, should be considered; however, the LOS thresholds would be different than for Class I.

Recommendations for Further Research

For the findings of this study to be adopted on a national level, it is recommended that the scope of the video data collection and participant recruitment be broadened to include regions outside of the University of Florida/north central Florida area. Additionally, a future study should include a larger number of drivers under the age of

26. Future research should also consider the use of more video clips, with a more diverse range of roadway and traffic conditions. Based upon focus group feedback, only two of the video clips featured roadways that fell under Class II (although not done intentionally). In this study, the core of the video clips depicted Class I and Class III two-lane highways. It is recommended that future research include more Class II examples.

While the use of written survey forms provided all participants with an opportunity to provide input, the data collected from the focus group discussions were more reliable and valuable. In a future study, it is recommended that if forms are to be provided for written input, there should be more time allotted for the participants to think about their comments or responses and record them, as well as more time to reiterate the instructions on filling out the forms. Of course, this must be balanced with the overall time requirement for the focus group effort. In this study, the focus group sessions lasted two hours, which may already be pushing the practical limits of what can be expected from recruited participants. It may be more desirable to not require any written input from focus group participants. However, if no written input is to be collected, an attempt should be made to obtain verbal input from each participant.

In the previous section, some suggestions were made for making some improvements to the current LOS methodology for two-lane highways. With regard to two-lane highways that clearly were neither Class I or III, it became evident that there were not enough video data collected with respect to these type of facilities to be able to make definitive recommendations in terms of performance measures. Furthermore, it was made clear that a number of roadway factors (e.g., pavement quality, roadway striping quality, etc.) are also important to motorists in evaluating trip quality. Thus, the development of a more comprehensive LOS methodology should be considered. The outcome of such research might be a level of service function that could be applied to all categories of two-lane highways. The function could be defined in terms of a series of variables (performance measures) and corresponding coefficients. The variables might include PFFS, ATS, PTSF, Passing Opportunities, % Heavy Vehicles, Pavement Quality, Lane Striping Quality, etc. The coefficients would be defined separately for each category of two-lane highway. Thus, the weighting of the importance of each variable to the overall evaluation of trip quality by a motorist could be different for each class of two-lane highway.

APPENDIX A
LETTERS FROM FLORIDA OFFICIALS REGARDING
HCM 2000 TWO-LANE HIGHWAY ANALYSIS METHODOLOGY

Florida Department of Transportation

JEB BUSH
GOVERNOR

605 Suwannee Street
Tallahassee, Florida 32399-0450

THOMAS F. BARRY, JR.
SECRETARY

November 2, 2001

Dr. Richard Dowling
Principal
Dowling Associates
180 Grand Avenue, Suite 995
Oakland, California 94612

Dear Dr. Dowling:

Subject: HCM2000 Uninterrupted Flow Two-Lane Level of Service Thresholds

Florida Department of Transportation (FDOT) staff has begun working with the new uninterrupted flow two-lane chapter of the HCM2000 and have serious concerns with the new thresholds presented. In some cases service volumes for Class I facilities have dropped approximately 50 percent from those in HCM1997. This change in service volumes will have a significant impact on FDOT actions in determining roadway deficiencies, reporting to legislators on the status of the highway system, and setting priorities. For those states and others who adopt the HCM, requiring the use of these new thresholds may have similar significant impacts.

It is my understanding that there was not a significant amount of discussion on setting the level of service thresholds by the Transportation Research Board Highway Capacity and Quality of Service Committee. Because of the significant change in the thresholds from HCM1997, we strongly request that the Committee revisit the level of service A-E thresholds set for those facilities. As appropriate, additional testing, new research, surveys to users or some other effort appears warranted.

As you are aware, Florida has been one of the leading states implementing and advancing the HCM. On an interim basis until the threshold issue is addressed and resolved, FDOT has made a decision to continue to use the HCM1997 level of service thresholds in rural undeveloped areas and will use a newly developed Class III two-lane class in developed areas. Our lead researchers and staff have submitted a professional paper encompassing these Class III facilities to your committee for its review and expected presentation at the 2002 TRB Annual Meeting.

www.dot.state.fl.us

RECYCLED PAPER

Dr. Richard Dowling
November 2, 2001
Page Two

If you have any questions or need further information on the FDOT concerns, please contact Doug McLeod, (850) 414-4932, of my staff.

Thank you for consideration of this issue.

Sincerely,

Ysela Llort
State Transportation Planner

YL:bkl

cc: Tom Barry, Chair, AASHTO Standing Committee on Planning
Dwight Bower, Chair, AASHTO Standing Committee on Research
Lily Elefteriadou, Chair, Two-Lane Subcommittee, TRB Highway Capacity and Quality of Service Committee
John Zegeer, Chair, User Liaison Subcommittee, TRB Highway Capacity and Quality of Service Committee
Richard Cunard, Transportation Research Board
Ken Courage, University of Florida
Scott Washburn, University of Florida
Jim St. John, Federal Highway Administration

North Central Florida
Regional Planning Council

2009 NW 67 PLACE, SUITE A, GAINESVILLE, FLORIDA 32653-1603
(352)955-2200 SUNCOM 625-2200 FAX (352) 955-2209

October 28, 2002

Mr. Douglas Harwood
Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64110

SUBJECT: Highway Capacity Manual (HCM) Rural Two-Lane Analysis

Dear Mr. Harwood:

As a member of the Florida Department of Transportation (FDOT) Level of Service Task Team, North Central Florida Regional Planning Council (NCFRPC) staff participated in the October 14-16, 2002 two-lane facility field study in Florida City, Florida. The purpose of this letter is to endorse FDOT's position to modify the HCM 2000 procedures regarding two-lane uninterrupted facility analyses for rural developed areas. This issue is of significant concern to us because the north central Florida region is predominantly rural and has a significant amount of two-lane arterial facilities that provide both intraregional and extraregional access.

The user's expectation while driving through a rural developed area is different than while driving through a rural undeveloped area. An increase in density of side-access from intersecting roadways and driveways lowers the user's expectation of unimpeded progression through the facility. In many instances, rural developed areas have land use intensity changes that are coincident with lower speed zones. Therefore, the user's expectation is changed. This perception change would indicate higher service volumes than those currently calculated using the HCM 2000 procedures. Exhibit 1 consists of some of the predominantly rural two-lane arterial facilities in north central Florida. It identifies nearly 100 settlements, most without traffic signals, that occur along these facilities.

If you have any questions or need more information, please call me at extension 103.

Sincerely,

Marlie Sanderson, AICP
Director of Transportation Planning

xc: Dr. Lily Elefteriadou, HCM Two-Lane Subcommittee Chair
FDOT Level of Service Task Team

EXHIBIT 1

TWO-LANE ARTERIAL FACILITIES THROUGH RURAL DEVELOPED AREAS OF NORTH CENTRAL FLORIDA

FACILITY	FROM	TO	MILEAGE	SETTLEMENTS
				FEDERAL HIGHWAY SYSTEM
US 27	**Archer**	**Perry**	88	**Archer**#, Half Moon, **Newberry**#*, **High Springs**#, **Fort White**#, Hildreth, **Branford**, **Mayo**#, Buckville, Townshend, **Perry**#
US 41	**High Springs**	**Jennings**	67	**High Springs**#*, Mikesville, Ellisville, Mason, Myrtis, **Lake City**#, Winfield, Suwannee Valley, **White Springs**, Genoa, Hillcoat, **Jasper**#, **Jennings**
US 90	**Monticello**	**Macclenny**	112	**Monticello**#, **Greenville**, **Madison**#*, **Lee**, Ellaville, Falmouth, Dickert, **Live Oak**#*, Houston, Wellborn, **Lake City**#*, Watertown, Newton, Wilburn, Olustee, Sanderson, **Glen St. Mary**#, **Macclenny**#
US 98	Newport	**Perry**	38	Newport, Nutal Rise, Scanlon, Hampton Springs, **Perry**#
US 129	**Chiefland**	**Jasper**	81	**Chiefland**, **Trenton**#, **Bell**, **Branford**, Obrien, McAlpin, **Live Oak**#*, Suwannee Spring, Hillcoat, **Jasper**#
US 221	**Perry**	Ashville	35	**Perry**#, Boyd, Lake Bird, Shady Grove, Ebb, **Greenville**, Ashville
				STATE HIGHWAY SYSTEM
State Road 24	**Cedar Key**	**Gainesville**	53	**Cedar Key**, Lukens, Rosewood, **Otter Creek**, Lennon, **Bronson**#, Meredith, **Archer**#*
State Road 26	**Fanning Springs**	Putnam Hall	54	**Fanning Springs**, Wilcox, Lottieville, **Trenton**#, **Newberry**#, Orange Heights, Melrose, Putnam Hall
State Road 47	**Trenton**	**Lake City**	42	**Trenton**, **Fort White**#, Columbia City, **Lake City**#
State Road 51	Steinhatchee	**Live Oak**	53	Steinhatchee, Clara, **Mayo**#, Luraville., **Live Oak**#
State Road 100	**Lake City**	**Palatka**	76	**Lake City**#, Lulu, **Lake Butler**#*, **Starke**#, **Keystone Heights**, Lake Geneva, Putnam Hall, Grandin, Florahome, Carraway, Springside, **Palatka**#
State Road 121	**Williston**	**Macclenny**	69	**Williston**, Wacahoota, **La Crosse**, Santa Fe, **Worthington Springs**, Dukes, **Lake Butler**#, Johnstown, **Raiford**, Ellerbee, Sapp, **Macclenny**#

Notes:
1. Settlements in **bold** are incorporated.
2. Pound symbol (#) indicates traffic signal within the settlement.
3. Asterisk (*) indicates greater than two throughlane cross-section within the settlement.
4. Gainesville Metropolitan Area facilities are not included.

C:\public\em03\hcm2ln.wpd

APPENDIX B
TRANSPORTATION RESEARCH BOARD
WORKSHOP PRESENTATIONS
JANUARY 2004

Presentation by Douglas Harwood of MRI

Midwest Research Institute

Level of Service Assessment

For Developed Two-Lane Highways

NCHRP Project 20-7(160)

Douglas W. Harwood

Midwest Research Institute

MRI Objective and Scope

OBJECTIVE

- Recommend procedures to assess quality of service for two-lane highways in developed areas

KEY DECISIONS

- What service measure to use?
- Where in HCM does procedure belong?

MRI Existing HCM Chapter 20 Procedure

- Class I highways:
  - motorists expect to travel at relatively high speeds
  - service measures: PTSF and ATS
  - threshold values: Exhibit 20-2
- Class II highways
  - motorists do not expect to travel at relatively high speeds
  - service measure: PTSF only
  - threshold values: Exhibit 20-4

MRI Scenarios Where Existing HCM Chapter 20 Does Not Apply

- two-lane highway through a small town with a reduced speed limit located on a major road with speeds of 55 mph or more
- two-lane highway in a transition area between rural and urban/suburban conditions with reduced speeds and low- to medium-density development

MRI Scenarios Where Existing HCM Chapter 20 Does Not Apply

- two-lane highway with continuous urban/suburban development but no traffic signals or traffic signals spaced at intervals greater than 2 mi
- Are such facilities:
  - "generally uninterrupted flow" ?
  - "partially interrupted flow" ?

MRI Two-Lane Highways with Continuous Development

- Candidate service measures:
  - PTSF
  - ATS
  - PTSF and ATS combined
- Recommended service measure:
  - ATS only
- Threshold values:
  - based on percentage of FFS

LOS Thresholds for HCM Chapter 15

• LOS A/B boundary	90% of FFS
• LOS B/C boundary	70% of FFS
• LOS C/D boundary	50% of FFS
• LOS D/E boundary	40% of FFS
• LOS E/F boundary	30% of FFS

HCM Chapter 15 Procedure for Urban Streets

- At signals:
  - use HCM Chapter 16 to estimate delay
- Between signals:
  - use running time per km from HCM Exhibit 15-3
- Combine segment running time and signal delay to get average running speed
- Apply LOS thresholds

Potential Weaknesses of HCM Chapter 15 Methodology as Applied to Developed Two-Lane Highways

- Running time between signals is based on signal spacing but does not consider:
  - effects of driveways and roadside development on delay
  - effects of unsignalized intersections on delay
- Procedure does not apply to:
  - streets without signals
  - streets with signal spacing over 2 mi

HCM Gaps Between Chapters

- HCM2000 does not address:
  - multilane urban streets without signals or with widely spaced signals
  - two-lane urban streets without signals or with widely spaced signals
  - developed two-lane highways
- HCM Chapter 21 addresses rural and suburban multilane highways
  - service measure: density

Where in HCM to Address Developed Two-Lane Highways

- Same service measures as HCM Chapter 15
- Same threshold values as HCM Chapter 15
- Physical facility like an arterial except for signal spacing
- Would very out of place in HCM Chapter 20
- Recommendation: incorporate in HCM Chapter 15 or a new facilities chapter

Related Questions for Two-Lane and Multilane Arterials

- How to evaluate arterials with no signals or widely spaced signals?
- Why not consider delays between signals when substantial?
- Need a true facilities chapter to combine:
  - multilane and two-lane segments (including driveway and development effects)
  - unsignalized intersections
  - signalized intersections

Alternative Approaches

- Adapt current procedures (combine appropriate elements of existing HCM Chapters 15 and 20)

OR

- Research effort to develop better developed two-lane highways procedure

OR

- Major research effort (new urban arterial facilities procedure)

Combine Existing Procedures

- If developed two-lane highway has no signals:
  - segment length has no effect, so HCM Exhibit 15-3 is not needed
  - determine ATS with HCM Equation 20-15
  - apply LOS thresholds from HCM Chapter 15

Combine Existing Procedures

- If signals are spaced more than 1 mi apart:
  - segment length has no effect, so HCM Exhibit 15-3 is not needed
  - determine ATS between signals with HCM Equation 20-15
  - determine signal delay from HCM Chapter 16
  - use HCM Chapter 15 procedures to combine segment speed and signal delay
  - apply LOS thresholds from HCM Chapter 15

Combine Existing Procedures

- If signals are spaced less than 1 mi apart:
  - determine running speed between signals based on HCM Exhibit 15-3
  - determine running speed between signals based on HCM Equation 20-15
  - use the lower of the two speeds

Combine Existing Procedures

- determine signal delay from HCM Chapter 16
- use HCM Chapter 15 procedures to combine segment speed and signal delay
- apply LOS thresholds from HCM Chapter 15

Small Towns and Transition Areas

- Analysis approach depends on length of area with reduced speeds
- Two-lane highway in an undeveloped area:
  - evaluate as Class I or Class II based on existing criteria in HCM Chapter 20

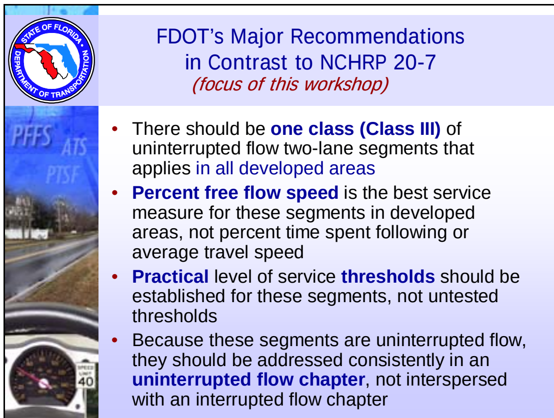
Small Town or Transition Area

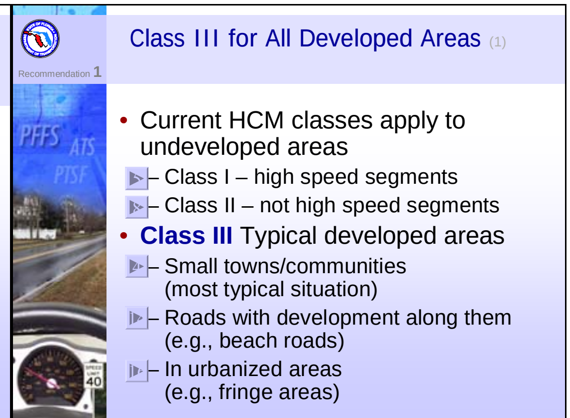
- Two-lane highway in a small town or transition area on a Class I highway:
  - evaluate as Class II highway if developed area with reduced speeds extends for less than 2 mi and most traffic is through traffic
  - if developed area with reduced speeds extends for more than 2 mi or there is substantial local circulating traffic, evaluate with developed two-lane highway procedure

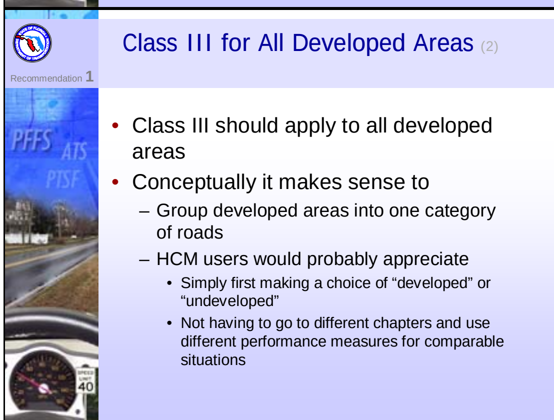
Research Needed

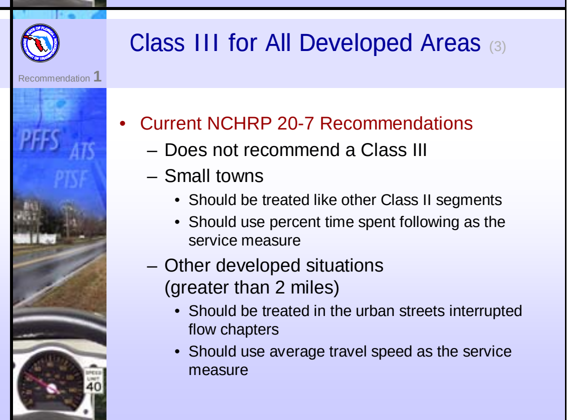
- Desirable, but not comprehensive:
  - HCM procedures for developed two-lane highways
- Long-term, more comprehensive:
  - urban arterial facilities procedure for any combination of:
    - segments (including driveways and development)
    - unsignalized intersections
    - signalized intersections

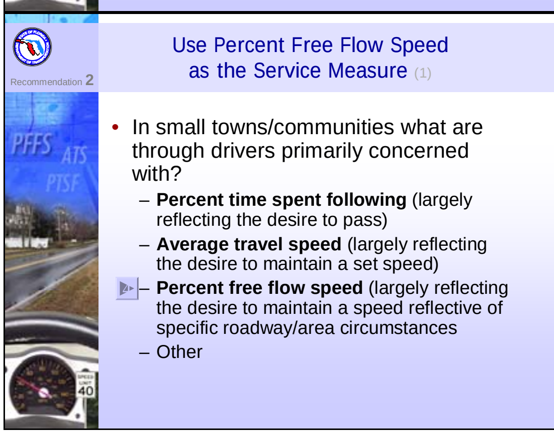
Presentation by Doug McLeod of FDOT

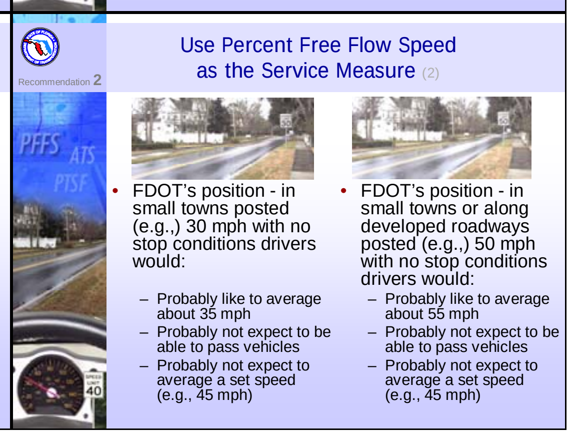












Use Percent Free Flow Speed as the Service Measure (3)

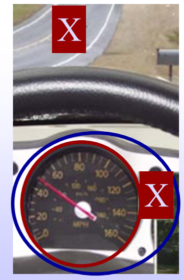
Recommendation 2

- Current NCHRP 20-7 Recommendations
  - Small towns
    - Percent time spent following as the service measure
    - Implied - drivers in these areas are most concerned about trying to pass
  - Other developed situations (greater than 2 miles)
    - Average travel speed as the service measure
    - Implied - drivers expect to go the same speed regardless of the roadway/surrounding conditions

Use Percent Free Flow Speed as the Service Measure (4)

Recommendation 2

- **Percent Free Flow Speed** is the best service measure for these segments in developed areas, not Percent Time Spent Following or Average Travel Speed



Practical LOS Thresholds Should Be Established (1)

Recommendation 3

- Practical level of service thresholds should be established for these segments, not untested thresholds

EXAMPLE

Recommendation 3

~ Service Volumes (using 20-7 Chapter 20 Class II approach for small towns)	~ Service Volumes (using FDOT's approach with Exhibit 20-2 as a base)	~ Service Volumes (using 20-7 Chapter 15 approach in other developed areas)
A = 1,900	A = 2,500	A = 3,100
B = 3,700	B = 7,200	B = 15,500
C = 7,100	C = 12,700	C = 23,500
D = 13,300	D = 17,300	D = N/A
E = 23,500	E = 23,500	E = N/A

EXAMPLE

Recommendation 3

~ Service Volumes (using 20-7 Chapter 20 Class II approach for small towns)	~ Service Volumes (using FDOT's approach with Exhibit 20-2 as a base)	~ Service Volumes (using 20-7 Chapter 15 approach in other developed areas)
A = 1,900	A = 2,500	A = 3,100
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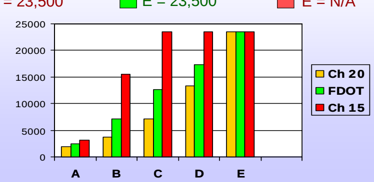


Practical LOS Thresholds Should Be Established (1)

Recommendation 3

- FDOT's position – LOS thresholds need to make sense when applied in the real world
  - HCM practitioners would probably appreciate LOS thresholds that can **be applied consistently** for these roads in developed areas
  - Resulting LOS calculations and service volumes for these roadways **need to make sense** in relation to those in undeveloped areas and those that are signalized

Practical LOS Thresholds Should Be Established (2)

Recommendation 3

- FDOT has provided LOS percent free flow speed thresholds directly linked to HCM Exhibit 20-2 (on average travel speed) that work reasonably well
- FDOT has provided closely related alternative percent free flow speed thresholds that may work even better in the field

Practical LOS Thresholds Should Be Established (3)

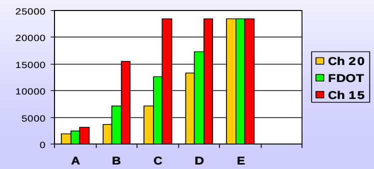
Recommendation 3

- Current NCHRP 20-7 Recommendations
  - Different service measures in different areas
  - Small towns
    - Use of Class II percent time spent following thresholds result in abnormally low LOS service volumes
      - Northern California case – (Local perceptions)
      - Georgia case – (FHWA requiring LOS C for design)
  - Other developed situations (greater than 2 miles)
    - Use of HCM's interrupted flow average travel speed criteria
      - The related percent free flow speeds have a heavy dependence on control delay
      - Essentially LOS D & E would never exist

Recommendation 3

Practical LOS Thresholds Should Be Established (4)

- Practical level of service thresholds should be established for these segments, not untested thresholds



Recommendation 4

These Roadways Should Be Addressed in the HCM Uninterrupted Flow Two-Lane Segment Chapter (1)

- FDOT's position - Uninterrupted flow highway segments should be treated in the same chapter of the HCM
  - They should not be split between the current two-lane segment chapter and the interrupted flow urban streets chapter

Recommendation 4

These Roadways Should Be Addressed in the HCM Uninterrupted Flow Two-Lane Segment Chapter (2)

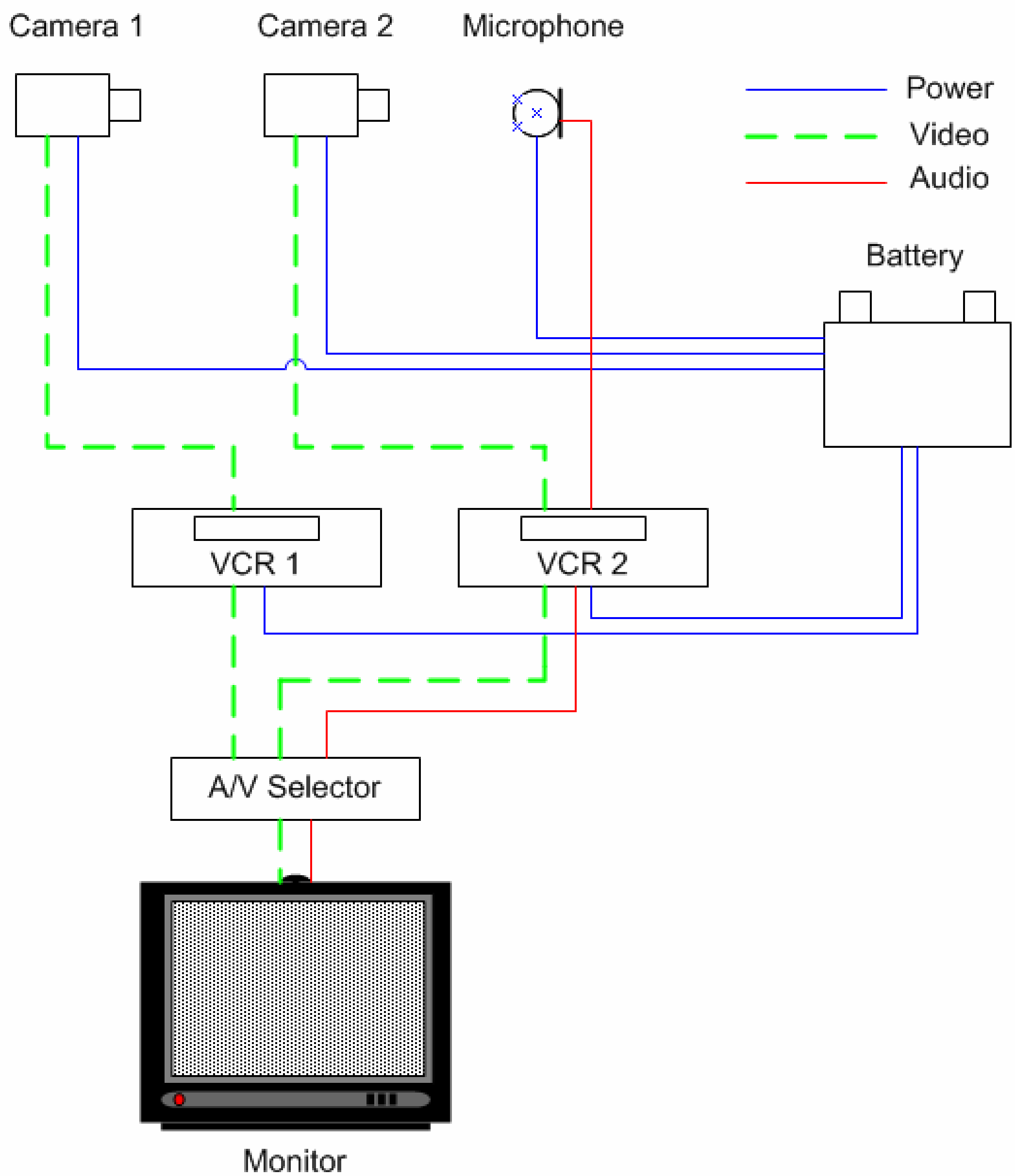
- Current NCHRP 20-7 Recommendations
  - Small towns – evaluate in the current uninterrupted two-lane chapter (20)
  - Other areas – evaluate in the current interrupted flow urban streets chapter (15), even though they are uninterrupted
    - Is this logical to the HCM practitioner?

FDOT Side Issues

(not the focus of this workshop)

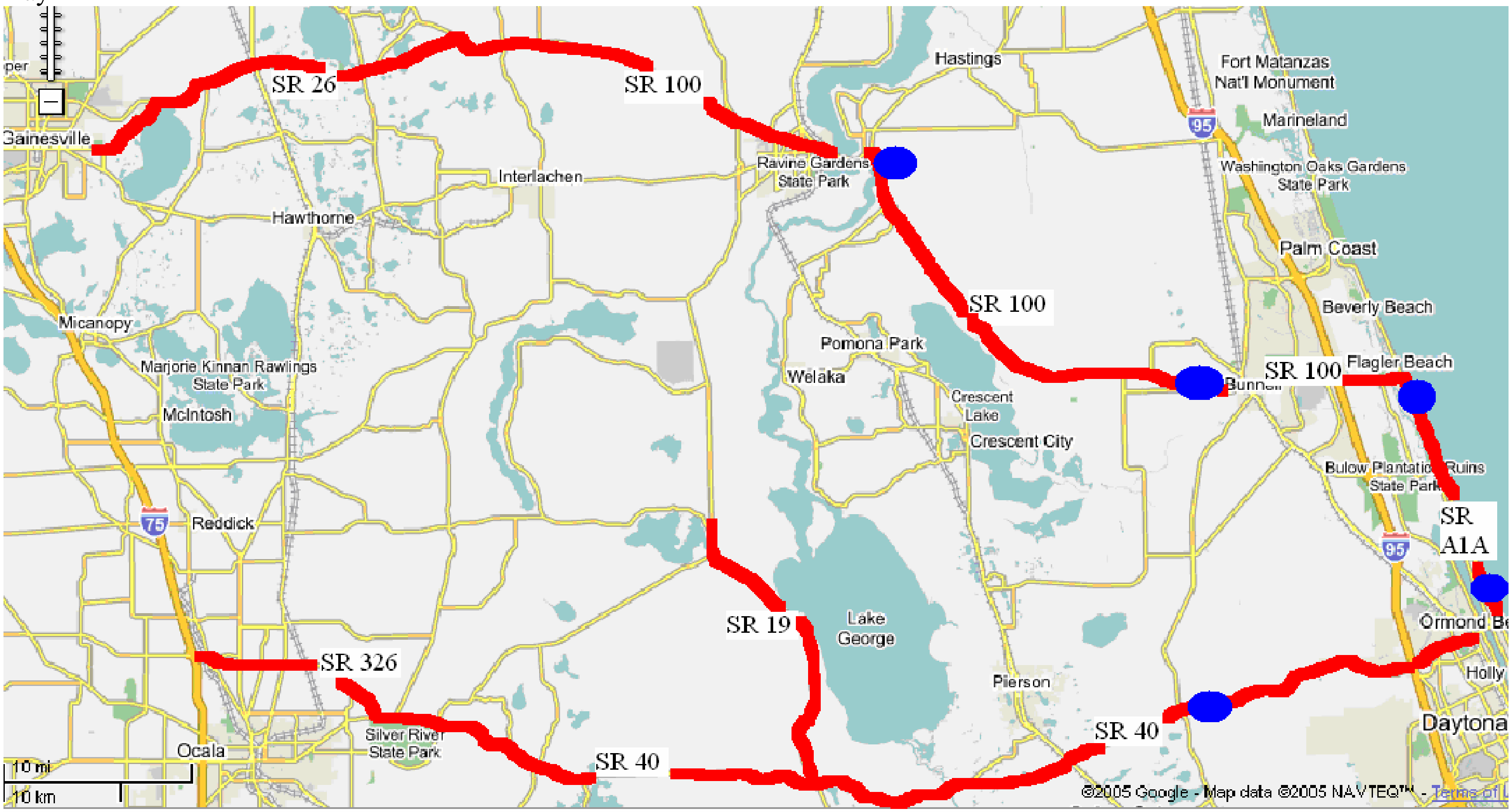
- Quality of service research should be conducted as to what drivers actually believe is most important
- Research is needed to develop an HCM **facility** chapter on generally uninterrupted flow facilities combining uninterrupted flow two-lane and multilane segments and isolated stop control conditions (FDOT has funded in-state research and has submitted a research proposal as a future NCHRP project)
- Concerns about the current service measures for Class I and II
- These roadways should be multimodal in approach (i.e., bike LOS analysis should be included)

APPENDIX C
SCHEMATIC OF IN-VEHICLE EQUIPMENT



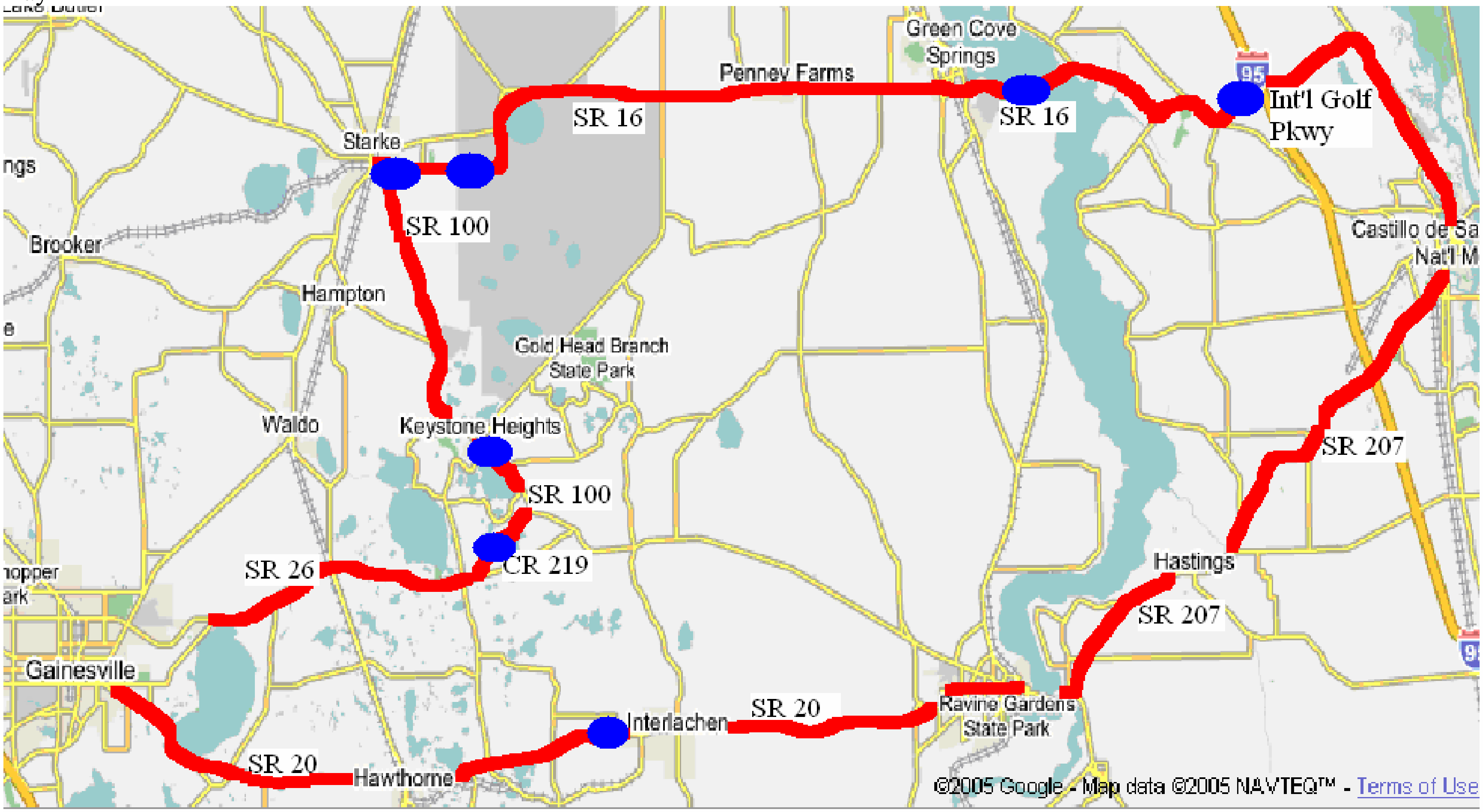
APPENDIX D
MAPS OF DRIVING ROUTES

Day 1



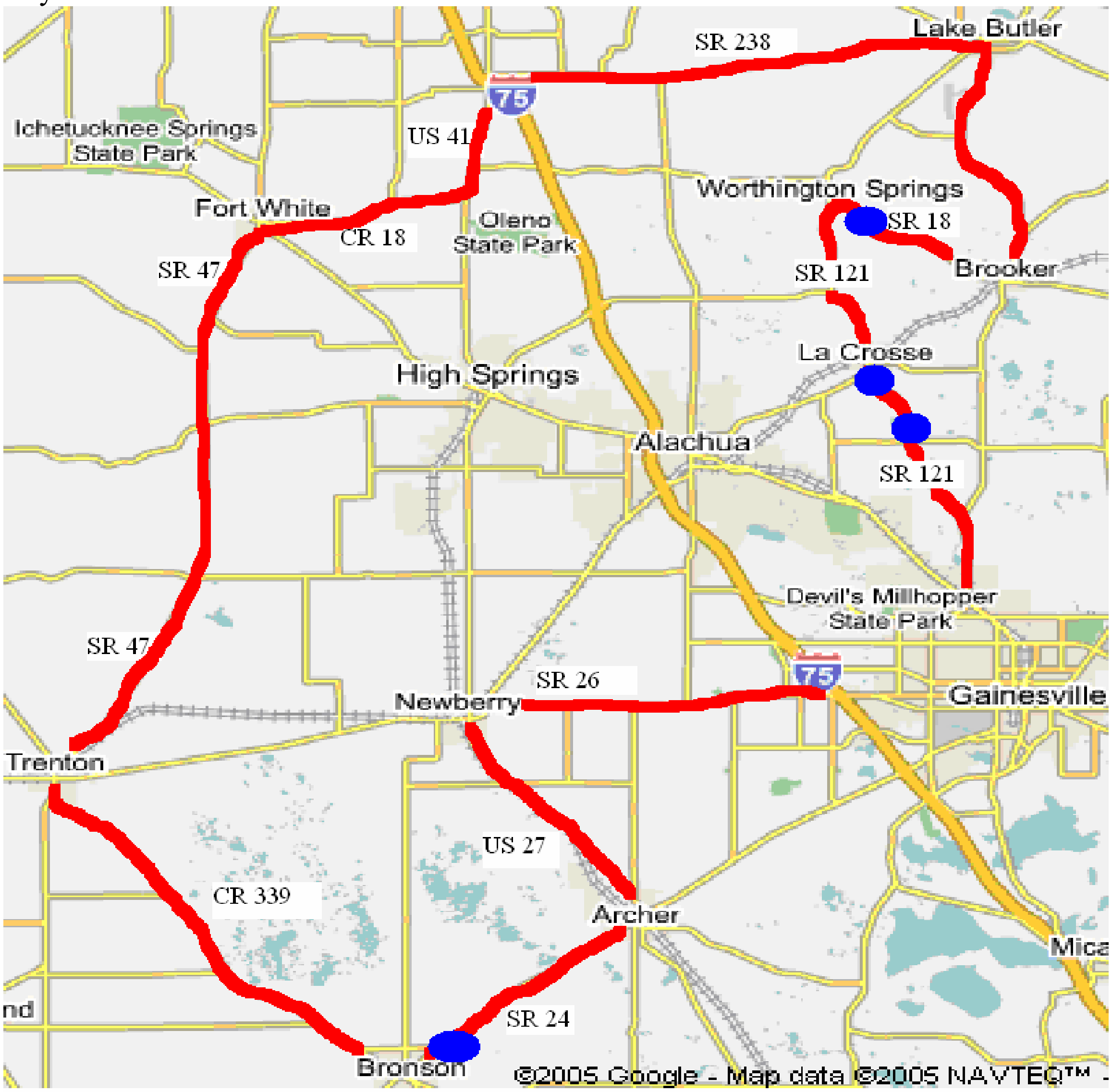
*Blue dot indicates approximate location of video clip footage

Day 2



*Blue dot indicates approximate location of video clip footage

Day 3



*Blue dot indicates approximate location of video clip footage

APPENDIX E
GAINESVILLE SUN NEWSPAPER ADVERTISEMENT

FOCUS GROUP PARTICIPANTS
Needed for a UF Transportation Study
If you are: A licensed driver at least 25 years of age and have experience driving on two-lane roadways
If you are willing to: Complete a short survey about your driving experience, participate in a 2 hour focus group session
Then you are eligible to participate In this study. You will be paid $50 for competing the study.
Please call 392-9537 ex. 1537 Leave a message with your name and contact phone #.

APPENDIX F
PRELIMINARY SURVEY FORM

CONTACT PHONE #: ________________

<u>2-Lane Highway Preliminary Questionnaire</u>

<u>Opening:</u> Hi, this is Jessica calling from the University of Florida Transportation Research Center with the Civil Engineering Department. We received your message about your interest in participating in a focus group session.

Do you have a few minutes now so I can tell you a little bit about the research project?

If yes:

These focus groups are being conducted to find out about people's opinions and perceptions of travel on 2-lane highways. Focus group participants will be shown several short video clips and then will participate in a group discussion. Participants will then be asked to complete a short survey. It will take about 2 hrs. and afterward you will receive $50 for your participation.

Are you still interested in being considered for participation in one of these focus groups?

If yes:

We are planning to hold the focus group sessions either on Saturday April 16th or Saturday April 23? Are you available for either or both of these dates?

Can you tell me about what time would you prefer to meet. Morning, mid-day or afternoon?

Now, I'd like to ask you a few demographic questions so that we can be sure that participants are a representative sample.

2. Number of years of driving experience: _________

3. Do you have experience driving on 2-lane highways?

   Yes   No   if no, thank and end call.

4. How frequently do you drive on 2-lane highways?

   Frequently   Somewhat Frequently   Not Frequently

5. Gender: Male   Female   don't ask, just record.

6. Age:

☐ 25 to 34 yrs ☐ 35 to 44 yrs ☐ 45 to 54 yrs ☐ Over 54 years

7. Marital Status:

☐ Single ☐ Married ☐ Other

8. # of Kids: _________

9. Highest level of education:

☐ High School ☐ College degree ☐ Some college

10. Is your family's total yearly income before taxes $35,000 or less, or more than $35,000?

☐ Less than $35,000 ☐ More than $35,000 ☐ Not Sure

11. Would you please tell me your race?

☐ Black/African American ☐ White ☐ Asian ☐ Hispanic ☐ Other

<u>Closing:</u>

Thank you very much for participating in our preliminary selection process. I'll be in touch with you within 7 days to let you know if you've been chosen to participate in the next phase of the study.

To facilitate that follow-up, can you please tell me:

12. Your first name:
13. Your last name:
14: Can I confirm that your telephone # is:_______________
15. Can I get your mailing address:

16. Do you have an email address where we can send you information?

Thank you, that completes the first part of the process. If you are selected to participate, we will contact you within 7 days Have a nice evening (day).

APPENDIX G
FOCUS GROUP INSTRUCTION SHEET AND SURVEY FORMS

Instruction Sheet

UNIVERSITY OF FLORIDA

TRC

Transportation Research Center

Two-Lane Trip Quality Survey

In the exercise you are about to participate in, you will be watching a series of 11 short video segments of various roadway and traffic conditions on two-lane highways. A two-lane highway is defined as a roadway that consists of one lane of travel in each direction. Two-lane highways make up a significant portion of our roadway network. While many two-lane highways can be used for regional or inter-city travel, they can also be used for local travel, providing access between other major roadways.

There are two objectives for this focus group exercise:

1. Identify the factors (e.g., traffic and/or roadway) that are most important to you in your assessment of the trip quality provided on a two-lane highway, and
2. Identify the relative differences, if any, between the importance of these factors on your assessment of trip quality for different types of two-lane highways.

The format of the focus group session will be as follows:

- Watch a video clip (each clip is approximately 1.5 to 2 minutes in length).
- Immediately following the conclusion of the video clip, the session moderator will facilitate group discussion about the conditions observed in the clip and what the important factors are for the assessment of trip quality for that roadway. Approximately 5 minutes will be allotted for the discussion of each clip.
- After the group discussion, you will write down your opinions on the survey form for the specific video clip.
- Repeat the above for each of the 11 video clips.
- Upon conclusion of the individual video clip viewings and discussions, the session moderator will facilitate a group discussion about the different types of two-lane highway classifications you observed and the relative importance of the various factors previously identified for the assessment of trip quality for each. After this discussion, you will fill out a final survey page relative to this issue.

Points to keep in mind:

- You should view each video clip from the perspective of the overall traffic stream and roadway conditions—do not focus on just the behavior of any one vehicle, either within the field of view, or the vehicle from which the video was recorded.
- The focus in the group discussion should be on the important factors to assessing trip quality, not about specific complaints with the conditions observed.
- Remember to be as specific as possible when discussing the reasons/factors that helped in forming your opinions.
- Do not consider the impacts of weather. While the weather conditions observed may vary from one clip to another, the effects of weather are beyond the scope of this study.
- Although the lighting conditions may vary somewhat, please do not factor in the environmental conditions unless you feel very strongly about a certain condition.

Thank you for your cooperation and participation.

Form 1 Section 1

UNIVERSITY OF FLORIDA

TRC
Transportation Research Center

About Yourself

Gender: ☐ Male ☐ Female

Age: ☐ 16 to 25 years ☐ 26 to 45 years ☐ 46 to 65 years ☐ Over 65 years

Marital Status: ☐ Single ☐ Married ☐ Separated/Divorced ☐ Widowed

Highest level of education:

☐ Some or no high school ☐ High school diploma or equivalent
☐ Technical college degree (A.A.) ☐ College degree ☐ Post-graduate degree

Approximate annual household income:

☐ No income ☐ Under $25,000 ☐ $25,000 – 49,999 ☐ $50,000 – 74,999
☐ $75,000 – 99,999 ☐ $100,000 – 149,999 ☐ $150,000 or more

Number of years possessing a driver's license: _________

About Your Two-Lane Highway Driving

Typical number of two-lane highway round trips made during a month?

☐ 1 to 2 ☐ 3 to 4 ☐ 5 to 6 ☐ 7 to 8 ☐ 9 to 10 ☐ 11 to 12 ☐ Over 12

Typical percentage of these trips made as a driver ______, as a passenger ______ (should sum to 100)

Typical one-way length of trip made on a two-lane highway (in miles)?

☐ less than 5 miles ☐ 6 to 10 ☐ 11 to 20 ☐ 21 to 40 ☐ 41 to 60 ☐ Over 60

Vehicle type most often used for two-lane highway trips:

☐ Sedan ☐ Sports car ☐ Pickup truck ☐ SUV ☐ Minivan
☐ Full-size van ☐ RV/Motorhome ☐ Motorcycle ☐ Other ______________

When making a trip on two-lane highway, what is your most common trip purpose?

☐ Business ☐ School ☐ Recreation ☐ Social ☐ Personal (e.g., grocery shopping)
☐ Other ________________

Typical number of passengers in vehicle for two-lane highway trips?

☐ 0 – Driver only ☐ 1 ☐ 2 ☐ 3 ☐ 4 or more

Typical driving style on two-lane highways (on a scale from 1-5, with 1 being 'Very Conservative' and 5 being 'Very Aggressive'): ________

Form 1 Section 2

Your Opinions

In the spaces provided below, please describe what you consider to be the primary indicators of the trip quality for each of the two-lane highway video clips. Please be as specific as possible when describing what you feel are the important factors used in your assessment of trip quality. Factors you should consider include traffic conditions and/or characteristics of the roadway itself.

Video Clip	Important Factors (Traffic and/or Roadway Characteristics)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

Form 2

From the list of items below, rate each item on a scale of 1 to 7 (1-not at all important, 7-extremely important) as to how that item affects the quality of your trip on a *two-lane highway*.

Item	High Speed Roadways (generally used for travel **between** cities)	Medium to Lower Speed Roadways (generally connect to higher speed roadways or are used for travel **within** cities)	Lower Speed Roadways that go through small towns (possibly with a traffic signal)	Lower Speed Roadways that ar scenic (could be coastal, or with a tree-canopy, etc.)
Ability to consistently maintain your desired travel speed				
Ability to travel at a speed no less than the posted speed limit				
Frequent passing zones (i.e., dashed yellow line)				
Frequent passing lanes				
Infrequent steep grades and/or sharp curves				
Small percentage of large commercial trucks in traffic stream				
Small percentage of large personal vehicles (pickups, vans, SUV's) in traffic stream				
Wide, paved shoulders				
Wide travel lanes				
Other (describe)				
Other (describe)				

APPENDIX H
WRITTEN SURVEY FORM RESULTS

Form 1 Results

Clip #	Comment Type	Frequency	Percentage of Comments
1	Good trip quality	2	3.4
	Good visibility, sight distance	6	10.3
	Low traffic volume, density	2	3.4
	Good passing opportunities	3	5.2
	Lane width good	2	3.4
	Shoulder and/or clearance space good	13	22.4
	Pavement quality good	5	8.6
	Positive guidance (signage, lane markings, reflectors,etc.) good	12	20.7
	Needs more positive guidance (signage, lane markings, reflectors,etc.)	6	10.3
	Posted speed limit good/appropriate	7	12.1
2	Mentioning of on-steet parking	6	15.4
	Good trip quality	1	2.6
	Shoulder and/or clearance space inadequate	5	12.8
	Positive guidance (signage, lane markings, reflectors,etc.) good	3	7.7
	Speed limit reduction warning signs needed	8	20.5
	Speed reduction as roadway approaches town too abrupt	4	10.3
	Posted speed limit in town was good/acceptable	8	20.5
	Posted speed limit should have resumed more quickly outside of town	4	10.3
3	Good trip quality	2	4.2
	Visibility not good	3	6.3
	Should be allowed to pass	4	8.3
	Should not be allowed to pass/not compelled to pass	4	8.3
	Should have designated passing lanes	2	4.2
	Lane width good/sufficient	1	2.1
	Lane width not good	3	6.3
	Shoulder and/or clearance space not good/inadequate	14	29.2
	Positive guidance (signage, lane markings, reflectors,etc.) good	2	4.2
	Wildlife crossing signs needed	3	6.3
	Posted speed limit good/appropriate	9	18.8
	Posted speed limit too high	1	2.1

Form 1 Results Continued

4	High level of activity/surrounding development	2	5.7
	No problem with having to stop for traffic signals	4	11.4
	Did not like having to stop for traffic signals	2	5.7
	Bad or poor trip quality	2	5.7
	Visibility not good	2	5.7
	Not compelled to pass	2	5.7
	Shoulder and/or clearance space not good/inadequate	3	8.6
	Did not like following larger vehicle	1	2.9
	Pavement quality good	1	2.9
	Positive guidance (signage, lane markings, reflectors,etc.) insufficient	2	5.7
	Posted speed limit in town was good/acceptable	7	20.0
	Posted speed limit in town was too slow or low	4	11.4
	Posted speed limit in town was too high	3	8.6
5	Liked safety aspect of guardrail	6	18.8
	Bad or poor trip quality	1	3.1
	Mediocre trip quality	1	3.1
	Good visibility, sight distance	2	6.3
	Following negatively affects trip quality-tailgater	3	9.4
	Good passing opportunities	3	9.4
	Shoulder and/or clearance space not good/inadequate	4	12.5
	Pavement quality bad	10	31.3
	Posted speed limit is good/adequate	2	6.3
6	Hills/terrain influence more cautious driving	1	2.3
	Negative comments about overhanging tree limbs	2	4.5
	Positive comments about the tree limbs - enhance driving quality	1	2.3
	Bad or poor trip quality	1	2.3
	Good trip quality	2	4.5
	Visibility, sight distance not good	1	2.3
	Good visibility, sight distance	1	2.3
	Lanes too narrow	3	6.8
	Shoulder and/or clearance space not good/inadequate	8	18.2
	Needs more positive guidance (signage, lane markings, reflectors,etc.)	12	27.3
	Posted speed limit is good/adequate	4	9.1
	Posted speed limit is too slow or low	6	13.6
	Posted speed limit too high	2	4.5

Form 1 Results Continued

7	Liked exclusive turn lanes at traffic signal	3	7.7
	Mediocre trip quality	1	2.6
	Good trip quality	3	7.7
	Should not be allowed to pass/not compelled to pass	3	7.7
	Lane width good/sufficient	1	2.6
	Shoulder and/or clearance space not good/inadequate	6	15.4
	Positive guidance (signage, lane markings, reflectors,etc.) good	4	10.3
	Pavement quality good	2	5.1
	Posted speed limit in town/developed area was good/acceptable	16	41.0
8	High level of activity/surrounding development/pedestrians	2	4.9
	Positive comments about scenic nature of roadway	3	7.3
	Negative comments about scenic nature of roadway - too distracting	1	2.4
	Mediocre trip quality	2	4.9
	Not compelled to pass	1	2.4
	Following negatively affects trip quality	4	9.8
	Shoulder and/or clearance space not good/inadequate	9	22.0
	Positive guidance (signage, lane markings, reflectors,etc.) good	3	7.3
	Posted speed limit is good/adequate	13	31.7
	Posted speed limit is too slow or low	1	2.4
	Posted speed limit is too high	2	4.9
9	Good visibility, sight distance	3	7.0
	Lanes too narrow	1	2.3
	Shoulder and/or clearance space not good/inadequate	8	18.6
	Shoulder and/or clearance space good	2	4.7
	Positive guidance (signage, lane markings, reflectors,etc.) good	7	16.3
	Needs more positive guidance (signage, lane markings, reflectors,etc.)	2	4.7
	Posted speed limit is good/appropriate	3	7.0
	Posted speed limit is too slow or low	17	39.5

Form 1 Results Continued

10	Good visibility, sight distance	1	2.9
	Good passing opportunities	3	8.8
	Would pass slower vehicle-does not like following at reduced speed	9	26.5
	Shoulder and/or clearance space not good/inadequate - not paved	6	17.6
	Shoulder and/or clearance space good	1	2.9
	Posted speed limit is good/adequate	11	32.4
	Posted speed limit is too high	3	8.8
11	Need for more pedestrian crossing/saftey zones and pedestrian crossing signs	10	23.8
	Does not like parking on side of roadway	4	9.5
	Mediocre trip quality	1	2.4
	Not compelled to pass	2	4.8
	Does not like vehicle following behind	1	2.4
	Shoulder and/or clearance space inadequate	2	4.8
	Positive guidance (signage, lane markings, reflectors,etc.) good	2	4.8
	Positive guidance (signage, lane markings, reflectors,etc.) insufficient	3	7.1
	Posted speed limit too high for high pedestrian activity and development	12	28.6
	Posted speed limit is good/adequate	5	11.9
12	Good trip quality	1	3.1
	Good visibility, sight distance	1	3.1
	Should not be allowed to pass/not compelled to pass	2	6.3
	Lane width not good	4	12.5
	Shoulder and/or clearance space not adequate	8	25.0
	Positive guidance (signage, lane markings, reflectors,etc.) good	1	3.1
	Pavement quality good	1	3.1
	Posted speed limit is good/adequate	8	25.0
	Posted speed limit is too high	6	18.8

Form 1 Results Continued

13	Liked exclusive turn lanes at traffic signal	2	6.3
	No problem with having to stop for traffic signals	2	6.3
	Good trip quality	1	3.1
	Should not be allowed to pass/not compelled to pass	1	3.1
	Does not like following at reduced speed	1	3.1
	Positive guidance (signage, lane markings, reflectors,etc.) good	6	18.8
	Positive guidance (signage, lane markings, reflectors,etc.) insufficient	2	6.3
	Speed reduction unclear	1	3.1
	Posted speed limit is good/adequate	14	43.8
	Posted speed limit is too high	2	6.3
14	Good trip quality	3	6.5
	Good visibility, sight distance	1	2.2
	Good passing opportunities	3	6.5
	Lane width not good	4	8.7
	Shoulder and/or clearance space inadequate	9	19.6
	No need for shoulder	1	2.2
	Pavement quality good	2	4.3
	Positive guidance (signage, lane markings, reflectors,etc.) insufficient	4	8.7
	Positive guidance (signage, lane markings, reflectors,etc.) good	2	4.3
	Posted speed limit is good/adequate	9	19.6
	Posted speed limit is too slow or low	8	17.4
15	Would like there to be exclusive turn lanes for vehicles turning off of roadway	4	9.1
	Good trip quality	6	13.6
	Good visibility, sight distance	5	11.4
	Lane width good	1	2.3
	Shoulder and/or clearance space inadequate	1	2.3
	Shoulder and/or clearance space good	3	6.8
	Positive guidance (signage, lane markings, reflectors,etc.) good	3	6.8
	Positive guidance (signage, lane markings, reflectors,etc.) insufficient	4	9.1
	Posted speed limit is good/adequate	14	31.8
	Posted speed limit is too high near the more developed area and driveways	3	6.8

Form 1 Results Continued

16	Good trip quality	1	2.5
	Did not like presence of side-parking	1	2.5
	No problem with having to stop for traffic signals	1	2.5
	High traffic volume negatively affects trip quality	4	10.0
	Does not like following at reduced speed	3	7.5
	Should not be allowed to pass/not compelled to pass	11	27.5
	Shoulder and/or clearance space good	1	2.5
	Shoulder and/or clearance space inadequate	1	2.5
	Positive guidance (signage, lane markings, reflectors,etc.) good	2	5.0
	Pavement quality good	2	5.0
	Posted speed limit is good/adequate	13	32.5

Form 2 Results

Two-Lane Highway Category or Type	Min	Max	Mean	Mode	St. Dev.	Frequency							
						1	2	3	4	5	6	7	Sum
High-Speed Roadways (generally used for travel between cities)													
Ability to consistently maintain your desired travel speed	3	7	6.1	7	1.21	0	0	2	3	1	10	18	**34**
Ability to travel at a speed no less than the posted speed limit	1	7	5.9	7	1.45	1	0	1	4	4	8	16	**34**
Frequent passing zones (i.e., dashed yellow line)	1	7	6.0	7	1.29	1	0	1	0	6	11	15	**34**
Frequent passing lanes	1	7	5.3	7	1.85	2	1	4	2	6	6	13	**34**
Infrequent steep grades and/or sharp curves	1	7	5.4	7	1.88	3	0	2	4	4	7	14	**34**
Small % of large commercial trucks in traffic stream	1	7	5.1	7	2.01	3	2	3	3	6	5	12	**34**
Small % of large personal veh. (pickups, vans,SUV's) in traffic stream	1	7	4.2	5	2.13	5	5	3	3	8	3	7	**34**
Wide, paved shoulders	1	7	5.9	7	1.77	2	0	3	0	4	4	20	**33**
Wide travel lanes	1	7	6.1	7	1.32	1	0	0	2	5	7	18	**33**
Medium to Lower-Speed Roadways (w/i cities or connects to HS)													
Ability to consistently maintain your desired travel speed	3	7	5.6	7	1.21	0	0	1	7	6	10	10	**34**
Ability to travel at a speed no less than the posted speed limit	2	7	5.5	5	1.28	0	1	2	3	10	10	8	**34**
Frequent passing zones (i.e., dashed yellow line)	2	7	5.5	7	1.31	0	1	1	5	9	8	10	**34**
Frequent passing lanes	1	7	4.9	5	1.54	1	1	5	4	9	9	5	**34**
Infrequent steep grades and/or sharp curves	1	7	4.9	7	1.91	3	2	2	6	7	5	9	**34**
Small % of large commercial trucks in traffic stream	1	7	5.1	7	1.85	2	1	5	2	9	3	12	**34**
Small % of large personal veh. (pickups, vans,SUV's) in traffic stream	1	7	4.5	5	1.96	3	4	4	2	10	4	7	**34**
Wide, paved shoulders	1	7	5.3	7	1.99	3	1	3	2	4	7	13	**33**
Wide travel lanes	1	7	5.7	7	1.55	1	1	1	3	5	9	13	**33**
Lower-Speed Roadway through Small Town (maybe w/ signal)													
Ability to consistently maintain your desired travel speed	2	7	4.91	5	1.54	0	3	4	4	12	4	7	**34**
Ability to travel at a speed no less than the posted speed limit	1	7	4.88	5	1.43	1	1	2	8	13	3	6	**34**
Frequent passing zones (i.e., dashed yellow line)	1	7	4.53	7	1.93	3	2	6	5	7	3	8	**34**
Frequent passing lanes	1	7	4.00	3	1.79	5	0	10	4	8	4	3	**34**
Infrequent steep grades and/or sharp curves	1	7	4.12	3	1.74	3	2	8	8	5	4	4	**34**
Small % of large commercial trucks in traffic stream	1	7	4.97	7	1.80	2	1	4	6	7	4	10	**34**
Small % of large personal veh. (pickups, vans,SUV's) in traffic stream	1	7	4.03	5	1.87	5	3	4	6	10	2	4	**34**
Wide, paved shoulders	1	7	4.64	7	2.03	4	2	3	5	6	5	8	**33**
Wide travel lanes	2	7	5.24	7	1.56	0	2	3	5	8	5	10	**33**
Lower-Speed Roadway that Scenic (coastal, tree canopy)													
Ability to consistently maintain your desired travel speed	2	7	4.53	4	1.58	0	4	5	9	6	5	5	**34**
Ability to travel at a speed no less than the posted speed limit	1	7	4.47	5	1.78	2	3	6	5	7	6	5	**34**
Frequent passing zones (i.e., dashed yellow line)	1	7	4.18	3	1.99	3	3	11	3	3	4	7	**34**
Frequent passing lanes	1	7	3.62	3	1.84	5	4	10	5	3	4	3	**34**
Infrequent steep grades and/or sharp curves	1	7	3.94	2	1.86	3	6	6	6	5	4	4	**34**
Small % of large commercial trucks in traffic stream	1	7	5.00	5	1.84	3	0	5	2	9	6	9	**34**
Small % of large personal veh. (pickups, vans,SUV's) in traffic stream	1	7	4.44	5	2.03	5	1	6	2	9	4	7	**34**
Wide, paved shoulders	1	7	4.42	7	2.21	5	2	7	1	5	4	9	**33**
Wide travel lanes	1	7	4.76	5	1.90	2	3	5	2	8	5	8	**33**

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Task 3

A Methodology for the Operational Performance Assessment of Two-Lane Highway Facilities

A Methodology for the
Operational Performance Assessment of
Two-Lane Highway Facilities

Table of Contents

CHAPTER 1
INTRODUCTION

1.1 Background

Two-lane highways, which account for approximately 80 percent of all paved rural highways in the United States, and carry about 30 percent of all traffic, are important facilities in our transportation network system [1]. With the increased development in rural areas, more signals are being installed on two-lane highways typically when these highways travel through a small town. Additionally, there are a number of other design and operational treatments developed on extended lengths of two-lane highways, such as passing lanes, two-way stop-controlled intersections, driveway turnouts, two-way left-turn lanes, etc. They can be effective in alleviating some operational problems on two-lane highways.

Because these design and operational treatments significantly affect traffic operations on two-lane highways, there is ongoing demand for analysis methodologies with which to analyze the operating effectiveness of the entire length of two-lane highway, that is, the facility as a whole. This is consistent with the fact that drivers typically evaluate the quality of their trip over its entire length, not just in separate pieces.

1.2 Problem Statement

Personnel with the FDOT Systems Planning Office have indicated that a facility-based evaluation methodology for two-lane highways would be much more useful to them than just the individual segment and point analysis methodologies. A facility level analysis will allow the various features (e.g., isolated intersections, continuous grades, passing lanes) that are typical to an extended length of two-lane highway to be addressed in a combined analysis with a single performance measure and level of service value resulting.

Frequently, a traveler is less concerned about the quality of service offered by a particular segment than the service over a facility that may be served by more than one segment type. For example, on a two-lane highway with several isolated intersections, most travelers are concerned about the operation of the whole facility and not just the operation of a particular intersection, or a particular two-lane highway segment.

From the view point of travelers or transportation engineers, a facility level analysis on a two-lane highway facility, instead of the segment level, is more practical and meaningful. Currently, there is not any operational analysis methodology to address two-lane highways with different segment types at the facility level.

In the Highway Capacity Manual (HCM) 2000 [1], the basic two-lane highways with or without passing lane can be evaluated with the methodology in Chapter 20, *Two-Lane Highways*. Isolated signalized intersections on two-lane highways can be evaluated with the methodology in Chapter 16, *Signalized Intersections*. The scope of analysis provided in the HCM 2000 for two-lane highways is mainly limited to separate segments within the facility, while the methodology to evaluate the facility as a whole is of much more practical value to transportation engineers.

In the HCM 2000, Chapter 15, *Urban Streets,* presents the methodology for evaluating arterials in urban and suburban areas with multiple signalized intersections at a spacing of 2.0 miles or less. To some degree, the analysis procedure is performed at the facility level, which combines the segment running time and control delay at the signalized intersection when determining the performance measure (average travel speed) for the entire facility. However, this methodology has some obvious drawbacks. They are:

1. The potential impacts between roadway segments and signalized intersections are not taken into account in this methodology. Continuing research has shown that the installation of signalized intersections can significantly affect traffic operations on the two-lane highways, such as decreasing average travel speed, and increasing percent time-spent-following. The impact between different segment types is a big issue differentiating the facility-level analysis from the segment-level analysis.

2. Segment division introduces error due to the segment between intersections being longer than they should. In this methodology, the urban street is divided into multiple segments, which is the full distance from one signalized intersection to the next. The signalized intersection is regarded as a typical point location within a traffic network, and control delay is regarded as a typical point performance measure without covering any distance. In the HCM 2000 [1], by definition, control delay includes movements at slower

speeds and stops on intersections approaches as vehicles move up in queue position or slow down upstream of an intersection, as well as delay due to re-acceleration downstream of a signal after stopping or slowing. It implies that control delay happens not at a point, but actually within a certain distance. Although the time lost due to slow movement before and after a stop, is technically part of the running time, it is also included in control delay. Segment division in this methodology causes the problem of double-counting the deceleration-acceleration delay.

In this proposal, a methodology for the operational performance assessment of two-lane highways with isolated signalized intersections (Spacing of signalized intersection is 3 miles or more) will be explored, in addition to a way to combine a number of different segments (passing lanes, basic segment, etc.).

1.3 Objectives and Tasks

The objective of this research is to develop a methodology that can be used to assess the operational performance of an extended length of a two-lane highway facility, one which might include an occasional signalized intersection and other control or roadway treatments. This two-lane highway would then be comprised of multiple segments, with segment delineations occurring with a change in either roadway or control attribute. The most common types of two-lane highway segments are:

- Basic segment—this is a segment that consists of a simple two-lane cross section, either level or rolling terrain
- Basic segments with a continuous specific up or down grade
- Three-lane cross section segments, with the additional lane being a passing lane
- Three-lane cross section segments, with the additional lane being a center left-turn lane
- Three-lane cross section segments, with the additional lane being a right-turn only lane
- Segments terminating with an isolated signalized intersection
- Segments terminating with an un-signalized intersection
- Segments terminating into a multilane highway

This research focuses the efforts on developing the methodology for operational analysis of a two-lane highway with an isolated signalized intersection at the facility level. Nonetheless, it is intended that this research will also provide a model for the basic structure of a facility level analysis that will be amenable to the incorporation of a variety of segment types. The tasks required to accomplish the research study objectives are as follows.

Task 1: Perform a literature review on current analytical and simulation methods for evaluating the performance of basic two-lane segments and signalized intersections, along with previous research on the effects of signalized intersections on a two-lane highway.

Task 2: Define the basic conceptual framework, from a segmentation and service measure perspective, for combining two-lane highway segments with intersections into a facility-wide of the operational analysis.

Task 3: Investigate traffic operations at the boundary of a two-lane segment and a signalized intersection (upstream of the signal) and develop an equation/method that can be used to determine the effective length of the signal's influence area upstream of the signal.

The conceptual approach being taken is that the effective upstream length of the signal's influence area is a function of average queue length on the approach to the signal and some portion of perception/reaction time and braking distance before the queue. The combination of the stopping sight distance (SSD) equation, from the AASHTO "Green Book", and average queue length formulas from Chapter 16 of the HCM 2000 are compared to simulation output from CORSIM. A comprehensive experimental design for simulation will be utilized to fully explore the relationship between influence area and the appropriate traffic and control variables. These results are reconciled against those from the SSD + Average Queue Length results to arrive at an appropriate relationship.

Task 4: Investigate traffic operations downstream of a signalized intersection and develop an equation/method that can be used to determine the effective length of the signal's influence area downstream of the signal.

The conceptual approach being taken is that the effective downstream length of the signal's influence area is a function of vehicle re-acceleration and platoon dispersion. Thus, three areas are being investigated:

- Simple vehicle dynamics equations related to vehicle acceleration

- Platoon dispersion downstream of a signal, such as the model currently used in the TRANSYT-7F program.
- Changes in the vehicle headway distribution due to the presence of a signal on downstream traffic operations. Previous work performed by Dixon et al. [7] related to this issue is investigated, with two main differences being:
  - A composite headway distribution model is used for headways instead of a simple negative exponential model, and
  - The EPF (Entering Percent Following) measure as used by Dixon et al. is related to downstream vehicle speeds.

Task 5: Join the components (basic two-lane segment, upstream signal influence area, signal delay, and downstream signal influence area) into an integrated methodology for the operational analysis of a two-lane highway facility. This methodology will be predicated upon the use of an aggregated percent-time-delayed measure as the facility-wide service measure. As part of this, two example problems are presented.

Task 6: Determine LOS thresholds that maintain a reasonable relationship with existing LOS thresholds in Chapter 20 (two-lane highways) of the HCM 2000. For example, with the use of a new service measure for the facility analysis, it should not be possible to get a better level of service for the two-lane highway when installing a signal compared to the previous LOS method.

Task 7: Provide a qualitative overview of how the method of analysis for multilane highways might be modified to fit into this framework such that combinations of two-lane highway segments, multilane highway segments, and occasional traffic signals can be analyzed as an overall facility.

CHAPTER 2
OVERVIEW OF ANALYSIS METHODS

This chapter summarizes current methodologies for evaluating the operational performance of basic two-lane segments, and signalized intersections. It also provides a brief overview of the TWOPAS, TRARR, and CORSIM simulation models and their potential ability to contribute to the performance evaluation for the two-lane highway facility. Finally previous research on effects of signalized intersections on a two-lane highway segment is presented.

2.1 Analytical Methods

The following sections give an overview of analytical methodologies presented in the HCM 2000. They are for two-lane highways, signalized intersections, and urban streets. Finally the adjustment method used in the FDOT HIGHPLAN software for the facility level analysis is presented.

2.1.1 HCM Methodology for Two-Lane Highways

The Highway Capacity Manual (HCM) published by the Transportation Research Board (TRB) presents the widely accepted standards for analysis of two-lane highway capacity and quality of service.

In the 1950 HCM [1], the first version of HCM, the procedure for analysis of two-lane highway capacity developed by O. K. Norman was presented. The capacity of a two-lane road was determined by comparing the demand for passing with observed actual passing rates at various flow rates. In the subsequent editions of 1965, 1985, and 2000 [1], the capacity and quality-of-service analysis procedure of a two-lane highway and their related service measures were revised. In the 1965 HCM, the capacity of a two-lane highway was estimated for both directions of travel combined, regardless of the direction split of traffic, and the two service measures for the operational analysis were: the operating speed of traffic over a roadway section and the volume-to-capacity ratio. A great improvement in analysis of two-lane highway capacity and quality of service was achieved in the 1985 HCM. The capacity of a two-lane highway was determined to be a function of the directional split of traffic, ranging from a capacity of 2800 pc/h in both directions of travel combined for a 50/50 directional split to 2,000 pc/h for a 100/0 split. In this version, a new level of service measure named "percent time delay" was developed. Percent time delay is measured as the percentage of vehicles traveling at headway of 5 sec or less at one or more representative points within the section.

In Chapter 20 of the HCM 2000, an improved operational analysis procedure for two-lane highway was presented. Key features of the improved operational analysis procedure are revised factors for the effects of grades and heavy vehicles, separate computational procedures for two-lane and directional segments, provision of operational analysis procedures for passing lanes in level and rolling terrain, climbing lanes on steep upgrades, and steep downgrades on which some trucks must use crawl speeds [1]. The combination of average travel speed and percent time-spent-following was determined as the level of service measure (i.e. the performance measures used to base level of service upon).

The above discussion reviews the historical development of the HCM procedure for analysis of two-lane highway capacity and quality of service. The analysis procedure has been limited to the segment level. The operational analysis methodologies in this chapter do not address two-lane highways with signalized intersections.

2.1.2 HCM Methodology for Signalized Intersections

In the HCM 2000, Chapter 16 "*Signalized Intersections*" contains a methodology for analyzing the capacity and level of service of signalized intersections [1]. The methodology addresses the capacity, LOS, and other performance measures for lane groups and intersection approaches and the LOS for the intersection as a whole. The ratio of demand flow rate to capacity is used as a capacity utilization measurement. The capacity analysis methodology for signalized intersections is based on known or projected signalization plans, and traffic characteristics. The control delay per vehicle is used as the service measure. In this methodology, the signalized intersection is regarded as an isolated point location. It does not take into account the potential impact of downstream congestion on intersection operation.

2.1.3 HCM Methodology for Urban Streets

In the HCM 2000, Chapter 15 "*Urban Streets*" contains a methodology used to access the mobility function of the urban street [1]. Four urban street classes are defined and reflect unique combinations of street function and street design. The degree of mobility provided is assessed in terms of average travel speed for the through-traffic stream. Computing the urban street or section speed requires the total time that a vehicle spends on the urban street. The total time consists of the segment running time and the intersection control delay of the lane group for through traffic.

The methodology may be used to analyze urban streets that have a traffic signal spacing of 2 miles or less. To some degree, the analysis procedure is performed at the facility level, which combines the segment running time and control delay at the signalized intersection when determining the performance measure (average travel speed) for the entire facility. However, the potential impacts between roadway segments and signalized intersections are not taken into account in this methodology. For example, the running time for a segment is considered to be from the stop line of one signalized intersection to that of the next signalized intersection, not to the back of a queue. In addition, an assumption in this methodology is that traffic signals are spaced 2 miles or less apart. The potential impacts between adjacent intersections are also not taken into account.

2.1.4 FDOT HIGHPLAN Software

HIGHPLAN, designed for uninterrupted flow highway level of service analysis for planning applications, is FDOT's software for two-lane and multilane uninterrupted flow highways [2]. HIGHPLAN maintains fidelity to the HCM 2000 two-lane and multilane procedures to the extent possible. However due to some unique characteristics in the State of Florida, HIGHPLAN incorporates a number of concepts and calculations that differ significantly from the basic procedures in the HCM 2000.

HIGHPLAN includes an adjustment to account for whether the analysis is at the segment level or the facility level. If a segment level analysis is performed, it is assumed that the highway section under consideration is short enough that it does not include any capacity reducing effects due to the presence of intersecting driveways or cross streets. If a facility level analysis is chosen, a 10% reduction is applied to the base capacity to account for driveway and cross street friction. This value is consistent with the capacity reducing effects of interchanges experienced on Florida freeways [3]. Nonetheless, this is a gross adjustment necessitated by the lack of a specific facility-level methodology.

2.2 Simulation Methods

The following section provides a brief overview of the TWOPAS, TRARR and CORSIM simulation models and their potential ability to contribute to the performance evaluation for the two-lane highway operations.

2.2.1 TWOPAS Software

TWOPAS (TWO-lane PASsing") rural highway simulation software is used for modeling traffic conditions on two-lane two-way roadways. This software was used extensively in developing the two-lane analysis methodology in the HCM 2000.

TWOPAS was first developed in the 1970s by Mid-West Research Institute for the US Federal Highway Administration (FHWA). TWOPAS was revised most recently in 1998, and was contained in a graphic interface, UCBRURAL, developed by the University of California-Berkeley. UCBRURAL provides a menu-driven interactive graphical interface with comprehensive input checking, carefully selected default values, and user-selected output options including graphic depictions of traffic performance, which is more convenient for users to run TWOPAS model. Figure 2-1 shows a view of the UCBRURAL road editor. Recently the TWOPAS traffic simulation model is built in the Traffic Analysis Module (TAM) of the Interactive Highway Safety Design Model (IHSDM) to estimate traffic quality-of-service measures for an existing or proposed design. The TAM facilitates use of TWOPAS by feeding it the roadway geometry data stored by IHSDM. Figure 2-2 shows a view of TAM input interface in IHSDM.

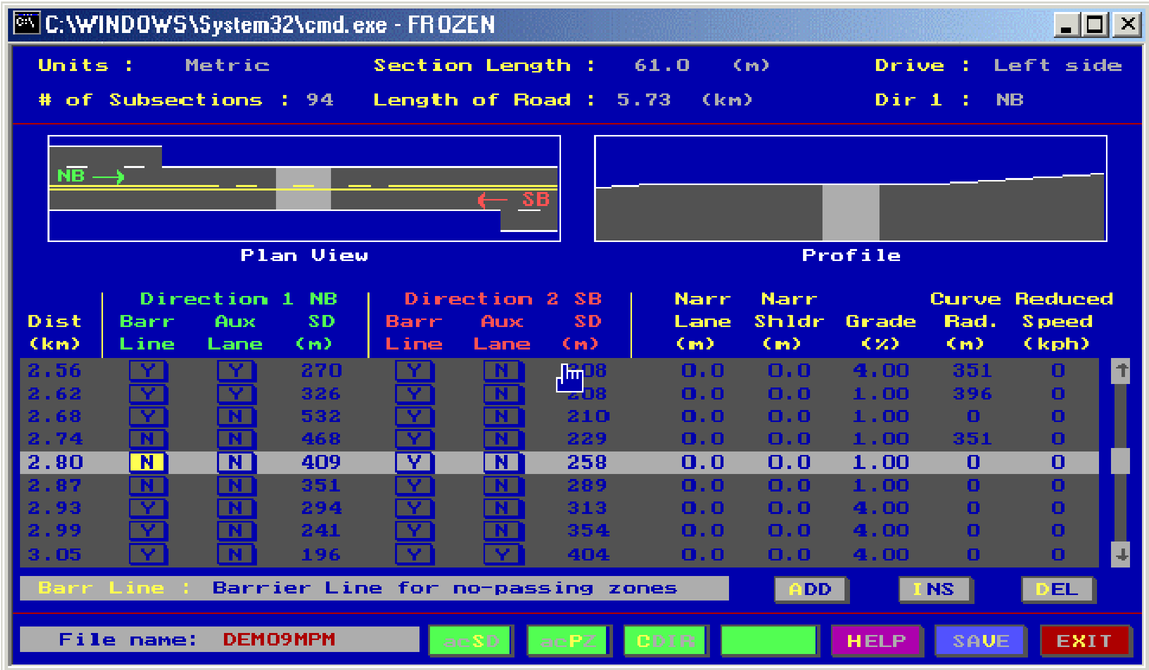

Figure 2-1: Screenshot from TWOPAS Road Editor

As a microscopic, stochastically based model, TWOPAS simulates traffic operations on a two-lane highway by reviewing the position, speed, and acceleration of each individual vehicle along the roadway at 1-second intervals. The operation of each vehicle is also influenced by the characteristics of the vehicle and its driver, by the geometrics of the roadway, and by the surrounding traffic simulation in a realistic manner as it advances along the road [4]. TWOPAS incorporates the major features:

- Highway Geometry specified in terms of grades, horizontal curves, lane and shoulder width, along with passing and climbing lanes.
- Traffic control specified by users, especially passing and no-passing zones, and reduced speed zones.
- Vehicle Characteristics including vehicle length, vehicle acceleration, and speed capabilities.
- Driver Characteristics and preferences including desired speeds, preferred acceleration levels, limitations on sustained use of maximum power, passing and pass-abort decisions, and realistic behavior in passing and climbing lanes.
- Entering Traffic streams generated in response to user-specified flow rate, vehicle mix, immediate upstream alignment, and the percent of traffic platooned.

- Driver speed choices in unimpeded traffic based on user-specified distribution of desired speeds; in the impeded traffic based on a car-following model that simulates driver preferences for following distances, relative leader/follower speeds, and desire to pass the leader [4].

TWOPAS has the capability to simulate both conventional two-lane highways and two-lane highways with added passing lanes. However, TWOPAS does not have the ability to simulate traffic turning on or off the highway at driveways, un-signalized intersection, or signalized intersections.

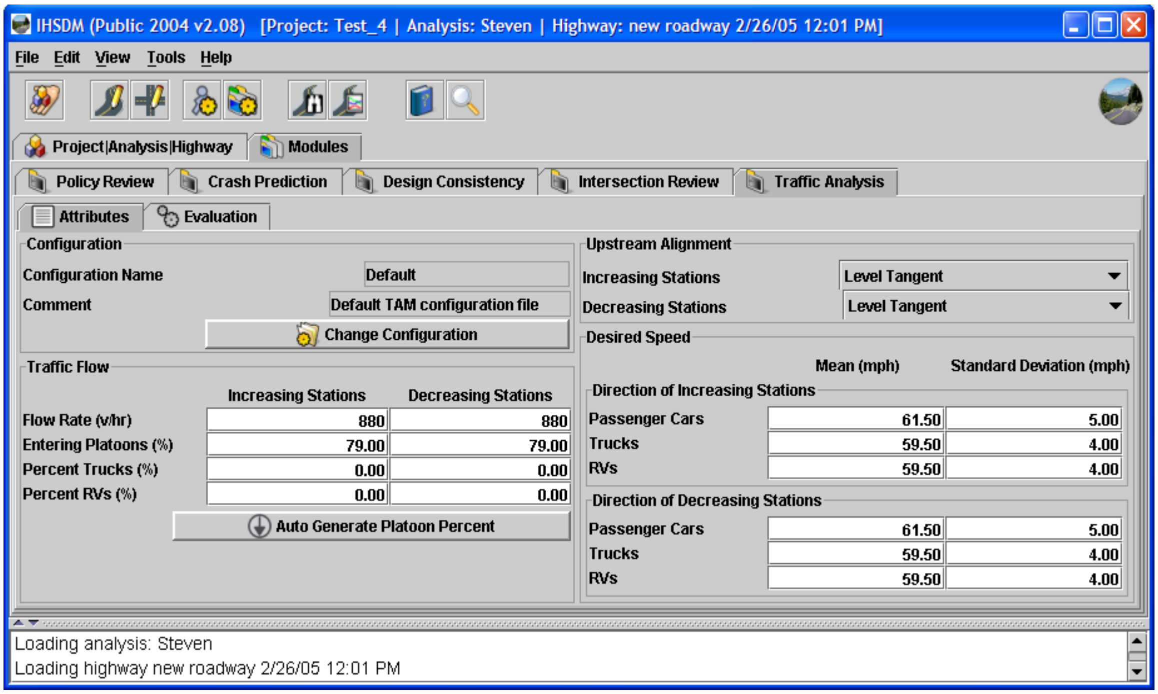

Figure 2-2: Screenshot from Traffic Analysis Module of IHSDM

2.2.2 TRARR Software

TRARR (TRAffic on Rural Roads) was developed in the 1970s and 1980s by the Australian Road Research Board. TRARR is designed for two-lane rural highways, with occasional passing lane sections. It is a micro-simulation model; i.e. it models each vehicle individually. Each vehicle is randomly generated, placed at one end of the road and monitored as it travels to the other end. Various driver behaviors and vehicle performance factors determine how the vehicle reacts to changes in alignment and other traffic. TRARR uses traffic flow, vehicle performance, and highway alignment data to establish, in detail, the speeds of vehicles along rural roads. This determines the driver demand for passing and whether or not passing maneuvers may be executed [6]. Figure 2-3 shows an interface of TRARR road editor.

TRARR is designed for two-lane rural highways, with occasional passing lane sections. TRARR can be used to obtain a more precise calculation of travel time, frustration (via time spent following), and VOC benefits resulting from passing lanes or road realignments. For strategic assessment of road links, TRARR can also be used to evaluate the relative benefits of passing lanes at various spacing.

Similar to TWOPAS, TRARR has no ability to handle varying traffic flows down the highway, particularly due to major side roads or signalized intersections. However, TWOPAS was developed with U.S. data and, therefore, was thought to be better representative of U.S. conditions than TRARR.

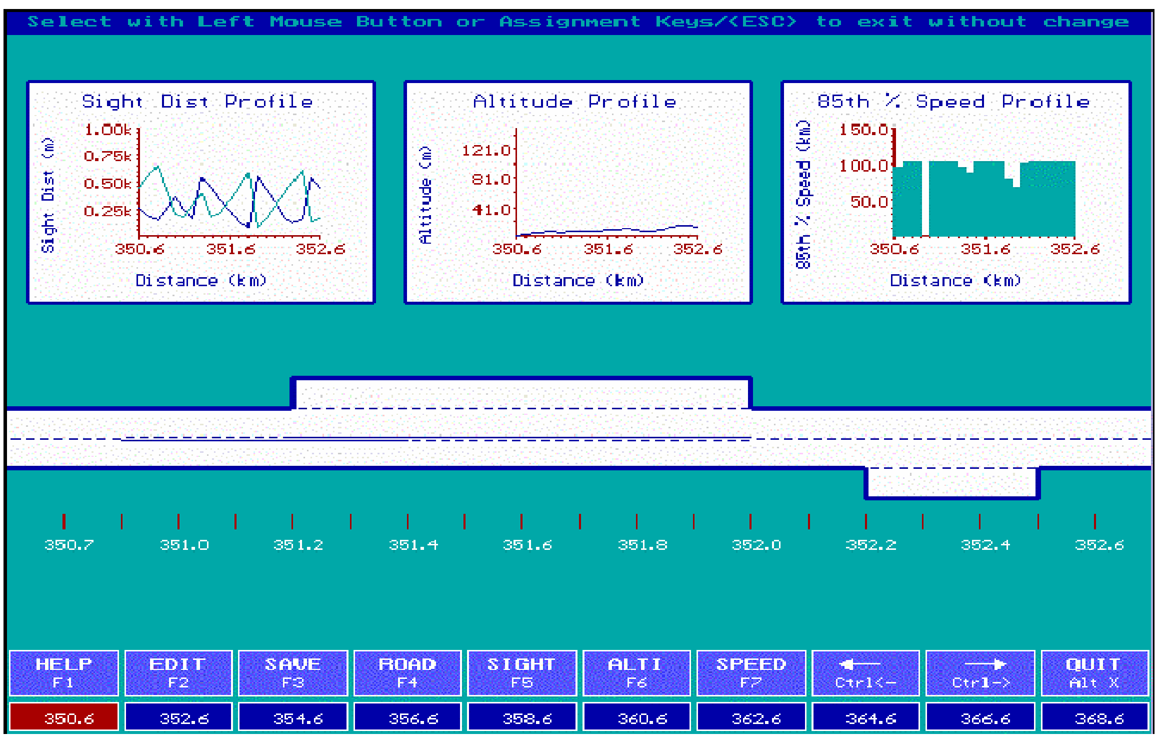

Figure 2-3: Screenshot from TRARR Road Editor

2.2.3 CORSIM Software

CORSIM (CORridor SIMulation), developed by the Federal Highway Administration, is the core simulation engine in the TSIS (Traffic Software Integrated System) suite [5]. CORSIM is a comprehensive traffic simulation program, applicable to surface streets, freeways, and integrated networks with a complete selection of control devices, such as stop/yield signs, traffic signals, and ramp metering. CORSIM is a microscopic, discrete time, stochastic, "state-of-the-practice" model used to simulate traffic operations. It integrates two microscopic traffic simulation models: the arterial network model, NETSIM, and the freeway model, FRESIM. CORSIM is able to simulate existing or proposed conditions on very large networks. CORSIM has been applied by thousands of practitioners and researchers worldwide over the past 30 years and embodies a wealth of experience and maturity [5]. Figure 2-4 shows an interface simulating traffic operations at a signalized intersection.

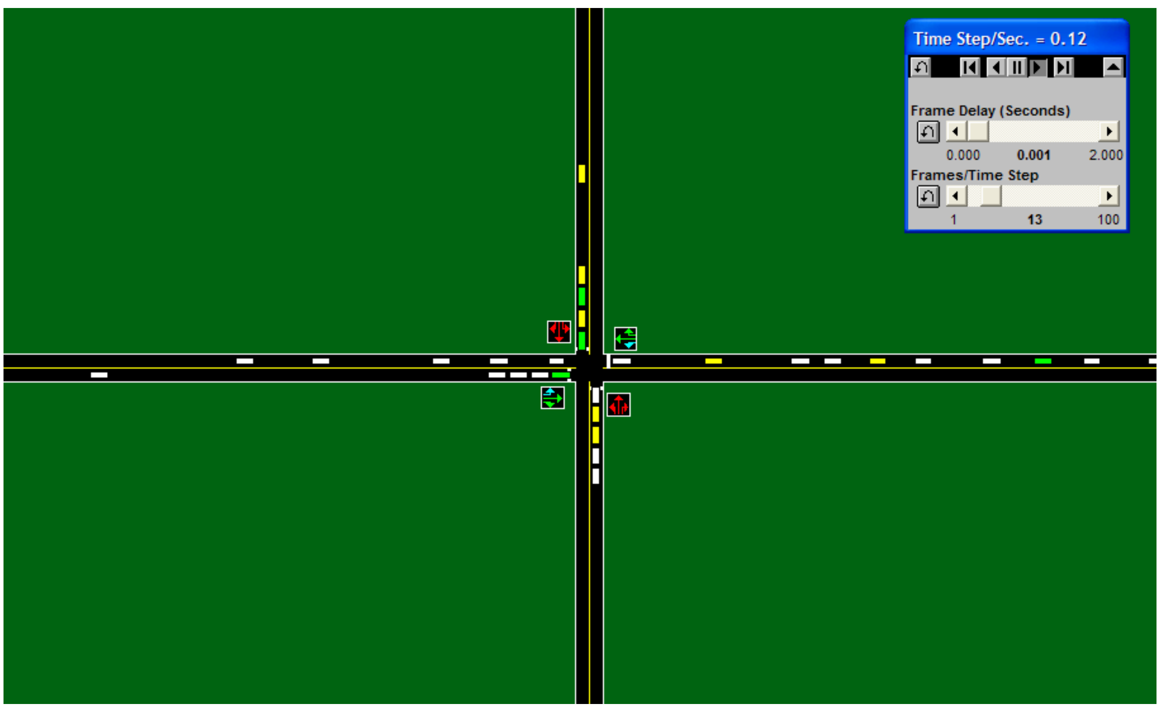

Figure 2-4: Screenshot from CORSIM Simulation Animation (TRAFVU)

CORSIM has expanded the capabilities of NETSIM and FRESIM with the following major enhancements:

- HOV lanes in FRESIM

- Freeway ramp metering
- Vehicle-type-specific turn percentages
- Support Larger Networks
- Path Following Capacity

CORSIM can simulate traffic and traffic control system using commonly accepted vehicle and driver behavior models. However, it does not have the ability to simulate vehicle passing operations on a two-lane highway using the opposing lane.

2.3 Effect of Upstream Signal on Two-Lane Highway PTSF

Dixon et al. [7] developed a methodology to estimate the effects of a simple isolated signalized intersection on a downstream two-lane highway segment in terms of percent time-spent-following. In their research, the potential effect of an upstream signalized intersection on the two-lane highway segment was to modify the distribution of entering headways. The condition with no signalized intersection is represented by assuming the negative exponential distribution of headways for entering traffic, which is derived from the Poisson distribution for random arrivals. However, the upstream signalized intersection will modify the headway distribution of the traffic stream entering the downstream two-lane highway segment.

In TWOPAS, the distribution of headways is defined through the input variable, Entering Percent Following (EPF), which is the percent of the total number of vehicles in the direction of travel that are following in platoons, defined as headways less than 3.0 seconds, as they enter the road being analyzed. In Dixon et al.'s research, it was assumed that as long as the percentage of vehicles following, immediately downstream of the signalized intersection, could be determined, it was appropriate to represent the effects of the signalized intersection through the EPF parameter. Vehicle headways were assumed to follow a random distribution, and EPF was calculated using a cumulative exponential distribution of headways less than 3.0 seconds.

The analysis procedure of two-lane highway segment affected by the upstream signalized intersection operations was broken down into four steps.

Step 1: Determine the percentage of vehicle following (EPF) downstream of the signalized intersection.

Step 2: Determine the *PTSF* for the downstream highway section without the upstream signalized intersection.

Step 3: Estimate the *PTSF* for the downstream highway section with the upstream signalized intersection. In this step, two methods can be used. One method is using TWOPAS and another method is using the HCM 2000 two-lane highway directional analysis procedures and deterministic adjustment factors.

Step 4: Estimate the level of service based on the criteria suggested in the HCM 2000 two-lane highway analysis procedure.

CHAPTER 3
CONCEPTUAL OVERVIEW OF TWO-LANE HIGHWAY FACILITY ANALYSIS METHODOLOGY

This chapter describes the development of operational analysis procedures for two-lane highway facilities. The developed methodology would maintain some fidelity to the Highway Capacity Manual by using the existing methodologies for two-lane highway segments and signalized intersections. The following discussion explains the development of these procedures.

This chapter begins with a discussion of the conceptual framework of the operational analysis procedure for a two-lane highway facility. It then puts forward a methodology of operational analysis for two-lane highway facilities and presents an overview of this methodology. Finally, the chapter discusses the selection of a facility-wide service measure and the first step of this methodology—facility segmentation.

3.1 Conceptual Framework for Facility Evaluation Methodology

To develop a methodology for the operational analysis of a two-lane highway facility, a two-lane highway with an isolated signalized intersection will be used as a model. This section discusses the conceptual framework of the operational analysis procedure for such a configuration. Aspects of the conceptual framework addressed are the definition of the two-lane highway facility, segment types, the features of operational analysis at the facility level, and the proposed methodologies.

3.1.1 The Definition of a Two-Lane Highway with Signalized Intersections

In the HCM 2000, the primary highway system structure consists of points, segments, facilities, corridors and areas. A facility is a length of roadway composed of points and segments. A point is a boundary between segments, in the other words, points are where modal users enter, leave, or cross a facility, or where roadway characteristics change. A segment is a portion of a facility defined by two end points. Segments are the primary building blocks of facility analyses. In addition, a sub-segment is a further breakdown of a segment. Although segments are the primary building blocks of facility analyses, at times it is desirable to subdivide them into smaller units. For example, an isolated signalized intersection on the two-lane highway produces operation effects on the upstream segment. The upstream two-lane highway segment can be divided into the upstream sub-segment within the effective length of the signalized intersection, and the upstream sub-segment beyond the effective length of the signalized intersection.

The potential segment types on a two-lane highway could include the following:

- Basic segment, this is a segment that consists only of a two-lane across section. Figure 3-1 shows a typical view of this type of segment.

Figure 3-1: Typical Basic Two-Lane, Two-Way Highway Segment

- Basic segment with continuous specific upgrade or downgrade
- Three-lane cross section segment, with the additional lane being a passing lane. Figure 3-2 shows a typical view of this type of segment.
- Segment with an un-signalized intersection. Figure 3-3 shows a typical view of this type of segment.

Figure 3-2: Typical Two-Lane, Two-Way Highway with a Passing Lane

Figure 3-3: Typical Two-Lane, Two-Way Highway with an Un-signalized Intersection

- Three-lane cross section segment, with the additional lane being a center left-turn lane
- Three-lane cross section segment, with the additional lane being a right-turn only lane
- Segment terminating into a multilane highway
- Segment with an isolated signalized intersection

A two-lane highway with signalized intersections is a kind of facility composed of isolated signalized intersections, and the basic two-lane highway. A two-lane roadway generally extends from one signalized intersection to the next signalized intersection. This kind of facility is typically located in a rural area, but the signal may be present in a small town. Figure 3-4 shows a typical view of a two-lane highway with a signalized intersection. The main features are as follows:

- Roadside development is not intense
- Density of traffic access point is not high
- Signalized intersections are more than 2 miles apart
- These conditions result in a smaller number of traffic conflicts, smoother flow, and dissipation of the platoon structure

Figure 3-4: Typical Two-Lane, Two-Way Highway with a Signalized Intersection

3.1.2 Service Measure Consistency

LOS is a qualitative designation of the operational conditions within a traffic stream based on performance measures such as speed, travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Six levels of service are defined in the HCM, using the letters A through F for each type of facility, where A is good, and F is bad. The performance measure chosen to base LOS upon is referred to as a service measure. For application in the segment LOS analysis, every type of segment has its own service measure based on to determine its LOS.

When performing the facility-level operational analysis, occasional inconsistencies can arise because of different service measures being applied. For example, in the two-lane highway with an isolated intersection, the combination of average travel speed and percent time-spent-following is used as the service measure to evaluate the level of service on the basic two-lane highway segment, however the service measure for a signalized intersection is based on control delay. In the HCM 2000, the measure of operational quality used for point locations is not related to highway segment. Thus, anomalies are possible when changing from one facility type to another.

So how to solve the conflicts of different service measures is a key issue in the development of operational analysis for the two-lane highway at the facility level. There are basically two methodological approaches that can be taken for an operational analysis of a facility composed of different types of segment. They are:

1. Each segment uses the service measure(s) already specified for it in the HCM 2000. The LOS of the entire facility is determined by combining the LOS of each segment in some manner.
2. A common service measure is used for each segment and point. LOS of the entire facility is determined by the aggregated service measure.

With the first methodology, no unified facility-wide service measure is applied for the segments of the entire facility. Each segment or point uses its own service measure(s) defined in the HCM 2000. Because of different service measures (e.g., ATS, PTSF, or control delay) being applied, inconsistencies can arise. For example, when determining the level of service of a two-lane highway with multiple signals, the combination of average travel speed and percent time-spent-following is used as the service measure to evaluate the level of service on an uninterrupted flow two-lane highway segment; however the service measure for a signalized intersection is based on control delay. Thus, anomalies are possible when changing from one segment type to another.

Another drawback of this methodology is the aggregation of the point and segment LOS grades into an estimate of the LOS grade for the entire facility. In the HCM 2000, the measure of operational quality used for point locations is not related to highway segments. It is very difficult to combine the LOS of points with that of segments. Equation 3-1 gives an example method of aggregating the LOS grades of segments and points weighted by the segment length.

$$LOS = \frac{\sum_{i=1}^{n} LOS_i L_i}{\sum_{i=1}^{n} L_i} \qquad (3\text{-}1)$$

Where:

LOS: the level of service of the entire facility,

LOS_i: the level of service of segment i,

L_i: the length of segment i, ft, and

n: the number of segments.

With this approach, segment LOS values are weighted by the segment length; however, LOS is not a quantitative value. It is simply a measure of user satisfaction for that service along the roadway. It is difficult to accurately convert the LOS grade into the corresponding numerical value for aggregation. Even though a certain conversion method is available, because each segment type has its own strategy to determine the LOS, every segment type needs a unique conversion method, which makes the LOS combination method somewhat complicated and possibly subjective.

In the HCM 2000, Chapter 15, the average travel speed is used as the service measure on the urban street with multiple signalized intersections at a spacing of 2.0 miles or less. The method using a common service measure for a facility consisting of multiple different segment types is a good reference. In the second methodology, a common service measure would be applied to every segment of the entire facility. The service measures at each segment are aggregated to obtain an estimate of service measure for the entire facility. The

LOS of the entire facility is determined by this aggregated service measure. The unified facility-wide service measure not only avoids many disadvantages of the application of multiple service measures, but also provides a Measure of Effectiveness (MOE) describing traffic operations in terms discernible by motorists from the scope of the entire facility.

The proposed second method would also maintain some fidelity to the Highway Capacity Manual by using the existing methodologies for two-lane highway segments and signalized intersections. For the two-lane methodology (HCM Chapter 20), the method for calculation of average travel speed (*ATS*) is utilized; however, percent time-spent-following (*PTSF*) is not utilized. For signalized intersections (HCM Chapter 16), the current method for the calculation of control delay is utilized.

By using a time/delay based service measure, this method will be similar to the current HCM methodology for urban streets. For transportation agencies looking to analyze the impacts of adding a lane (or lanes) to a two-lane highway, along with adding some signalized intersections, thus possibly changing the classification to a urban arterial in some sections, this will provide for consistency in the analyses (assuming the LOS thresholds are set accordingly). This methodology will be completely presented and explained in Section 3.2.

3.1.3 Impacts of Signalized Intersection on Adjacent Highway Segments

Another important issue in the development of an operational analysis at the facility level is the impacts with different segment types. Continuing research has shown that installing a signalized intersection on a two-lane highway can produce effects on traffic operations of the upstream and downstream two-lane highway segment.

To illustrate the potential effects of an isolated signalized intersection on the two-lane highway operation, CORSIM and TRANS-7F programs are used to simulate the operations of a two-lane highway with an isolated signalized intersection.

3.1.3.1 Effects of Intersections on the Upstream Two-Lane Highway Operation

When vehicles approach the signalized intersection facing a red signal indication, drivers will safely sop their vehicles with sufficient sight distance to avoid entering the intersection or colliding with queued vehicles. Here CORSIM is used to model the variation of average travel speed as vehicles are near to the upstream signalized intersection.

Six CORSIM simulations are made with 30 replicate runs for each. This is a preliminary simulation experiment. The six conditions are as follows:

Table 3-1: Traffic Simulation Conditions:

	Traffic Volume (veh/h)	With or Without Signal
1	600	With
2	600	Without
3	1000	With
4	1000	Without
5	1400	With
6	1400	Without

The operational effects of a signalized intersection on the two-lane highway based on average travel speed are shown in Figure 3-5. This figure is directly derived from preliminary simulation runs. Figure 3-5 shows a comparison of the modeled average speed as it varies along a two-lane highway with an isolated signalized intersection and with no isolated signalized intersection under different traffic flow levels. As seen in Figure 3-5, on the two-lane highway segment upstream of the signalized intersection, when vehicles enter the basic two-lane highway segment, the difference in the values of average travel speed is very small. The average travel speeds along the two-lane highway with an isolated signalized intersection are very much in agreement with those with no isolated signalized intersection. When near to the signalized intersection (about 1000 ft before the stop line of signalized intersection), the difference in average travel speed becomes very large. The average travel speed under the condition with an isolated signalized intersection drops dramatically because of queuing in front to the signal. After the signalized intersection, average traffic speed quickly increases and returns to its former level.

So installing a signalized intersection on a two-lane highway significantly affects traffic operations on the upstream two-lane highway segment based on average travel speed, and the effective length of a signalized intersection is greater than its actual length. The effective length of the upstream influence area of a signalized intersection is defined from the dividing point, at which vehicles begin decelerating to the stop line of this signalized intersection.

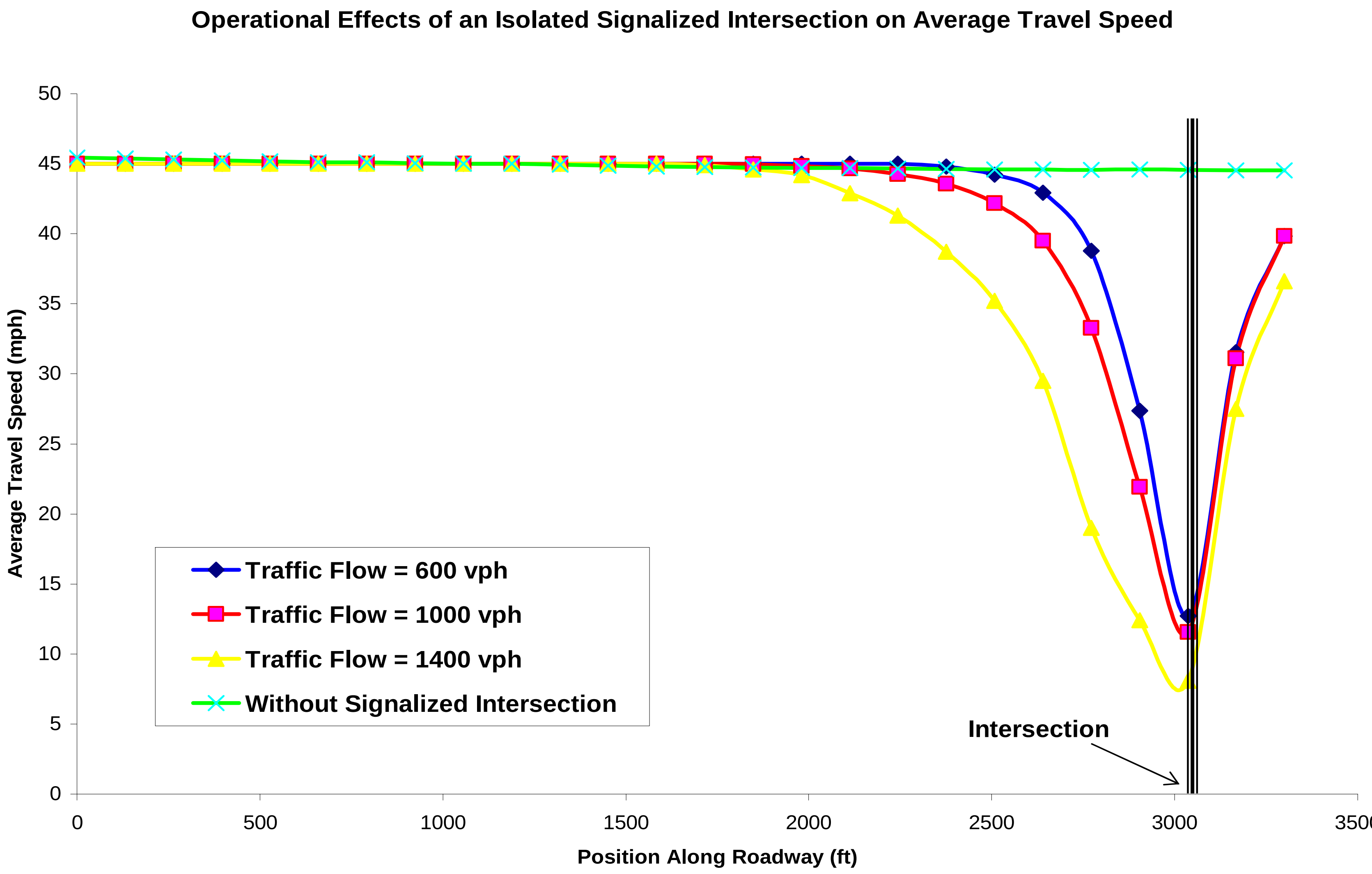

Figure 3-5: Effect of a Signalized Intersection on Average Travel Speed

3.1.3.2 Effects of Intersections on the Downstream Two-Lane Highway Operation

After passing through the signalized intersection, the vehicle platoon will go into the downstream two-lane highway. The platoon dispersion pattern is affected not only by the upstream signalized intersection, but also by the right-turn vehicles and left-turn vehicles from minor streets. There are three movements that contribute to the flow profile, as follows:

- through movement from the major street
- right-turn movement from the minor street
- left-turn movement from another minor street

The start-and-stop operation of signals on the two-lane highways tends to create platoons of vehicles that travel along a two-lane highway link. Here TRANSYT-7F is used to model the dispersion of these platoons as they progress along the downstream two-lane highway segment. In TRANSYT-7F, for each time interval (step), t, the arrival flow downstream is found by the following recurrence equation [8]:

$$v'_{(t+\beta T)} = F \cdot v_t + \left[(1-F) \cdot v'_{(t+\beta T-1)}\right] \tag{3-2}$$

Where:

$v'_{(t+\beta T)}$: predicted flow rate (in time interval of the predicted platoon);

v_t: flow rate of the initial platoon during step t;

β : an empirical factor, generally 0.8;

T: the cruise travel time on the link in steps; and

F: a smoothing factor

$$F = (1 + \alpha \cdot \beta \cdot T)^{-1} \tag{3-3}$$

Where:

α : platoon dispersion factor (PDF)

Equation 3-3 is based on field studies by Hillier and Rothery [9]. The factor α has been found by researchers to best represent measured dispersion on typical urban streets in the U.S. when it was set at 0.35. This PDF will vary to consider site-specific factors such as grades, curvature, parking, opposing flow interference and other sources of impedance.

The diagrams below illustrate the nature of platoon dispersion on the downstream two-lane highway of a signalized intersection. As traffic moves downstream, the initially tight platoon formed from the departing queue tends to disperse the farther downstream it travels. Because drivers tend to maintain safe headways, or spacing, between vehicles and often travel at different speeds, the platoon tends to spread out - a few moving ahead and some dropping back. The flow rate decreases with time as the platoon reaches each point of observation. They are the "snapshots" of the traffic flow at the different observation stations of the downstream link (the average traffic flow is 1200 veh/h).

The first diagram (Figure 3-6) illustrates a platoon after it has traveled 300 feet after being stopped at the upstream signalized intersection. The most intense portion of the platoon is at a rate higher than 1870 veh/h, and the lowest portion is at a rate near 0 veh/h. The platoon has spread out extremely unevenly. At this point, the timing plan of the upstream signal and traffic streams from the minor streets produce significant effects on the pattern of platoon dispersion.

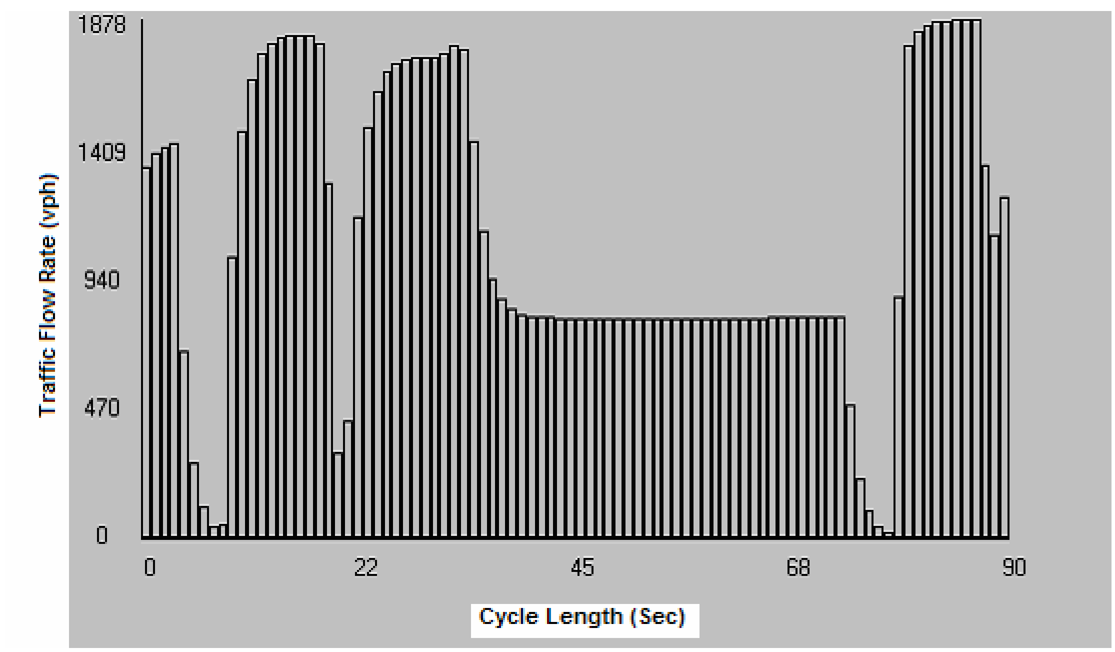

Figure 3-6: Platoon Dispersion, 300 ft from the Upstream Signalized Intersection

As traffic moves downstream, the initially tight platoon formed from the departing queue tends to disperse the farther downstream it travels. The second diagram (Figure 3-7) illustrates the same platoon after traveling one-full mile, or 5280 feet. Notice that after a full-mile, the most intense portion of the platoon is a rate slightly higher than 1500 veh/h, whereas after 300 feet the most intense portion of a platoon is approximately 1900 veh/h. At this point, the platoon has spread out to cover the whole portion of the cycle. The effect produced by the upstream signal on the platoon dispersion becomes smaller and smaller.

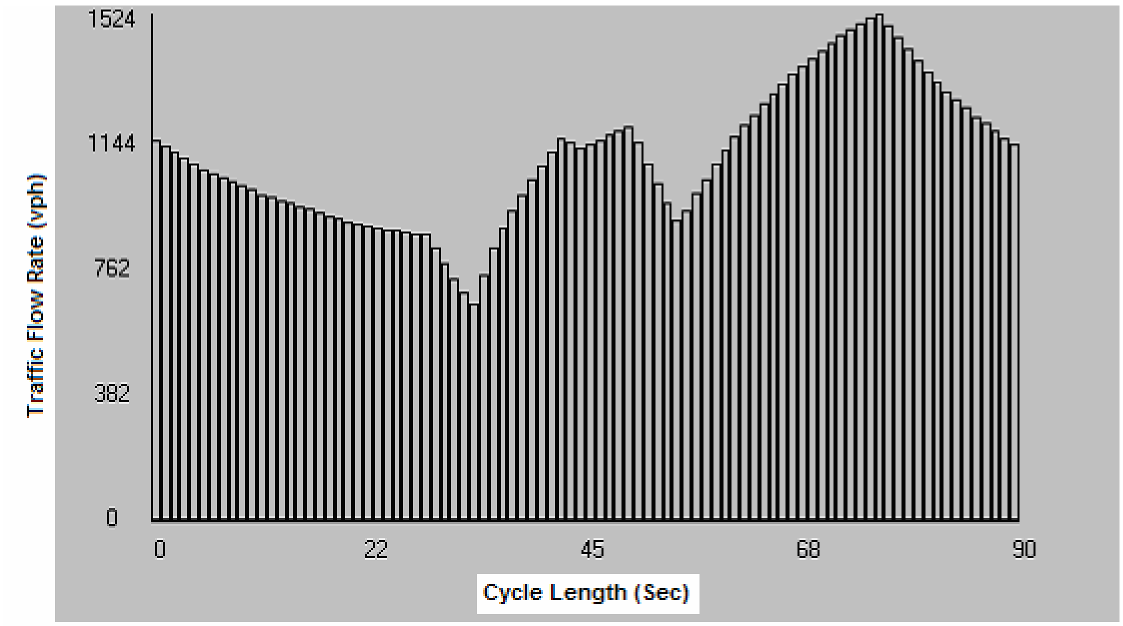

Figure 3-7: Platoon Dispersion, 5280 ft from the Upstream Signalized Intersection

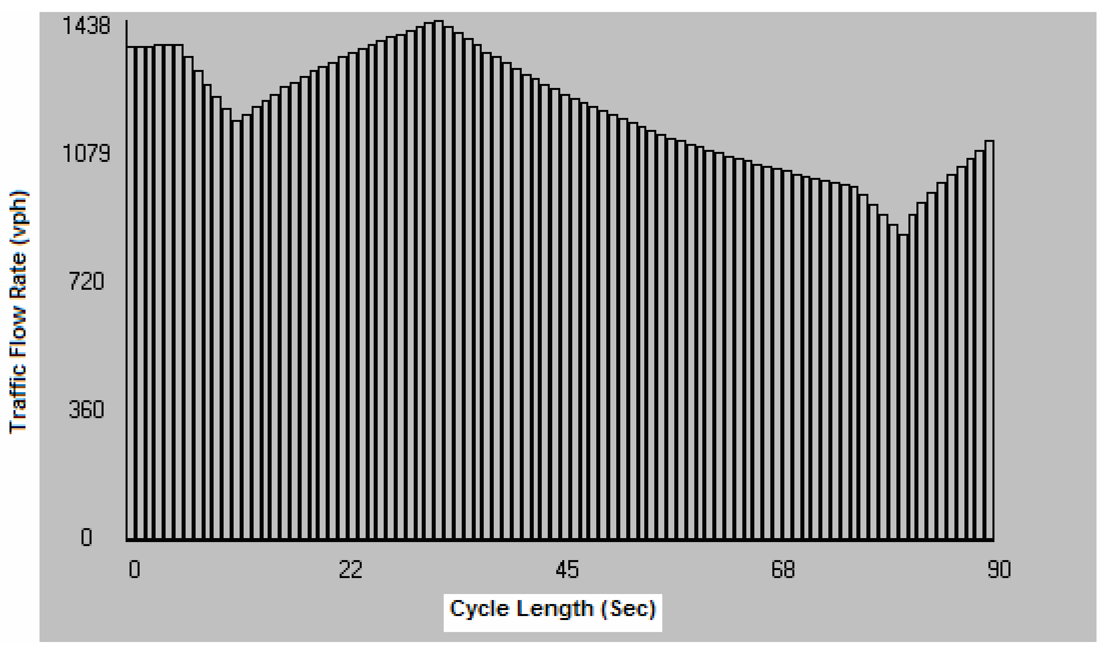

Figure 3-8: Platoon Dispersion, 10560 ft from the Upstream Signalized Intersection

The same phenomenon can be observed from the third diagram (Figure 3-8), which illustrates the same platoon after traveling 2 miles, or 10560 feet. The platoon has spread out more evenly and covered the whole portion of the cycle. The most intense portion of the platoon is about 1400 veh/h, which is near to the average flow rate of 1200 veh/h. At this point, the effect produced by the upstream signal on the platoon dispersion is negligible.

Based on the above analysis, it can be determined that the upstream signalized intersection and traffic streams from the cross street alter the pattern of platoon dispersion. The degree of platoon dispersion in turn directly affects vehicle delay, speed, queuing, and other measures of effectiveness.

Given the potential impact of a signalized intersection on upstream two-lane highway operations, it is necessary to investigate the effects further when performing an operational performance assessment of two-lane highway facilities. To quantify the effect of a signalized intersection on the upstream two-lane highway segment, a key issue is to determine this effective length of influence area, downstream and upstream of the signalized intersection.

3.2 Methodological Approach

Based on the discussion in the former section, the methodology of using a common service measure for the entire facility is better choice. A two-lane highway with an isolated signalized intersection will be used as a model. This section begins with a discussion of service measure selection, facility segmentation for a two-lane highway with isolated intersections. Next the section presents an overview of the operational analysis procedures for a two-lane highway with an isolated signalized intersection.

3.2.1 Service Measure Selection

In this methodology, a common service measure would be applied to every segment of the entire facility. The LOS of the entire facility is determined by this aggregated service measure. One of the key steps in the methodology is the selection of a service measure(s) used to define the overall level of service for the facility. Based on the features of the two-lane highway and the signalized intersection, some candidate service measures are described as follows:

- ***Volume to Capacity Ratio (v/c)***

  The *v/c* ratio is often used as a measure of the sufficiency of existing or proposed capacity. According to the 2000 HCM, this *v/c* ratio measure of capacity sufficiency of the overall intersection is a good indication of whether the physical geometry design features and the signal design provide sufficient capacity for the intersection. But the ratio is not sensitive to speeds and travel time. With an acceptable LOS grade, a *v/c* ratio may indicate that the same facility is operating at or near all capacity. Conversely, road segments operating at deficient levels of service may have an acceptable *v/c* ratio in cased where the adjoining intersections are not operating efficiently.

  Generally, the *v/c* ratio is often used as a measure of the sufficiency of existing or proposed capacity. The ratio however, is not sensitive to speeds and travel time. The *v/c* ratio is better as a measure of the capacity sufficiency, but not good as a measure of the quality of service. The combination of *v/c* ratio and other performance measures may be better.

- ***Average Travel Speed (ATS)***

  [Definition:] *ATS* is defined as the length of the roadway segment under consideration divided by the average total travel time for all vehicles to traverse that segment during some designed time interval.

  ATS reflects the mobility function of traffic facilities. Speed, as represented by *ATS*, is a very important part of the LOS definition and is also easy for the public to understand. And it is easily calculated using the data that is already being collected. As a space-average measure, *ATS* can be estimated in the field by travel time studies or by measure of spot speeds. One potential drawback to the use of average travel speed as the single service measure for two-lane highways is that it is not as sensitive as *PTSF* to the relative balance between passing demand and passing supply.

- ***Percent Time-Spent-Following (PTSF)***

  [Definition:] *PTSF* is defined as the average percentage of travel time that vehicles on a given roadway segment must travel in platoons behind slower vehicles due to the inability to pass during some designed time interval.

  Given the platooned nature of traffic on the two-lane highway, *PTSF* represents freedom to maneuver and the comfort and convenience of travel on a two-lane highway. However, some researchers [3] think this measure is not appropriate for application to developed, tourist-oriented sections, such as US Route 1 in the Florida Keys, on which motorists are more concerned about the ability to maintain a reasonable speed. *PTSF* is also a space-averaged measure. It is difficult to measure directly in the field. While the HCM suggests that it be estimated as the percentage of vehicles traveling at a headway of 3 seconds or less at a representative point, the LOS is very sensitive to the chosen headway threshold [10].

  Both *ATS* and *PTSF* are measured over a section of roadway. In the highway structure system of the HCM, the signalized intersection is regarded as a point, or a segment with a short length, so *ATS*, *PTSF*, or their combination is a conceptually adequate service measure for two-lane highway segments, but a poor one for the signalized intersection by itself. So *ATS*, *PTSF*, or their combination is not a good facility-wide service measure for the facility consisting of two-lane highway segments and signalized intersections.

- ***Percent Free Flow Speed (PFFS)***

  [Definition] *PFFS* is defined as the ratio of vehicle average travel speed to free flow speed.

  Washburn, et al. [3] proposed percent free flow speed as the primary performance measure for two-lane highways in developed areas. This measure makes some sense for these areas due to the fact that drivers probably do not have much expectation for passing in these areas and they are willing to tolerate following other vehicles as long as their speed is close to the desired free-flow speed.

- ***Density***

  [Definition]: Density is used as the primary service measure for the types of uninterrupted flow facilities, such as freeway and multilane highway.

  Density is the number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per mile per lane. Given the platooned nature of traffic on a two-lane highway, density is much less evenly distributed on a two-lane highway than on a freeway or multilane highway [10]. Density is not a good service measure for the two-lane highway facility. Percent time-spent-following does a much better job of representing density; percent time-spent-following is the percentage of the total travel time that drivers spend traveling in local high-density conditions. An additional difficulty with density is that direct measurement of it in the field is difficult, requiring a vantage point for photographing, videotaping, or observing significant lengths of highway. Furthermore, conceptually it does not work for signalized intersections.

- ***Control Delay***

  [Definition:] Control delay includes "Movements at slower speed and stops on intersection approaches as vehicles move up in queue position or slow down upstream of an intersection" [1].

  It is the principal service measure for evaluating LOS at intersections, which are point locations within a traffic network. However, the measure of operational quality of effectiveness used for point locations is not related to highway segments, such as two-lane highway segments.

- ***Percent Time-Delayed***

  Percent time-delayed is defined as the percentage of the travel time that vehicles on a given roadway segment must travel at speeds less than their desired speed due to inability to pass or traffic control during some designated time interval. Percent time-delayed is a good performance measure on interrupted-flow facilities, such as two-lane highways with occasional signalized intersections. It reflects the effects of speed reductions by motorists due to restrictive roadway geometry, traffic control, and other traffic, and represents the degree to which drivers are forced to travel at speeds less than their desired speed.

Just like other delay-related performance measures, percent time-delayed also has a direct economic interpretation and can be used in economic studies if the monetary value of a vehicle's delay can be established. The primary drawback of percent time-delayed as a performance measure is the difficulty of measuring it accurately in the field.

Table 3-2: Service Measure Evaluation

	Undeveloped uninterrupted two-lane segments	Developed uninterrupted two-lane segments	Intersection influence area	Facility incorporating two-lane highway and signalized intersection
Volume/Capacity Ratio	F	F	F	F
Average Travel Speed	G	G	P	P
Percent Time-Spent-Following	E	F	P	P
PTSF and ATS	E	E	P	P
Percent Free-Flow-Speed	G	E	P	P
Density	F	F	F	F
Control Delay	P	P	E	P
Percent Time-Delayed	G	G	G	G

Note: E = excellent, G = good, F = Fair, P = poor

Table 3-2 summarizes the evaluation of potential service measures for a two-lane highway with signalized intersections. Based on a review of the advantages and disadvantages of candidate service measures discussed above, it is concluded that percent time-delayed is an appropriate selection as the single service measure for the interrupted-flow facility of a two-lane highway with signalized intersections. Percent time-delayed is a measure that directly relates to the driver's experience. It not only represents freedom to maneuver and the comfort and convenience of travel on a two-lane highway, but also reflects the effects of speed reductions due to traffic control (e.g., signalized intersection, stop sign), and due to restrictive geometric features (e.g., vertical grade, horizontal curve, no-passing zone), and other traffic (e.g., opposite traffic flow, heavy vehicles).

3.2.2 Facility Segmentation

To perform an operational analysis for a facility consisting of different segment types, and obtain the LOS of the facility, the entire facility is divided into several segments. Thus, the analysis methodology must prescribe how to segment the facility.

In the HCM 2000, Chapter 15, *Urban Streets,* presents the methodology for evaluating arterials in urban and suburban areas with multiple signalized intersections at a spacing of 2.0 miles or less. In this methodology, the urban street is divided into segments, which is the full distance from one signalized intersection to the next. Figure 3-9 illustrates the segment division of this methodology. Running time is computed for each segment, along with control delay at each signalized intersection. In this methodology, the signalized intersection is regarded as a point location within a traffic network, and control delay is regarded as a typical point performance measure without covering any distance. In the HCM 2000 [1], by definition, control delay includes movements at slower speeds and stops on intersections approaches as vehicles move up in queue position or slow down upstream of an intersection, as well as delay due to re-acceleration downstream of a signal after stopping or slowing. It implies that control delay happens not at a point, but actually within a certain distance. Although the time lost due to slow movement before and after a stop is technically part of the running time, it is also included in control delay. Thus, this segment division method introduces error due to the segment between intersections being longer than they should.

In the HCM 2000, Chapter 16, *Signalized Intersections,* presents the methodology for evaluating isolated signalized intersections. In this methodology, the signalized intersection is regarded as a single isolated traffic control installation. So the length of the signal influence area is not a key factor in determining control delay, or in the decision of LOS based on control delay.

When evaluating highways with multiple signalized intersections, the signalized intersection should not be regarded as an isolated point. The impacts between signalized intersections and highway segments should be taken into account. In Sections 3.1.3.1 and 3.1.3.2, it has been shown that the installation of a signalized intersection actually affects the operations on the highway segments, and the signal influence area does extend a certain length. So when evaluating a two-lane highway with signalized intersections, the signalized intersection is not regarded as a single point, but as a segment with a certain length.

Figure 3-10 shows the division of a two-lane highway with multiple isolated signalized intersections. The whole facility is divided into three kinds of segments, described as follows:

- Type 1: the basic two-lane highway. This type of segment may be located in the upstream or downstream of the signalized intersection, but beyond the signal effective length. These segments are not affected by signalized intersections.

- Type 2: the signal influence area. In the highway structure system of HCM 2000, the signalized intersection is defined as a point; the boundary between segments. In this operational analysis methodology, it will be regarded as a segment with a certain length, which is composed of not only its own actual length, but also the deceleration and acceleration lengths. The length of the signal influence area corresponds to the three components of control delay—deceleration delay, stopped delay, and acceleration delay.

- Type 3: the affected downstream segment. This type of segment is still the two-lane highway, but affected by the upstream signalized intersection. Potential operational effects on this segment are produced by the upstream signalized intersection and traffic flows coming from the cross street. Note the length of this type of segment does not include the acceleration length of the signal influence area.

The lengths of these different segment types should add up to the total length of the analyzed facility.

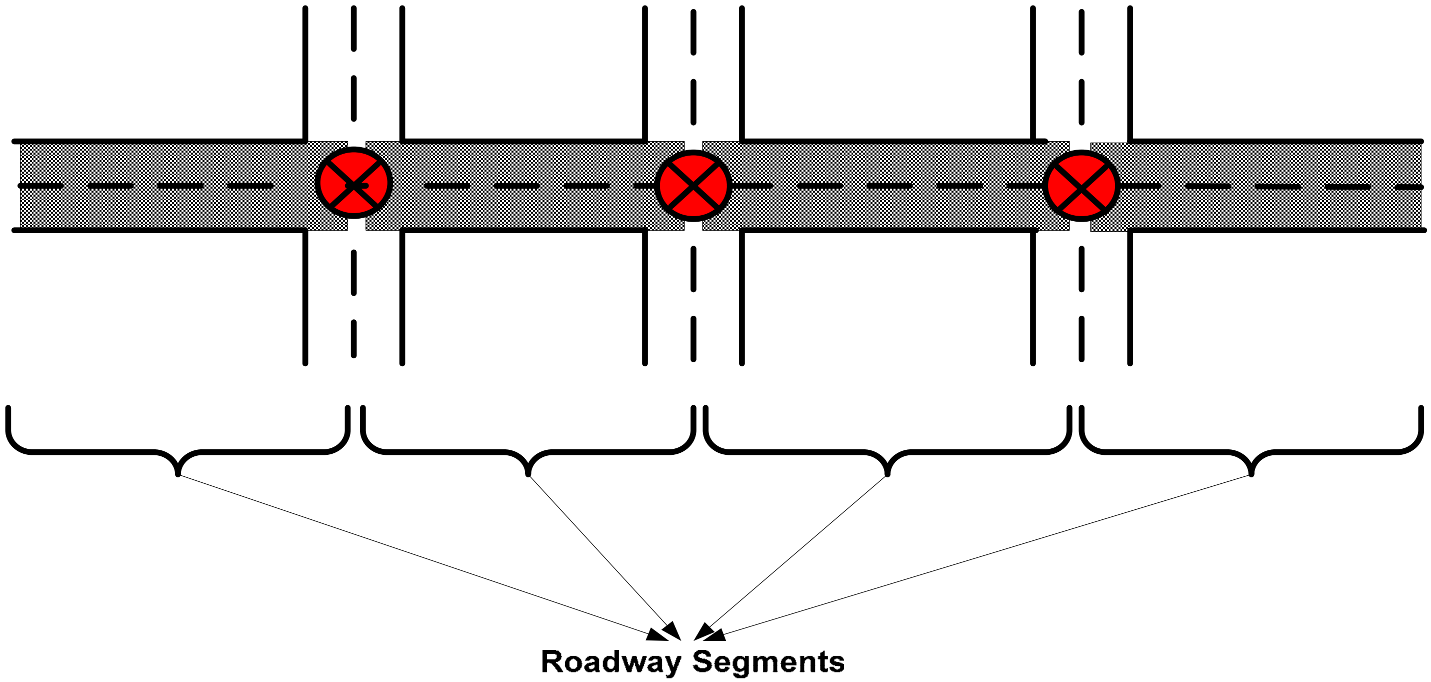

Figure 3-9: Segment Division of a Two-lane Highway with Multiple Isolated Signalized Intersections

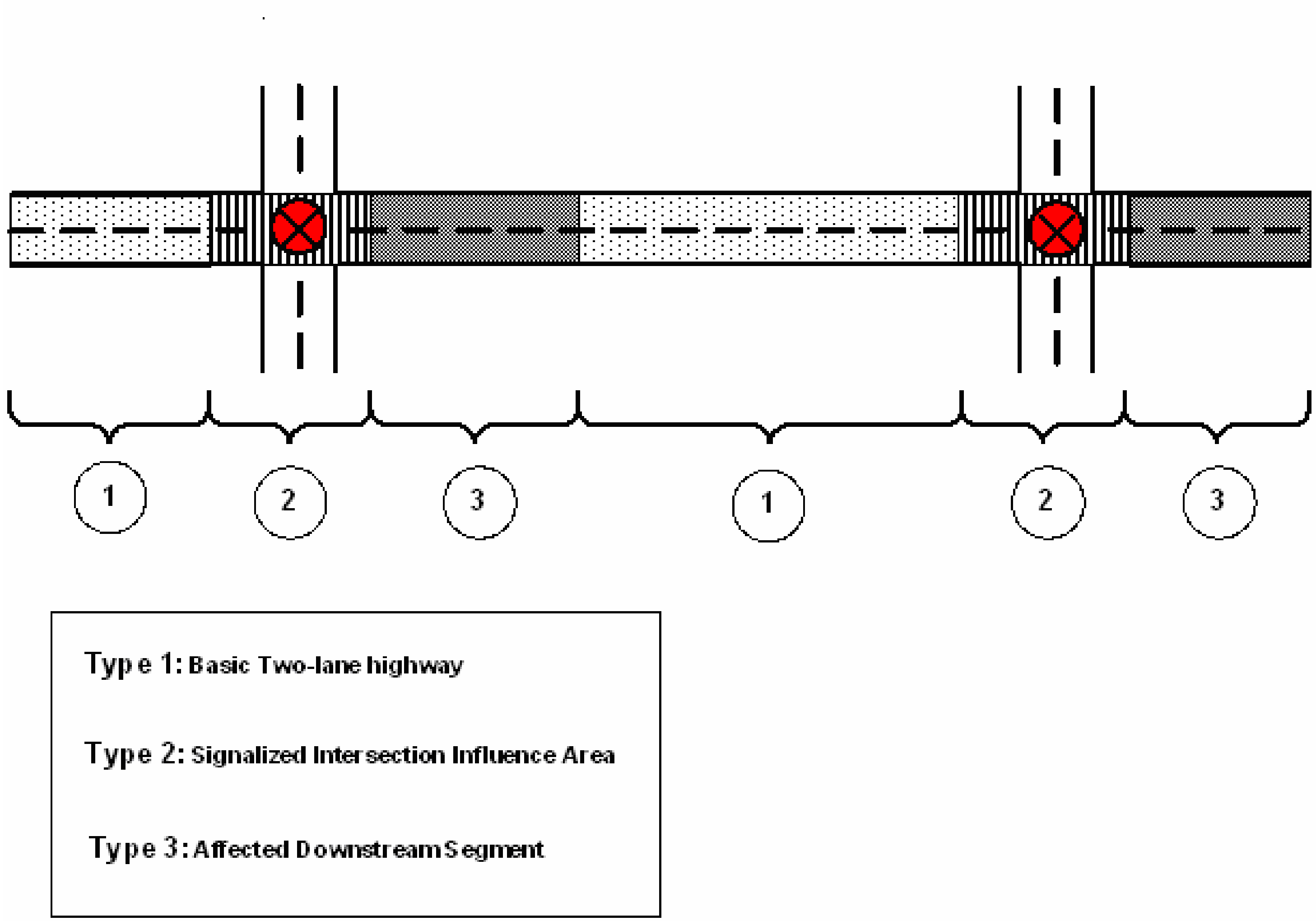

Figure 3-10: Facility Segmentation of a Two-lane Highway with Multiple Isolated Signalized Intersections

3.2.3 Overview of Computational Methodology

In this methodology, a common service measure would be applied to every segment of the entire facility. The service measures at each segment are aggregated to obtain an estimate of the overall service measure for the entire facility. The LOS of the entire facility is determined by this aggregated service measure.

An example of analyzing a two-lane highway with signalized intersections using this methodology is provided here. Percent time-delayed is applied as the common service measure for the whole facility composed of two-lane highway segments and signalized intersections. Figure 3-11 illustrates the analysis procedure for determining LOS on the two-lane highway with signalized intersections.

The first step in this analysis is to segment the facility based on the features of segment type. The second step is to determine the free-flow speed. The free-flow speed is used to determine the average travel speed and delay time at each segment. The basic free-flow speed for the two-lane highway is observed at basis conditions and range from 45 to 65 mile/h, depending on the highway's characteristics. The speed study should be conducted at a representative site within the study section. The best location to measure free-flow speed on the two-lane highway is mid-block and as far as possible from the nearest signalized or stop-controlled intersection. If field observation of free-flow speed is not practical, free-flow speed on the two-lane highway may be estimated using the method presented in the HCM 2000.

The next step in the analysis is to perform operational analysis at the point and segment levels. At the first type of segment, which is the basic two-lane highway sections, and not affected by the signalized intersection, the average travel speed can be calculated using the two-lane highway procedure presented in Chapter 20 of HCM 2000. The length of the conventional two-lane highway segment is determined by the actual placement of the signalized intersection within the analysis section.

At the second type of segment, which is the signalized intersection influence area, the control delay is the portion of the total delay for a vehicle approaching and entering a signalized intersection. Control delay concludes the delays of initial deceleration, move-up time in the queue, stops, and reacceleration. It can be calculated using the signalized intersection procedure presented in Chapter 16 for the through-traffic lane group. The length of the signal influence area includes the deceleration length, stopped length, and acceleration length.

The third type of segment is the downstream segment, affected by the upstream signalized intersection, and the traffic flow coming from the cross streets. The potential impacts of the signalized intersection on this segment will be assessed further in the term of average travel speed. The effective length of influence area downstream of the signalized intersection is also decided. For the analysis of this type of segment, statistical methods and TWOPAS simulation model will be used to quantify the impacts. The methodology will be completely presented in the later chapter.

Once average travel speed on the two-lane highway segments and control delay within the signalized intersection are determined, the delay time on the two-lane highway segments and the signalized intersection can be calculated using the following equations.

Delay time on the two-lane highway segment:

$$D_H = \frac{L_H}{S_H} - \frac{L_H}{FFS} \quad (3\text{-}4)$$

Where:

D_H : delay on the two-lane highway segment, s/veh

L_H : length of two-lane highway segment, ft

FFS : free flow speed for the two-lane highway segment, ft/s

S_H : average travel speed for two-lane highway segment, ft/s

Control delay at the signalized intersection:

$$D_S = d_1(PF) + d_2 + d_3 \quad (3\text{-}5)$$

Where:

D_S : control delay per vehicle at the signalized intersection, s/veh

d_1 : uniform control delay, s/veh

d_2 : incremental delay, s/veh

d_3 : initial queue delay, s/veh

PF: uniform delay progression adjustment factor

After estimates of delay time at the segment and point levels are done, segment and point delays are then added together to obtain the entire facility estimate. Percent time-delayed is then computed through dividing total delay time on the entire facility by the total travel time at the free-flow speed on the entire facility. Equation 3-6 shows the aggregation of point and segment results to obtain an estimate of percent time-delayed for the entire facility. After the facility-wide performance measure, percent time-delayed is obtained, the facility's LOS grade can be determined based on the LOS table. This will have to be developed. An initial set of thresholds will be established as part of this research, but further research on this issue will likely be warranted.

$$PTD = \frac{\sum_{H,S}(D_H + D_S)}{\sum_{H,S}(\frac{L_H}{FFS_H} + \frac{L_S}{FFS_S})}$$

$$L = \sum_{H,S} L_H + L_S \qquad (3\text{-}6)$$

Where:

PTD: percent time-delayed per vehicle for the entire facility, %

D_H: delay time per vehicle for the two-lane highway segment, s/veh

D_S: delay time per vehicle for the signalized intersection influence area, s/veh

FFS_H: free flow speed for the two-lane highway segment, ft/s

FFS_S: free flow speed for the signalized intersection influence area, ft/s

L: length of the entire facility, ft

L_H: length of the two-lane highway segment, ft and

L_S: length of the signalized intersection influence area, ft

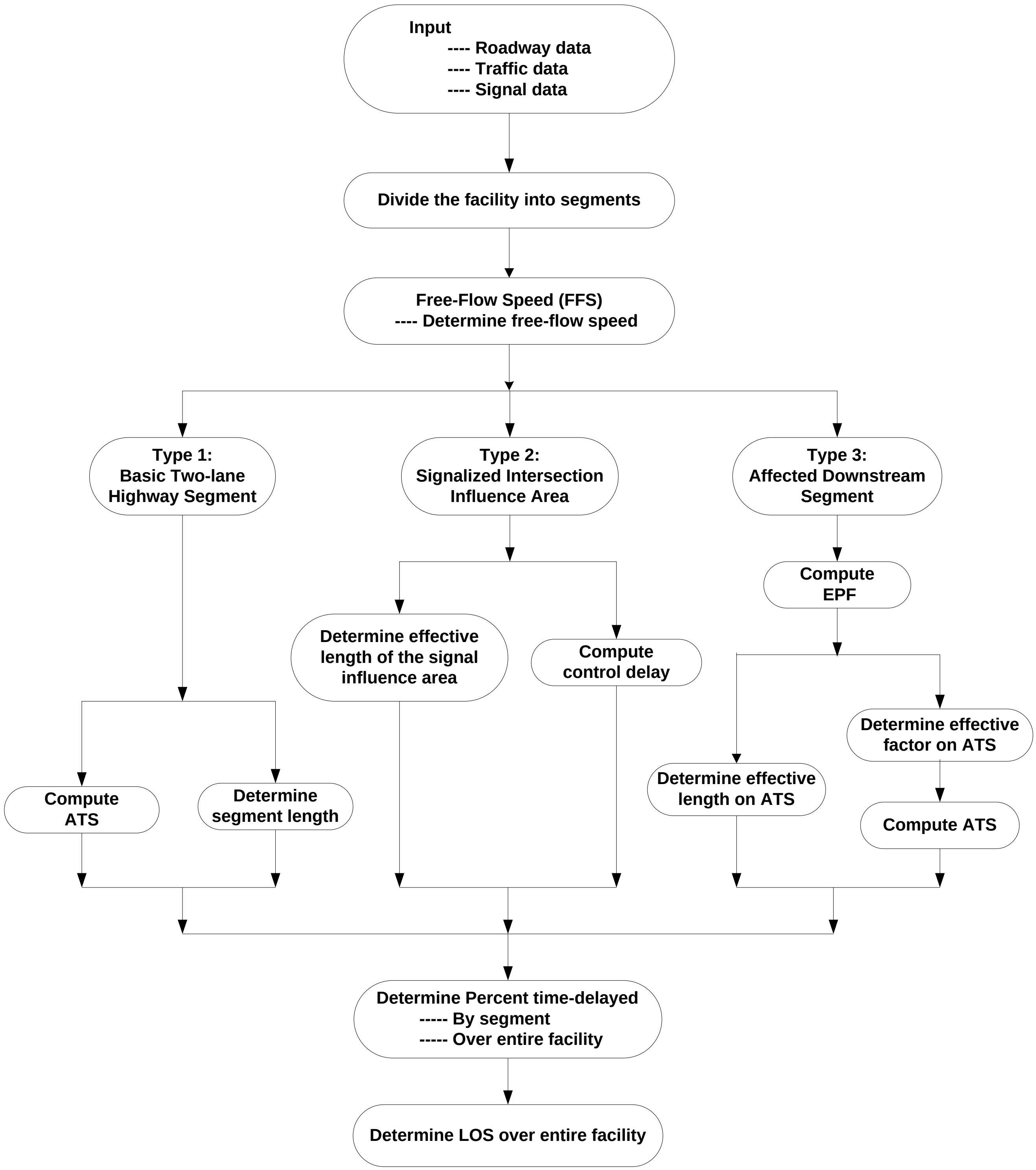

Figure 3-11: Flow Diagram of Two-lane Highway Facility Operational Analysis Methodology

CHAPTER 4
DEVELOPMENT OF FACILITY SEGMENTATION COMPUTATIONS

The methodology developed in Chapter 3 divides the entire facility into three types of segments. They are the basic two-lane highway, the signalized intersection influence area, and the affected downstream two-lane highway segment. In this methodology, the overall LOS for the facility is calculated by aggregating the service measure values of the segments, as weighted by segment length. The focus of this chapter is the determination of the length of each of the component segments of a two-lane highway facility.

Here the relation of the signalized intersection influence area and the affected segment downstream of the signalized intersection is clarified again. The components of the signal influence area include deceleration distance, stopping distance, and acceleration distance, which are consistent with those of control delay defined in the HCM 2000–deceleration delay, stopped delay, and acceleration delay. The segment delay time for the signalized intersection influence area is determined by the intersection control delay. The affected downstream segment is still affected by the upstream signalized intersection. As the traffic stream discharges from the upstream intersection into the downstream highway segment, it will take some distance for traffic to return to the same flow condition as before the influence of the signal. The delay time for the affected downstream segment is determined by the difference in free-flow travel time and actual travel time.

This chapter includes two sections. Section 1 presents three methods to determine the length of a signalized intersection influence area and their advantages and disadvantages are evaluated. Section 2 explores the methodology to determine the length of the downstream segment affected by the upstream signal. How to accurately define the headway distribution and calculate the parameter of EPF (Entering Percent Following) is discussed in this section. Finally, this methodology is verified by comprehensive comparisons with other simulation programs.

4.1 Effective Length of the Signal Influence Area

This section discusses the methodology of determining the effective length of the signalized intersection influence area. Three methods are presented. The first method is to apply the recommended length in FDOT's 2002 Level/Quality of Service Handbook; the second one determines the length of a signalized intersection influence area from the view point of its components; the third one is to apply the simulation and statistical method.

4.1.1 Recommended Length in FDOT's 2002 Level/Quality of Service Handbook

In FDOT's 2002 Level/Quality of Service Handbook, for a preliminary engineering analysis FDOT recommends breaking the facility into uninterrupted and interrupted flow segments [2]. *The interrupted flow intersection segments, "intersection influence areas," extend 0.5 miles in length centered on the midpoint of the crossing facility. The LOS for this influence area is determined by the intersection LOS.* Figure 4-1 shows an example how to determine the intersection length in the two-lane highway facility with signalized intersections.

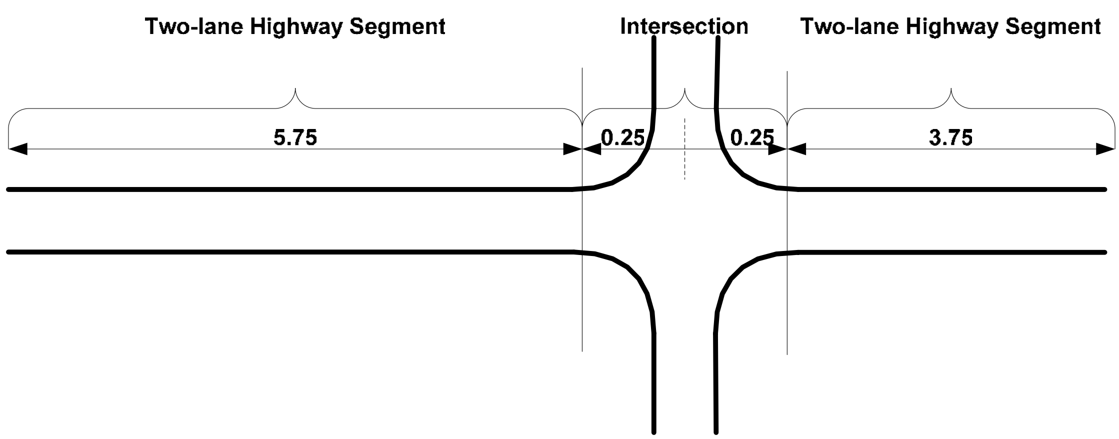

Figure 4-1: Length of Intersection Area

In this example, a two-lane highway with a signalized intersection extends 10 miles, and the isolated intersection is located at the 6-mile point. The first 5.75 miles would be regarded as a two-lane highway segment, the next 0.5 miles would be regarded as the intersection area, and the last 3.75 miles would be regarded as a two-lane highway segment.

The recommended length in FDOT's 2002 Level/Quality of Service Handbook is only a simplified value. It does not take into account any actual factors such as traffic conditions and signal timing plans in the field. A new method to determine the effective length of the signalized intersection influence area under specific conditions is presented here from a component-based perspective.

4.1.2 Components of the Signal Influence Area

The signalized intersection influence area is the place where control delay happens. Control delay is defined as the total delay due to the signalized intersection and includes deceleration delay, stopped delay, and acceleration delay. The length of the signalized intersection influence area should be consistent with control delay, and its components correspond to those of the control delay. That is, the components of the signalized influence are deceleration length, stopped length, and acceleration length. The detailed distance-time diagram shown in Figure 4-2 is useful for defining the general shape of the relationship of control delay (Time), and the length of the signalized intersection area (Distance) associated with a specific vehicle.

Figure 4-2 shows the main delay terms at a signalized intersection, and components of the signal influence area. Before Point 1 on the time-distance diagram, the vehicle is moving at a relatively uniform speed. From Point 1 to Point 2, the vehicle decelerates until it stops at Point 2 to join the standing queue before the signalized intersection. The vehicle remains stopped between Points 2 and 3. Between Points 3 and Point 4, the vehicle accelerates until it reaches a uniform speed again at Point 4. Notice that Point 3 is the stop bar.

In Figure 4-2, the deceleration distance L_D is given by

$$L_D = L_2 - L_1 \tag{4-1}$$

Similarly, the stopped distance L_S is given by

$$L_S = L_3 - L_2 \tag{4-2}$$

Similarly, the acceleration distance L_A is given by

$$L_A = L_4 - L_3 \tag{4-3}$$

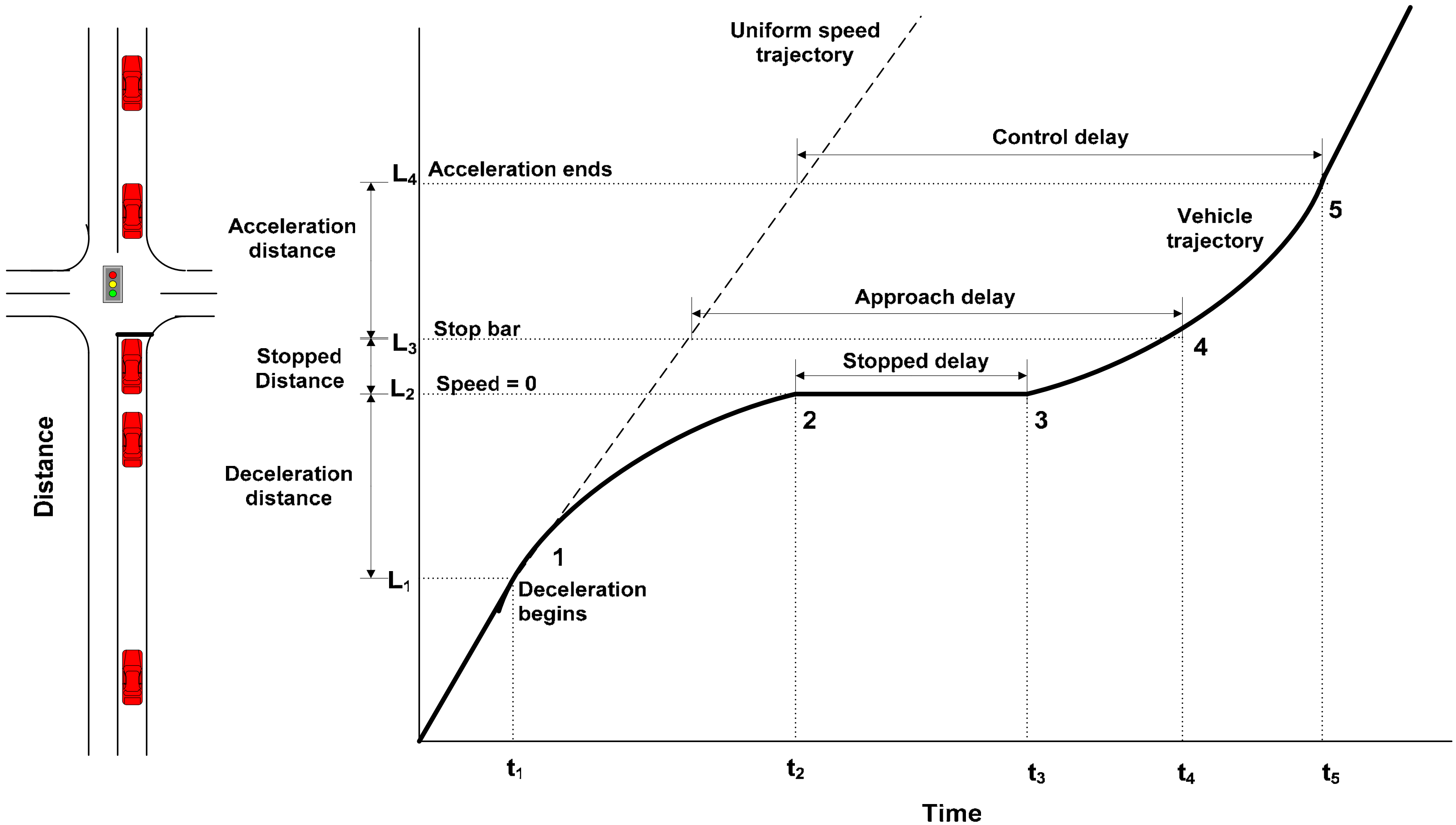

Figure 4-2: Schematic Distance-Time Diagram at Signalized Intersection

To determine the overall length of the signal influence area, the lengths of each of the three components must be determined. The method to determine the lengths of these three components will be discussed in the following section.

Figure 4-3 illustrates several kinds of conditions for which vehicles pass through a signalized intersection. Figure 4-3(a) shows the condition for which vehicles are near to the intersection facing a red signal indication and a queue exists in front of intersection, so drivers will safely stop their vehicles within sufficient sight distance to avoid entering the intersection or colliding with queued vehicles. For this condition, the effective length is equal to the sum of stopping sight distance (*SSD*) and queue length. At the end of the red period, the queue length increases to the maximum value. Figure 4-3(b) shows the condition for which vehicles are near to the intersection facing a green signal indication, a queue exists in front of the intersection, and drivers do not need to stop their vehicle completely, but still need to take the action of decelerating. For this condition, the effective length is still equal to the sum of *SSD* and queue length. At the end of the green period, the queue length decreases to the minimum value. Figure 4-3(c) shows the condition for which vehicles are near to the intersection facing a green signal indication, and no queue exists in front of the intersection. In this case, the effective length is equal to *SSD* only. When a vehicle randomly arrives at the intersection, it may encounter any condition, where queue length is at a maximum, median, or not present. Based on the above discussion, the upstream effective length of the signalized intersection influence area can be calculated as the summation of stopping sight distance and average queue length. That is,

$$L_U = SSD + \overline{Q} \tag{4-4}$$

Where:

L_U: effective length of influence area upstream of signalized intersection, ft

SSD: Stopping Sight Distance, ft

$\overline{Q}$: average queue length, ft

In the above equation, *SSD* corresponds to the distance traveled during perception/reaction time plus the braking/deceleration distance, and $\overline{Q}$ corresponds to the stopped distance (i.e., distance over which queued vehicles are stopped).

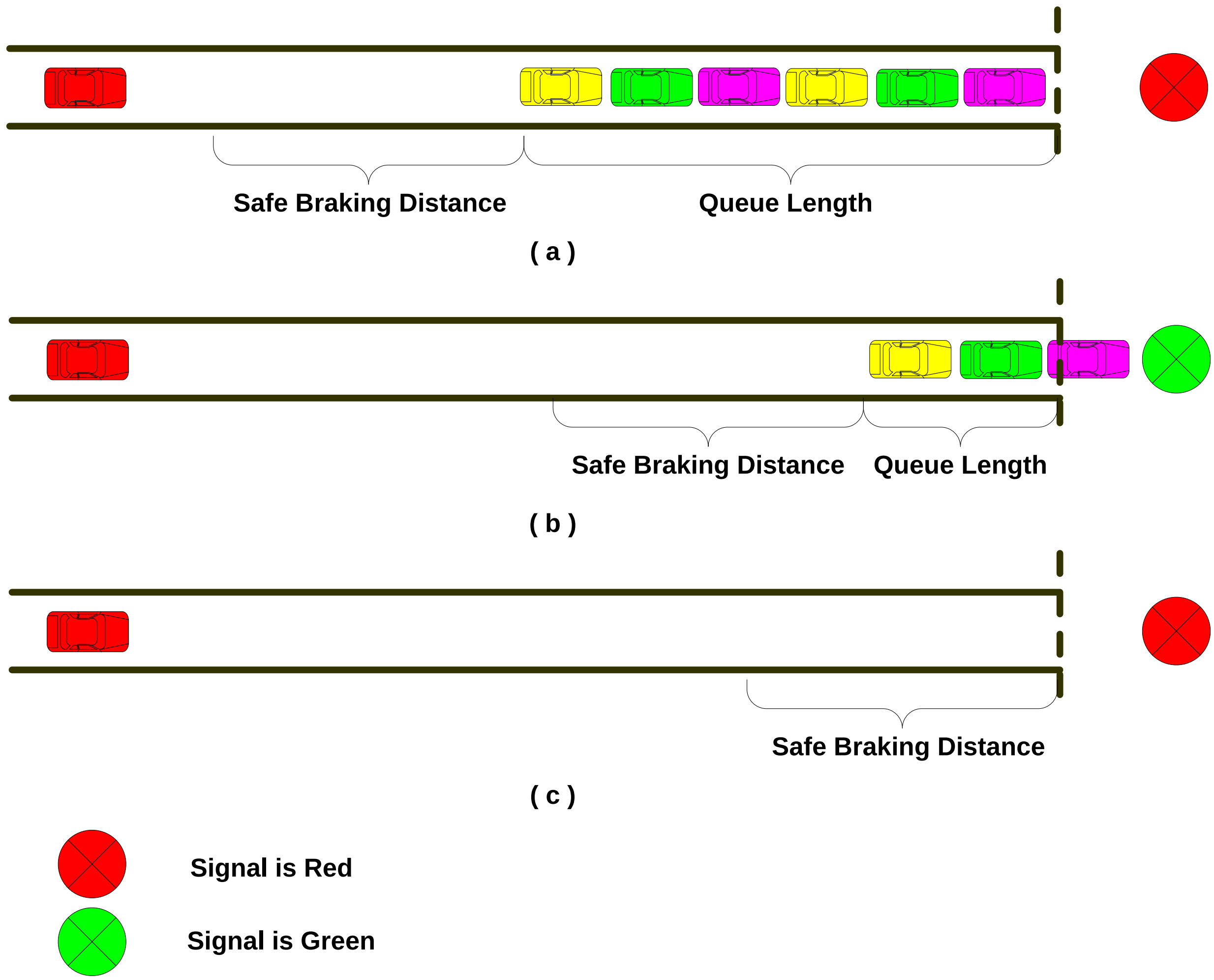

Figure 4-3: Queue Length Estimation

4.1.2.1 Determining Stopping Sight Distance

The stopping sight distance can be calculated using Equation 4-5, as follows:

$$SSD = V_1 t_r + \frac{V_1^2}{2g\left(\left(\frac{a}{g}\right) \pm G\right)} \tag{4-5}$$

Where:

SSD: Stopping Sight Distance, ft

V_1: initial vehicle speed, ft/s

t_r: perception-reaction time, sec

a: deceleration rate, ft/s

g: gravitational constant, ft/s

G: roadway grade (+for uphill and – for downhill), percent/100

This equation is from AASHTO's "Green Book" [16]. In this equation, the perception-reaction time is taken as 2.5 seconds and a deceleration rate of 11.2 ft/s^2 (3.4 m/s^2) is assumed.

Perception-reaction time and initial vehicle speed are two important elements in calculating the stopping sight distance. The perception-reaction time is the time it takes to initiate the physical response, which includes the detection, identification, and decision elements involved in responding to a stimulus. The perception-reaction time used to calculate the stopping sight distance, when vehicles are near to the signalized intersection should be analyzed from the features of actions taken by drivers when near the signalized intersection.

- Vehicle deceleration when approaching an intersection is an expected event. Perception-reaction time varies depending on whether the event is expected or unexpected, with expected events logically requiring less time.
- Vehicle deceleration when approaching an intersection is a relatively simple task. Perception-reaction time varies with the complexity of the task. The simpler the task, the shorter the time required for a response.

Decelerating vehicles near to the signalized intersection is an expected event, and it is also a fairly simple task. At the first part of perception-reaction time, vehicles still keep the initial speed; at the ending part of perception-reaction times, drivers begin taking actions to decelerate the vehicles. The AASHTO Green Book [16] suggests a perception-reaction time of 2.5 seconds, which is a design recommendation, accounting for unexpected events or obstacles in the roadway. Based on this recommended value and the characteristics of actions taken by drivers nearing a signalized intersection, the perception-reaction time is assumed to be in the range of 1 second (1 second is typically used for yellow interval timing calculations). It is also assumed that the latter part of this perception-reaction time will consist of some vehicle deceleration as a driver will lift their foot off the accelerator in preparation for applying the vehicle's brakes.

Initial vehicle speed is another important element of stopping sight distance. The travel speed is generally inversely proportional to the traffic volumes. When the traffic volume is lower, vehicles approach the intersection at a higher speed; when the traffic volume is higher, vehicles approach the intersection at a relatively lower speed.

4.1.2.2 Determining Average Queue Length

The HCM 2000 puts forward the concept of the average back-of-queue measure [11] at signalized intersections. In this model the back of queue is the number of vehicles that are queued depending on arrival patterns of vehicles and vehicles that do not clear the intersection during a given green phase. The average back of queue is used as the average queue length, and can be calculated using Equation 4-6:

$$Q = Q_1 + Q_2 \qquad (4\text{-}6)$$

Where:

Q: maximum distance in vehicles over which queue extends from stop line on average signal cycle, veh

Q_1: first-term queued vehicles, veh, and

Q_2: second-term queued vehicles, veh

The first term, Q_1, represents the number of vehicles that arrive during the red phases and during the green phase until the queue has dissipated. The first term is calculated using equation 4-7.

$$Q_1 = PF_2 \frac{\frac{V_L C}{3600}\left(1 - \frac{g}{C}\right)}{1 - \left[\min(1.0, X_L)\frac{g}{C}\right]} \qquad (4\text{-}7)$$

Where:

PF_2: adjustment factor for effects of progression

V_L: lane group flow rate per lane, veh/h

C: cycle length, sec

g: effective green time, sec, and

X_L: ratio of flow rate to capacity

Q_1 represents the number of vehicles that arrive during the red phases and during the green phase until the queue has dissipated. The adjustment factor for effects of progression is calculated by Equation 4-8.

$$PF_2 = \frac{\left(1 - R_P \frac{g}{C}\right)\left(1 - \frac{v_L}{s_L}\right)}{\left(1 - \frac{g}{C}\right)\left(1 - R_P \frac{v_L}{s_L}\right)} \tag{4-8}$$

Where:

PF_2: adjustment factor for effects of progression, veh

v_L: lane group flow rate per lane , veh/h

s_L: lane group saturation flow rate per lane, veh/h

C: cycle length, sec

g: effective green time, sec, and

R_p: platoon ratio

The second term, Q_2, is an incremental term associated with randomness of flow and overflow queues that may result because of temporary failures. This value can be an approximate cycle overflow queue when there is no initial queue at the start of the analysis period. The second term of the average back of queue can be computed using Equation 4-9.

$$Q_2 = 0.25 c_L T \left[(X_L - 1) + \sqrt{(X_L - 1)^2 + \frac{8 k_B X_L}{c_L T} + \frac{16 k_B Q_{bL}}{(c_L T)^2}} \right] \tag{4-9}$$

Where:

c_L: lane group capacity per lane, veh/lane

T: length of analysis period, h

k_B: second-term adjustment factor related to early arrivals, and

Q_{bL} : initial queue at start of analysis period, veh

The second term adjustment factor related to early arrivals is calculated using Equation 4-10:

$$k_B = 0.12I\left(\frac{s_L g}{3600}\right)^{0.7} \qquad (pretimed\ signals)$$

$$k_B = 0.10I\left(\frac{s_L g}{3600}\right)^{0.6} \qquad (actuated\ signals) \tag{4-10}$$

Where:

k_B: second-term adjustment factor related to early arrivals

s_L: lane group saturation flow rate per lane, veh/h

g: effective green time, sec

I: upstream filtering factor for platoon arrivals

4.1.2.3 Determining Acceleration Length

Another component of the signal influence area, acceleration length after the signalized intersection stop bar, can be determined using a linearly-decreasing acceleration model. Continuing research [12] has shown that the linearly-decreasing acceleration model better represents both maximum vehicle acceleration capacities as well as actual motorist behavior. The linearly-decreasing acceleration model can be rewritten as a differential equation and integrated to derive the following relationships (treating a grade as being constant), as Equation 4-11 through 4-14. It should be noted that this is only part of the full derivation. The full derivation can be found in most traffic flow theory textbooks, for example [13].

$$\frac{\partial v}{\partial t} = \alpha - \beta v \pm Gg \tag{4-11}$$

$$v = \frac{(a \pm Gg)}{\beta} - \left(\left(\frac{a \pm Gg}{\beta}\right) - v_o\right)e^{-\beta t} \tag{4-12}$$

$$t = \frac{\beta d + v - v_0}{a \pm Gg} \tag{4-13}$$

$$d = \frac{(a \pm Gg)}{\beta}t - \left(\left(\frac{a \pm Gg}{\beta}\right) - v_o\right)\frac{(1 - e^{-\beta t})}{\beta} \tag{4-14}$$

Where:

v: speed at the end of the acceleration cycle, ft/s

v_0: speed at the beginning of the acceleration cycle, ft/s

α, β : acceleration model parameters, based on the design vehicle type

g: gravitational constant, ft/s

G: roadway grade (+for uphill and – for downhill), percent/100

t: time for vehicle to accelerate from beginning speed, v_0, to ending speed, v, sec

d: distance for vehicle to accelerate from beginning speed, v_0, to ending speed, v, ft

The equations presented above arising from the linearly-decreasing acceleration model are not quite as simple or as easy to apply as their counterparts based on constant acceleration rates, but they are processed readily by a computer.

Transportation and Traffic Engineering Handbook [13] also contained one of the most comprehensive summaries of previous research and field studies of maximum and normal acceleration and deceleration rates. Table 4-1 summarizes acceleration rates, distances traveled, and elapsed time for passenger vehicles on level terrain and under normal operating conditions.

Table 4-1: Normal Acceleration Rates, distance, and elapsed time

Initial Speed		Final Speed (mph)				
		15	30	40	50	60
0	Initial Speed (mph)	3.3	3.3	3.3	3.1	2.9
	Elapsed Time (sec)	4.5	9.1	12.1	15.9	20.9
	Distance Traveled (ft)	49	200	354	574	929
30	Initial Speed (mph)	---	---	3.3	2.9	2.5
	Elapsed Time (sec)			3.0	6.8	11.8
	Distance Traveled (ft)			154	374	729
40	Initial Speed (mph)	---	---	---	2.6	2.3
	Elapsed Time (sec)				3.8	8.8
	Distance Traveled (ft)				220	575
50	Initial Speed (mph)	---	---	---	---	2.0
	Elapsed Time (sec)					5.0
	Distance Traveled (ft)					355

Source: Reference 11.

After the *SSD*, back of queue, and acceleration length are determined, the length of the signalized intersection influence area can be calculated as the summation of the three components. That is,

$$L_S = SSD + \overline{Q} + L_A \tag{4-15}$$

Where:

L_S: length of a signalized intersection influence area, ft

L_A: acceleration length, ft

The components of the signal influence area, *SSD*, back of queue, and acceleration length, are consistent with those of control delay defined in the HCM 2000, which are deceleration delay, stopped delay, and acceleration delay. A regression model was developed for the control delay calculated using the methodology presented in the HCM 2000, and the length of the signal influence area as the summation of *SSD*, average back of queue, and acceleration length. The results indicated that the assumption of a linear relationship is reasonable with an adjusted *R*-squared value of 0.895.

In this methodology, the length of a signal influence area is calculated as the summation of its components. In determining the length of each component, especially the *SSD* and back of queue, several significant factors are not reflected in the calculation formulas, such as the availability of a left-turn bay, the directional distribution of traffic flow, and the percentage of left-turn vehicles in the traffic flow. A new methodology is explored in the next section to fully take into account all major contributing factors which can affect the length of a signalized intersection influence area.

4.1.3 Simulation and Regression Analysis

To fully account for all significant contributing factors affecting the length of a signalized intersection influence area, the method of regression analysis method is applied. Ideally, field data would largely be used to develop the regression model. However, in many cases, available study sites are either too limited and/or data cannot be collected without great complication. Additionally, it is often difficult to collect enough field data to provide a statistically valid sample size. In this study, the simulation method is applied to simulate the operations of a two-lane highway with a signalized intersection. The overall procedure consists of the following four major steps:

1. Select the potential contributing factors that are expected to have an impact on the effective length.
2. Select the appropriate simulation model.
3. Develop the simulation model to simulate the effects of contributing factors on effective length.
4. Develop the regression model.

These steps are discussed in detail in the following sections.

4.1.3.1 Contributing Factor Selection

The contributing factors considered include those that are expected to affect the effective length. Many factors can produce effects on the effective length of a signalized intersection. In the following section, traffic data, geometric data, and signal data are discussed, respectively.

- **Traffic Data**

Traffic data include the hourly traffic volume, a Peak-Hour Factor (PHF), the proportion of trucks and recreational vehicles in the traffic stream, and the directional split (D-factor). Traffic flow rate can be used to represent the traffic conditions by making adjustments to the hourly traffic demand. These adjustments are the PHF, the heavy-vehicle adjustment factor, and the grade adjustment factor. The conversion can be made using Equation 4-16 [1]:

$$v_P = \frac{V}{PHF \times f_G \times f_{HV}} \tag{4-16}$$

Where:

v_p: passenger-car equivalent flow rate for peak 15-min period, pc/h

V: demand volume for the full peak hour, veh/h

PHF: peak-hour factor

f_G: grade adjustment factor

f_{HV}: heavy-vehicle adjustment factor

Traffic data also include the proportion of through vehicles, left-turn vehicles and right-turn vehicle in the traffic stream. The left-turning vehicles may have a negative effect on the flow of the through movements, particularly when higher percentage of left-turning vehicles may result in lane overflow or obstruction of the through movements. The directional distribution of traffic flow is another important characteristic of traffic stream. On two-lane highways, lane changing and passing are possible only in the face of oncoming traffic in the opposite lane. There is a strong interaction between the directions of travel on a two-lane highway because passing opportunities are reduced and eventually eliminated as the opposing traffic volume increases. At an intersection, left-turn vehicles execute their turning maneuvers through the gaps of the opposing through traffic stream. When the opposing through traffic volume is high, left-turn vehicles have less opportunity to execute their turning movements.

- **Geometric Data**

  Geometric data include the two-lane highway geometry and intersection geometry. The basic geometric conditions of the two-lane highway and intersection are used to determine the effective length. The existence of exclusive left-or right-turn lanes, along with the storage lengths of such lanes should be noted, as these are important factors in determining the effective length.

- **Signal Data**

  The signalization conditions include control mode (i.e., pre-timed, semi-actuated, and fully-actuated), the phase plan, cycle length, green time, and clearance intervals. In this study, the simplest and most widely used form of signalization, the two-phase pre-timed signal, is used. All left-turn and right-turn movements are made on a permitted basis from shared or exclusive lanes. The cycle length and effective green time are selected as contributing factors to determine the effective length.

Based on the above discussion on traffic, geometric, and signalization conditions, contributing factors are selected for calibration of the upstream length of roadway affected by the signalized intersection. They are:

- peak volume
- D-factor
- percentage of left-turn and right-turn movements
- cycle length
- ratio of effective green time to cycle length
- availability of a left-turn bay

4.1.3.2 Simulation Model Selection

The next step is to select a simulation model to simulate traffic operations on a two-lane highway with a signalized intersection. As reviewed in Chapter 2, TWOPAS rural highway simulation model has the ability to simulate traffic operations on a conventional two-lane roadway. However, the model has no ability to simulate traffic turning on or off the highway at driveways and does not handle signalized intersections. Therefore, the TWOPAS simulation model is not an appropriate selection to determine the effective length of the influence area upstream of the signalized intersection.

CORSIM, developed by the Federal Highway Administration, is the most widely used and accepted traffic simulation model in the U.S. It has the ability to simulate traffic operations on a two-lane roadway and includes detailed modeling of traffic signal operations. However, CORSIM cannot simulate passing maneuvers using the on-coming lane of traffic.

Before making a decision, TWOPAS was used to simulate the traffic operations on the basic two-lane roadway to study the relation of passing demand, passing capacity, the percentage of passing zones, the advancing traffic volume, and the opposing traffic volume. CORSIM was used to determine the features of service measure variation on the upstream two-lane highway segment of the signalized intersection. After large quantities of simulations, the following conclusions can be drawn from the study:

- Although on the two-lane highway, passing operations can be performed using the opposite lane in the face of oncoming traffic, the percentage of vehicles undertaking passing maneuvers is rarely more than 6% of traffic volume under different conditions of advancing traffic flow rate and opposing traffic flow rate.
- At the same advancing traffic volume level, the difference in average travel speed at the different opposing traffic volume levels is very small, less than 2%; the difference in the average travel speed between 100% no-passing zones and 0% no-passing zones is also small. As the advancing traffic flow rate increases, the difference decreases and gradually becomes negligible.
- The variance of travel speed due to a downstream signalized intersection is much larger than due to following a slower leading vehicle.

As vehicles approach a signal (i.e., within the influence area of the signalized intersection), the spacing between vehicles decreases, and following vehicles are unlikely to pass leading vehicles. Experience has shown that as drivers approach a signal, they generally will be more cautious; thus usually not undertaking passing maneuvers and possibly slowing down even if the signal indication is green. The roadway is also often marked with solid yellow dividing lines (i.e., no passing) in the vicinity of traffic signals. Under this assumption, it is feasible to use a program such as CORSIM to model vehicular operations on a two-lane roadway in the vicinity of a traffic signal, and determine the effective length of the signal influence area on the upstream two-lane highway segment. In addition, the CORSIM simulation model typically simulates the traffic system on a vehicle-by-vehicle basis by updating roadway position, speed, acceleration, and other state variables in discrete time steps. The ability to calibrate, modify, and manipulate these parameters is a key characteristic of the CORSIM simulation model amenable for use to determine the effective length of the signal influence area.

4.1.3.3 Simulation Model Experimental Design

A two-way, two-lane roadway network with an isolated fixed-time signalized interaction was simulated using CORSIM. It extended 3 miles, and the isolated intersection was located at the 1-mile point. The attributes of the simulated network were set to fulfill the basic conditions for a two-lane highway and signalized intersection according to the HCM 2000. These were defined as:

- Design speed greater than or equal to 60 mi/h
- Lane widths greater than or equal to 12 ft
- Clear shoulder wider than or equal to 6 ft
- Level terrain
- All passenger cars in traffic stream
- Two phase pre-timed signal

Two sets of CORSIM base road network were developed. One is the signalized intersection with a 250-foot left-turn bay; the other is the signalized intersection without a left-turn bay. Once the base road networks were developed, the values for the contributing variables were systematically changed to model different scenarios. The values for each contribution variable are displayed in Table 4-2 and Table 4-3. The different inputs resulted in a combination of 243 (3×3×3×3×3=243) simulation scenarios for the base network. Multiple simulation runs were made to account for the variability in stochastic micro-simulation program output, a total of 10 runs were made for each scenario to get a more representative estimate on the effective length. A total of 2430 simulated runs were performed. The length of simulation time for each run was 15 minutes.

Table 4-2: Variable Input Values (With a left-turn bay)

Peak Volume (pc/h)	Cycle length (sec)	g/C	Percentage of left-turn and right-turn vehicles
400	60	0.55	5%
800	75	0.65	10%
1200	90	0.75	15%

Table 4-3: Variable Input Values (Without a left-turn bay)

Peak Volume (pc/h)	D-Factor	Cycle length (sec)	g/C	Percentage of left-turn and right-turn vehicles
400	0.50	60	0.55	5%
700	0.55	75	0.65	8%
1100	0.60	90	0.75	11%

4.1.3.4 Regression Model Development

After simulation, average travel speeds at the interval of 0.025 miles along the two-lane roadway were obtained from the CORSIM output file. Figure 4-4 illustrates the variations of average travel speed along the two-lane highway with an isolated signalized intersection.

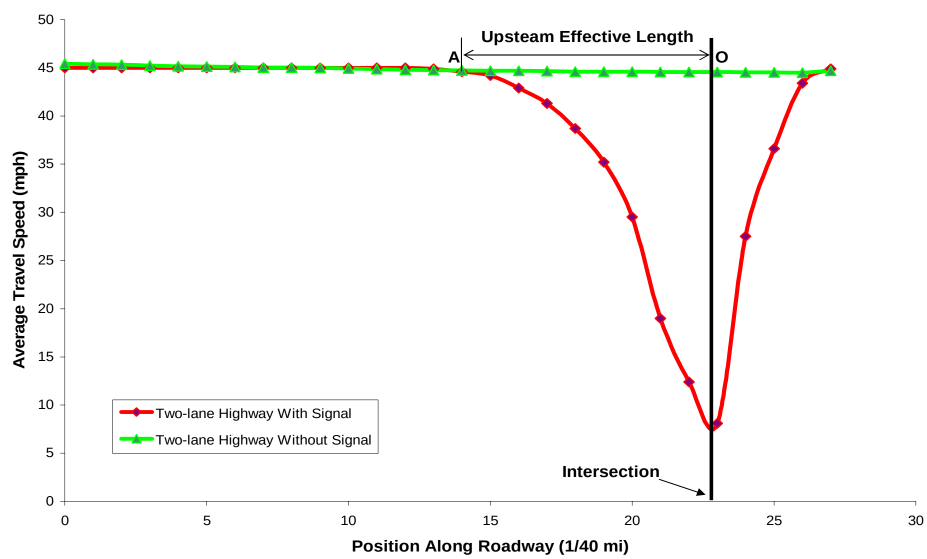

Figure 4-4: Average Travel Speed along the Two-lane Highway with Signal

Based on the variation of average travel speed, the effective length of the signalized intersection on the upstream two-lane highway segment can be measured from the dividing point, at which vehicles begin decelerating to the stop line of the signalized intersection, such as the section AO in Figure 4-4. After extracting the needed data, regression analysis was performed to establish the model of the upstream effective length with contributing factors.

The regression model for the upstream effective length of a signalized intersection with a left-turn bay is developed as follows:

$$\begin{aligned} Len_{eff\_up} &= 43.2463 + 4.2688 \times (V/100)^2 + 5.2178 \times Cycle \\ &- 57.3041 \times (V/100) \times \%LT - 5.2444 \times Cycle \times g\_C \end{aligned} \quad (4\text{-}17)$$

Where:

Len_{eff_up}:	upstream effective length of a signalized intersection, ft
V:	traffic flow rate, veh/h
Cycle:	cycle length, sec
g_C:	ratio of effective green time to the cycle length, and
$\%LT$:	percentage of left-turn vehicles in the directional traffic flow

The effective length model for the signalized intersection with the left-turn bay (250 ft) is presented in Table 4-4.

Table 4-4: Regression Model (with LT bay)

R^2 = 0.95743; Adj R^2 = 0.95519		
	Coefficient	**t-stat**
Intercept	43.2463	4.84765
V/100(Q)	4.2668	29.38653
Cycle (L)	5.2178	11.41796
V/100(L) by %LT(L)	-57.3041	-3.05196
Cycle (L) by gCRatio (L)	-5.2444	-9.45781

The regression model for the upstream effective length of a signalized intersection without a left-turn bay is developed as follows:

$$Len_{eff\_up} = 3074.49 + 5.89 \times (V/100)^2 - 440.00 \times DFactor$$
$$+1.69 \times Cycle - 7336.59 \times g\_C + 4758.52 \times (g\_C)^2 \qquad (4\text{-}18)$$
$$+1171.01 \times (V/100) \times (\%LT)^2$$

Where:

Len_{eff_up}: upstream effective length of a signalized intersection, ft

V: traffic flow rate, veh/h

$DFactor$: percentage of traffic traveling in the peak direction

$Cycle$: cycle length, sec

g_C: the ratio of effective green time to the cycle length, and

$\%LT$: the percentage of left-turn vehicles in the directional traffic flow

The upstream effective length model for the intersection without a left-turn bay is presented in Table 4-5.

Table 4-5: Regression Model (without LT bay)

R^2 = 0.77764; Adj R^2 = 0.77199		
	Coefficient	**t-stat**
Intercept	3074.49	3.97573
V/100(Q)	5.89	20.44190
Dfactor (L)	-440.00	-2.08639
Cycle (L)	1.69	2.40322
gCRatio (L)	-7336.59	-3.08700
gCRatio (Q)	4758.52	2.60546
V/100(L) by %LT(Q)	1171.01	3.98667

When using the above regression model to calculate the upstream effective length, the following conditions need to be observed:

(1): The maximum g/C value for this regression model is 0.8.

(2): When the traffic flow rate is less than or equal to 300 veh/h, the upstream effective lengths in Table 4-6 are recommended.

Table 4-6: Upstream effective length with low traffic volume, ft

V (veh/h)	g/C			
	0.5	**0.6**	**0.7**	**0.8**
100	160	130	110	90
200	180	150	130	110
300	210	180	163	140

4.2 Effective Length of the Influence Area Downstream of the Signalized Intersection

After passing through the signalized intersection, the vehicle platoon will travel into the downstream two-lane highway. The platoon dispersion pattern is affected not only by the upstream signalized intersection, but also by the right-turn vehicles and left-turn vehicles from minor streets.

This section begins with the discussion of Entering Percent Following (EPF) in the TWOPAS model and headway distribution. Then the effect of the signalized intersection on the downstream two-lane highway segment is quantified through the parameter of EPF. Next, the methodology using TWOPAS simulation to determine the effective length of a signalized intersection on the downstream segment is presented. Finally CORSIM simulation is used to validate this methodology.

4.2.1 Entering Percent Following of TWOPAS

A study by Dixon et al. [7] concluded that the potential effect of a signalized intersection on the downstream two-lane highway operations was to modify the distribution of headways. The condition with no signalized intersection is represented by assuming randomly distributed headways for entering traffic. However, the signalized intersection in the upstream will modify the headway distribution of the traffic stream entering the two-lane highway.

The TWOPAS model is used to simulate the effects of a signalized intersection on the downstream two-lane highway. In TWOPAS, the distribution of headway is defined through the input variable, Entering Percent Following (EPF), which is the percentage of the total vehicles in the direction of travel that are following in platoons when they enter the road being analyzed. Figure 4-5 illustrates an interface of TWOPAS for inputting traffic data. In this interface, EPF is identified in text, ‘% Traf in Platoons’.

In Dixon et al.’s study, it was assumed that it was appropriate to represent the effects of a signalized intersection through the EPF parameter, the percentage of vehicles following immediately downstream of a signalized intersection. To analyze the potential effect of a signalized intersection on the downstream two-lane highway operation, the key point is how to accurately decide the EPF at the point immediately downstream of a signalized intersection.

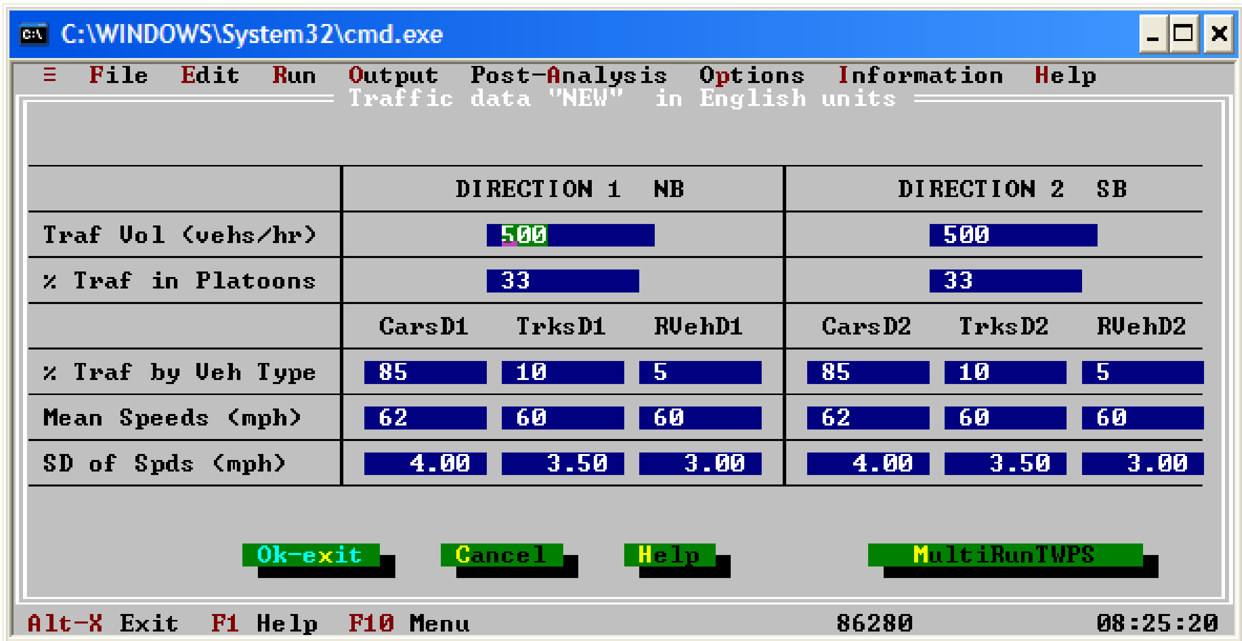

Figure 4-5: TWOPAS Traffic Data Input Interface

4.2.2 Headway Distribution

The time headway distribution between vehicles is an important flow characteristic that affects the safety, level of service, driver behavior, and capacity of a transportation system. Previous research [14] has established that the shape of the time headway distribution varied considerably as the traffic flow rate increased. In Dixon et al.'s study, the negative exponential distribution is used to define the headway distribution for the different traffic flow levels. For example, for the basic two-lane highway without signalized intersection, the EPF parameter is calculated using a cumulative exponential distribution for headways less than or equal to 3.0 seconds, using Equation 4-19:

$$\% \, Platooned = 100(1 - e^{-q\frac{t}{3600}}) \qquad (4\text{-}19)$$

Where:

q: hourly flow rate of traffic entering the two-lane highway, veh/h

t: headway criteria used to define when vehicles are following, (3.0 sec)

The simple negative exponential distribution could not completely capture the features of headway distribution. To accurately quantify the effect of an isolated signalized intersection on the downstream two-lane highway segment, the shifted negative exponential distribution and composite distribution are introduced into the Dixon et al. methodology to calculate the EPF parameter.

4.2.2.1 Shifted negative exponential distribution

Under very low conditions, all the vehicles may be thought of as traveling independent of one another. Any point in time is as likely to have a vehicle arriving as any other point in time. This situation will be classified as the random headway state. The negative exponential distribution can be used to define the time headway distribution for this condition. However, drivers typically maintain a minimum time headway for safety considerations, although their perception of the minimum safe headway is often too low. Thus, the shifted negative exponential distribution can better define the time headway distribution under very low volume conditions. The probability density function of the shifted negative exponential distribution is given by equation 4-20:

$$f(t) = \lambda e^{-\lambda(t-\alpha)} \qquad (4\text{-}20)$$

Where:

$f(t)$: probability density function,

α : user-selected parameter greater than or equal to zero that affects the shift of the distribution, sec, and

λ : parameter that is a function of the mean time headway and α .

λ can be calculated as:

$$\lambda = \frac{1}{\bar{t} - \alpha} \qquad (4\text{-}21)$$

The percentage of vehicles in platoon with the shifted negative exponential distribution can be calculated using Equation 4-22:

$$
\begin{aligned}
\% platoon &= 1 - P(h \geq t) \\
&= 1 - \int_t^{\infty} \left[\lambda e^{-\lambda(t-\alpha)}\right] dt \qquad (4\text{-}22) \\
&= 1 - e^{-(t-\alpha)/(\bar{t}-\alpha)}
\end{aligned}
$$

4.2.2.2 Composite Distribution

As the traffic flow level increases, there is increasing interaction between vehicles. Gerlough et al. [15] proposed that the traffic flow consisted of two classes of vehicles: constrained vehicles and free-moving vehicles. According to May [14], the random headway state (Negative exponential distribution) was best suited for very low flow conditions, while the nearly-constant headway state (Normal distribution) was best suited for very high flow conditions. The intermediate headway state lies between the two boundary conditions of the random- and constant-headway states. The composite model is a better alternative to represent the headway distribution as the traffic flow level increases. The composite model approach utilized the combination of a normal headway distribution for these constrained cars that are in the car-following or platoon mode and a shifted negative exponential distribution for those free-moving vehicles. The composite distribution represents the time headway distribution well when the traffic flow rate is higher. The percentage of vehicles in platoon with the composite distribution can be calculated using Equation 4-23.

$$
\begin{aligned}
\% Platooned &= 1 - P(h \geq t) \\
&= 1 - \left[P_{NP} e^{-(t-\alpha)/(\bar{t}_{NP}-\alpha)} + P_P \int_t^{\infty} \frac{1}{s\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{t-\bar{t}_P}{s}\right)^2} dt \right] \qquad (4\text{-}23)
\end{aligned}
$$

Where:

P_p: proportion of vehicles in platoon, %

P_{NP}: proportion of vehicles not in platoon, %

$\bar{t}_p$: mean headway of the vehicles in platoon, sec

$\bar{t}_{Np}$: mean headway of the vehicles not in platoon, sec

α : the minimum time headway for vehicles not in platoon, sec

s: standard deviation of normal distribution

t: time headway being investigated, sec

$\bar{t}$: mean headway, sec/veh

In the composite distribution, there are four independent parameters that need to be specified: mean and standard deviation of the normal distribution, the proportion of vehicles in platoon, and the minimum time headway for vehicles not in platoon. Numerous calculations and sensitivity analyses of a matrix of the four independent parameters need to be conducted to find the “best” composite model distribution for each traffic flow level. An example is given here to show how to find an appropriate composite distribution for the traffic flow of 1636 veh/h. Detailed calculations of the theoretical time headway for this traffic flow level are shown in Table 4-7. The theoretical shifted negative exponential headway distribution, normal headway distribution, composite headway distribution, and the measured time headway distribution are presented graphically in Figure 4-6. The Chi-Squared test is used to access statistically how closely the measured distribution is similar to the theoretical composite distribution. An example is given to compare the measured time headway distribution for the traffic flow level of 1636 veh/h with a composite distribution. The Chi-Squared test calculations are shown in table 4-8. The individual Chi-Squared contributions are summed, and the calculated Chi-Squared value is found to be 13.94. The number of degrees of freedom is determined to be 10 based on 15 time intervals and 4 parameters required for the composite distribution. Assuming a 0.05 significance level the reference Chi-Squared value is determined to be 18.30. Since the calculated Chi-Squared value is less than the reference Chi-Squared value, the hypothesis is not rejected and the conclusion is that there is no evidence of a statistical difference between the two distributions.

Although the composite distribution is the combination of a normal headway distribution and a shifted negative exponential distribution, when the traffic flow rate is lower, a larger difference occurs between the composite distribution and the measured distribution. So in this study, the shifted negative exponential distribution and composite distribution are used together to mathematically describe time headway distribution, including boundary conditions of random headway state and nearly-constant headway state, and the intermediate headway state.

Table 4-7: Composite Time Headway Distribution Calculation: (Traffic Flow Rate = 1500 veh/h ~ 1740 veh/h)

	Vehicles Not in Platoons						Platoon Vehicles				Composite Distribution	
t	$t-\alpha$	$\bar{t}-\alpha$	$\bar{t}-\alpha$	$e^{-\frac{(t-\alpha)}{(\bar{t}-\alpha)}}$	100%	P	z	$P(t<z)$	100%	1-P	(Prob.)	(Freq.)
0.0	0.0	1.5	0.0000	----	----	0.0000	-3.000	0.0013	0.0215	0.0147	0.0147	24
0.5	0.0	1.5	0.0000	----	----	0.0000	-2.000	0.0228	0.1359	0.0927	0.0927	152
1.0	0.0	1.5	0.0000	----	----	0.0000	-1.000	0.1587	0.3413	0.2327	0.2327	381
1.5	0.0	1.5	0.0000	1.0000	0	0.0000	0.0000	0.5	0.3413	0.2327	0.2327	381
2.0	0.0	1.5	0.0000	1.0000	0.1813	0.0577	1.0000	0.8413	0.1359	0.0927	0.1503	246
2.5	0.3	1.5	0.2000	0.8187	0.2321	0.0738	2.0000	0.9772	0.0215	0.0147	0.0885	145
3.0	0.8	1.5	0.5333	0.5866	0.1663	0.0529	3.0000	0.9987	0.0013	0.0009	0.0538	88
3.5	1.3	1.5	0.8667	0.4204	0.1192	0.0379	4.0000	1			0.0379	62
4.0	1.8	1.5	1.2000	0.3012	0.0854	0.0272					0.0272	45
4.5	2.3	1.5	1.5333	0.2158	0.0612	0.0195					0.0195	32
5.0	2.8	1.5	1.8667	0.1546	0.0438	0.0139					0.0139	23
5.5	3.3	1.5	2.2000	0.1108	0.0314	0.0100					0.0100	16
6.0	3.8	1.5	2.5333	0.0794	0.0225	0.0072					0.0072	12
6.5	4.3	1.5	2.8667	0.0569	0.0161	0.0051					0.0051	8
7.0	4.8	1.5	3.2000	0.0408	0.0116	0.0037					0.0037	6
7.5	5.3	1.5	3.5333	0.0292	0.0083	0.0026					0.0026	4
8.0	5.8	1.5	3.8667	0.0209	0.0059	0.0019					0.0019	3
8.5	6.3	1.5	4.2000	0.0150	0.0043	0.0014					0.0014	2
9.0	6.8	1.5	4.5333	0.0107	0.003	0.0010					0.0010	2
9.5	7.3	1.5	4.8667	0.0077	0.0077	0.0024					0.0024	4
											1.0	1636

$\bar{t}_{NP} = 3.7\sec, \alpha = 2.2\sec, s_{NP} = 1.5\sec, P_{NP} = 0.3182, E_P = 1.5\sec, s_p = 0.5\sec, P_p = 0.6818$

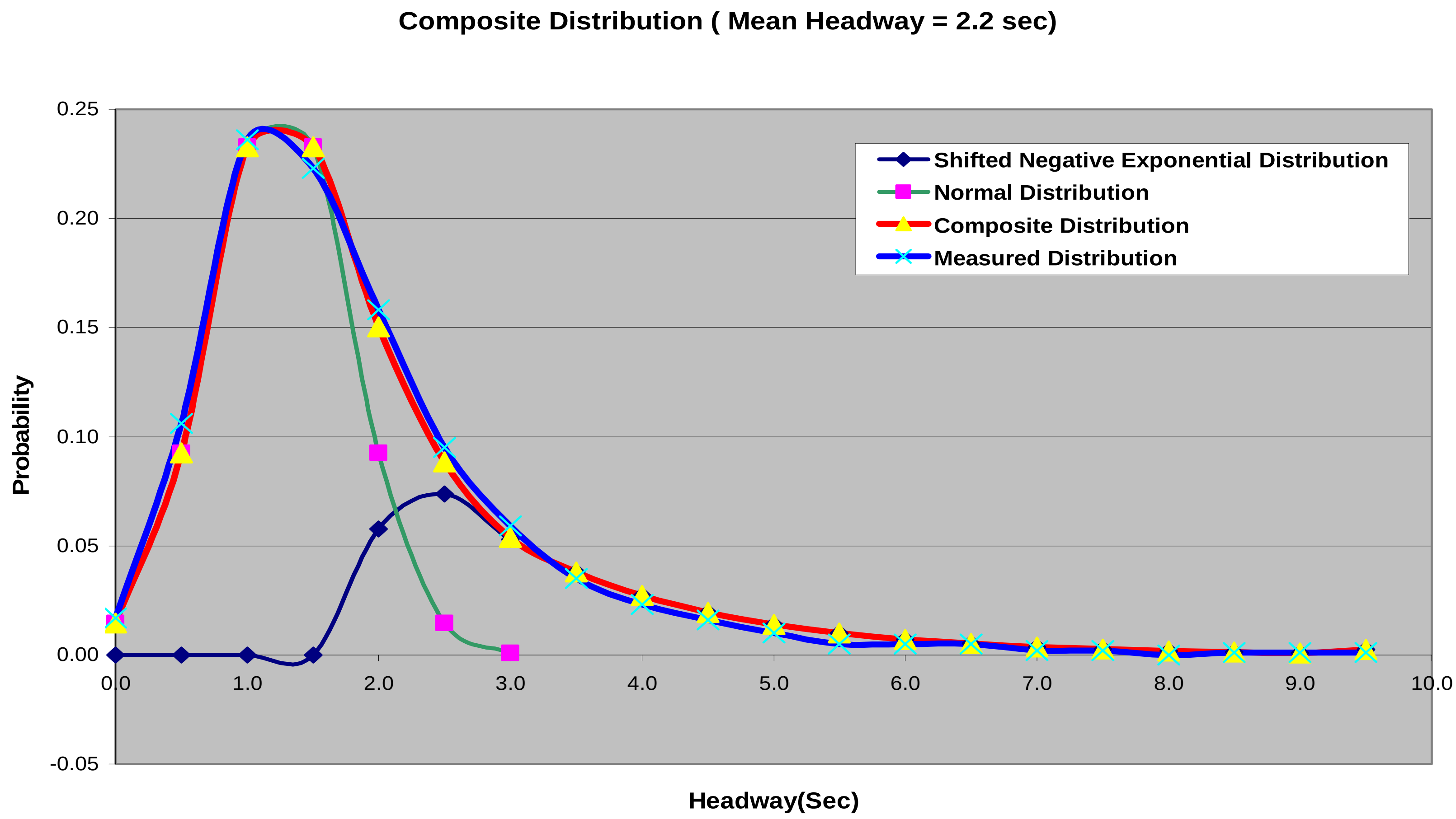

Figure 4-6: Composite Time Headway Distribution

Table 4-8: Chi-Squared Test Calculation

Time Headway Group	f_0	f_t	$f_0 - f_t$	$(f_0 - f_t)^2$	$\frac{(f_0 - f_t)^2}{f_t}$
0.0 - 0.5	22	19	3	10	0.4934
0.5 – 1.0	140	122	18	310	2.5355
1.0 - 1.5	312	307	4	19	0.0616
1.5 – 2.0	294	307	-13	164	0.5342
2.0 – 2.5	209	198	10	102	0.5158
2.5 – 3.0	125	117	9	74	0.6293
3.0 - 3.5	78	71	7	47	0.6638
3.5 – 4.0	46	50	-4	15	0.2955
4.0 - 4.5	30	36	-5	30	0.8433
4.5 – 5.0	21	26	-5	21	0.8143
5.0 - 5.5	13	18	-5	27	1.4748
5.5 – 6.0	7	13	-7	43	3.2939
6.0 - 6.5	7	9	-3	8	0.8607
6.5 – 7.0	7	7	0	0	0.0044
7.0 – 7.5	3	5	-2	5	
7.5 – 8.0	3	3	-1	1	
8.0 – 8.5	0	2	-2	6	
8.5 – 9.0	2	2	0	0	0.9136
9.0 - 9.5	1	1	0	0	
> 9.5	3	1	-2	4	
	1320	1320	0		$\chi^2_{CALC} = 13.9396$

$n = (I - 1 - p) = (15 - 1) - 4 = 10$. Significance Level = 0.05, $\chi^2_{ref} = 18.30$.

$\chi^2_{CALC} < \chi^2_{ref}$, $13.94 < 18.30$; Therefore, do not reject null hypothesis

4.2.3 Determining Entering Percent Following

Dixon et al. [7] conclude that it is appropriate to represent the effects of a signalized intersection on the downstream two-lane highway operations through the EPF parameters, as long as the percent following immediately downstream of a signalized intersection can be determined. In this study, the methodology for determining Entering Percent Following is based on Dixon et al.'s methodology. The main difference from their methodology is the application of distributions for time headway. As discussed in Section 4.2.2, the shifted negative exponential distribution and composite distribution are introduced into this methodology. Estimation of the percentage of entering traffic following is based on a flow profile immediately downstream of the signalized intersection. A flow profile immediately downstream of the signalized intersection at location “A” is shown in the Figure 4-7. The “A” denotes a location immediately downstream of the signalized intersection. As shown in the Figure 4-7, there are three movements that contribute to the flow profile:

- Movement 1: Primary contributing movement. They are through movements from the upstream major street;
- Movement 2: Secondary contributing movement. They are right-turn movements from the minor street; and
- Movement 3: Secondary contributing movement. They are left-turn movements from the minor street.

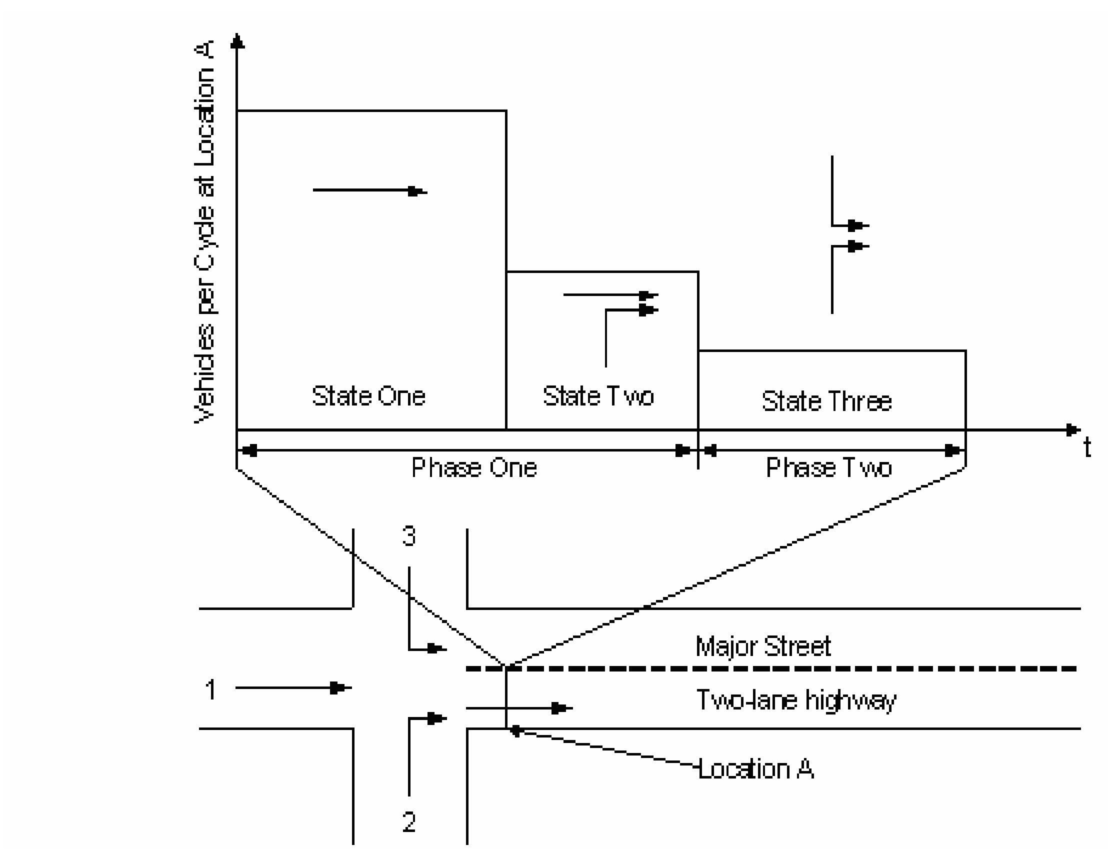

Figure 4-7: Two-lane highway traffic flow downstream of a signalized intersection

Source: Dixon, Michael P., Michael Kyte, and Satya Sai Kumar Sarepali. *Effects of Upstream Signalized Intersections on Two-Lane Highway Operations, Transportation Research Board, Washington D.C., 2004*

As shown in the Figure 4-7, the total cycle-length is divided into three states. The above three movements are charged through the three states. They are:

- First state: Discharged from the through movement queue during the first phase
- Second state: Discharge from the through movement without a queue plus any right-turn on red executed during the first phase
- Third state: Discharge from the right and left turn movements during the second phase

Entering percent following at location A can be estimated using equation 4-24:

$$EPF_a = \frac{VF_a}{V_a}$$
$$VF_a = \sum_i VF_i \qquad (4\text{-}24)$$

Where:

EPF_a: percent of vehicles following at Point A, immediately downstream of a signalized intersection,

VF_a: total number of vehicles following per cycle at location A, veh

VF_i: total number of vehicles following per cycle from movement i, veh, and

V_a: total number of vehicles per cycle at location A, veh

To determine the EPF_a, the key point is to decide on the value of the denominator, V_a, and numerator, VF_a. Because V_a is the summation of the cycle-by-cycle volumes from movements 1, 2, and 3, it can be determined if volumes for movements 1, 2 and 3 and the cycle length are known. This leaves the estimation of VF_a, the number of vehicles following at location A, which can be estimated by each movement.

Table 4-9 summarizes the values of Entering Percent Following under different traffic conditions and signal timing plans. Due to the complexity of the calculations, a Visual Basic program was developed to calculate the EPF values.

Table 4-9: Entering Percent Following

g/C=0.6					
		Cycle Length (sec)			Without signal
		60	90	120	
Traffic Volume	220	0.2069	0.2978	0.3433	0.1458
	440	0.4515	0.4969	0.5197	0.2778
	660	0.5988	0.6291	0.6442	0.3962
	880	0.7213	0.7441	0.7554	0.5015
	1100	0.8435	0.8617	0.8708	0.5941

g/C=0.7					
		Cycle Length (sec)			Without signal
		60	90	120	
Traffic Volume	220	0.1192	0.2101	0.2556	0.1458
	440	0.3662	0.4117	0.4344	0.2778
	660	0.5149	0.5452	0.5803	0.3962
	880	0.6372	0.6599	0.6713	0.5015
	1100	0.7789	0.7980	0.8071	0.5941
	1320	0.8657	0.8808	0.8884	0.6745

g/C=0.8					
		Cycle Length (sec)			Without signal
		60	90	120	
Traffic Volume	220	0.0324	0.1233	0.1687	0.1458
	440	0.2826	0.3281	0.3508	0.2778
	660	0.4334	0.4637	0.4789	0.3962
	880	0.5582	0.5789	0.5903	0.5015
	1100	0.7184	0.7366	0.7475	0.5941
	1320	0.8030	0.8182	0.8258	0.6745
	1540	0.8915	0.9045	0.9110	0.7434

After estimating EPF_a, the percent following immediately downstream of a signalized intersection is determined and then input into the TWOPAS model. A series of runs of TWOPAS model are performed to determine the effective length of a signalized intersection on the downstream two-lane segment, and performance measures (average travel speed and percent time-spent-following) of the downstream two-lane highway segment. The detailed procedure is presented in the next section.

4.2.4 Effective Length of a Signalized Intersection on the Downstream Segment

In the appendix section, the procedures to determine the Entering-Percent-Following for the conditions with no signalized intersection and where the signalized intersection is present were presented. In this section, the input variable, Entering-Percent-Following will be entered into the TWOPAS simulation model to illustrate the potential downstream effects of a signalized intersection on the two-lane highway operations. Two types of TWOPAS run were made with 10 replicate runs for each. The two conditions are as follows:

- A traffic stream of 600 veh/h travels along a two-lane highway with no signalized intersection.
- A traffic stream composed of through vehicles from the main street, left-turn vehicles and right-turn vehicles from the minor streets disperses from the signalized intersection into the downstream two-lane highway. The volumes of these three movements are 400 veh/h, 100 veh/h and 100 veh/h, respectively.

A value of *EPF* = 36.83% was used for the condition with no signalized intersection, assuming a volume of 600 veh/h. A higher value of *EPF* = 48.04% is used to represent the situation where a signalized intersection is present and modifying the headway distribution of a traffic stream consisting of 400 through vehicles from the main street, 100 left-turn vehicles from one minor street, and 100 right-turn vehicles from the cross-street entering the downstream two-lane highway segment.

A 5-mile section of two-lane highway was simulated using TWOPAS with the following conditions:

- Through movement saturation flow rate, s_1 = 1800 veh/h
- *PHF* = 1.0
- 100% passenger cars
- 0% no-passing zones
- 0% reduced speed zone
- Level terrain
- Lane width = 12 ft

- 50/50 directional split
- Two-phase timing plan
- Inter-green time is equal to the lost time per phase
- Desired speed and speed standard deviation using the recommended default values presented in Table 4-10.

Table 4-10: Recommended Default Values for Desired Speed by Vehicle Type

	Passenger Car	Recreational Vehicle	Truck
Mean Desired Speed (mi/h)	61.5	59.5	59.5
Standard Deviation (mi/h)	5.0	4.0	3.5

When establishing the TWOPAS model, a series of data collection stations were set along the two-lane highway at the interval of 100 ft. After simulation, the average travel speed at each data collection station was obtained from the TWOPAS output file. $ATS_{sig,i}$ denotes the average travel speed at the i^{th} data collection station on the two-lane highway with a signalized intersection. $ATS_{wo\_sig,i}$ denotes the average travel speed at the i^{th} data collection station on the two-lane highway without a signalized intersection. Figure 4-8 shows the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ along the two-lane highway downstream of the signalized intersection.

Point ‘O’ in Figure 4-8 is the location of the stop line of the signalized intersection. Point ‘C’ is the end of the two-lane highway downstream segment. The black thick line is the trendline of the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ along the roadway. As observed from Figure 4-8, when the traffic stream travels into the downstream segment from Point ‘O’, the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ becomes larger until it reaches the peak point (Point ‘A’). During the section (‘OA’), vehicles in the tight platoon have no opportunity to pass the slow leading vehicles and travel at the desired speed. It is mainly due to the initially tight platoon formed from the upstream signalized intersection. As traffic moves downstream, the initially tight platoon formed from the departing queue tends to disperse the farther downstream it travels. The platoon tends to spread out – a few moving ahead and some dropping back. After the peak point, it can be observed that the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ drops dramatically. It is mainly because the initially tight platoon formed from the signalized intersection has spread out and its effect is becoming smaller and smaller. Point 'B' can be considered as the transition point, at which point the decreasing slope changes from steep to fairly level. After Point 'B', the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ becomes negligible, near to 0.2 miles per hour. It still keeps dropping, but the decreasing rate becomes extremely small. After a certain distance, the platoon has spread out, and the impacts produced by the upstream signal on the platoon dispersion gradually disappear.

Based on the above discussion, the effective length of a signalized intersection on the downstream two-lane highway segment can be determined from the stop line of this signalized intersection to the point, at which the difference between $ATS_{sig,i}$ and $ATS_{wo\_sig,i}$ becomes negligible, and its decreasing rate becomes smaller.

To estimate the downstream effective length of a signalized intersection, a key issue is to measure the variation of the difference between ATS_{SIG} and ATS_{W_SIG}. Ideally, the downstream effective length of a signalized intersection can be measured from the on-site observation. However, available study sites are often too limited. Furthermore, it is very difficult to get the information about the difference in average travel speed between the condition with signalized intersection and without signalized intersection at the same location. In this study, TWOPAS is used to simulate traffic operations on the two-lane highway under different traffic conditions, and it is assumed that it is appropriate to represent the effects of a signalized intersection through the entering percent following parameter.

The average travel speed at the interval of 100 ft along the downstream two-lane highway can be obtained from the TWOPAS simulation output. Figure 4-9 illustrates the difference in the average travel speed between the condition of with a signalized intersection and with no signalized intersection. The traffic volume is 1100 veh/h. When the signalized intersection is present, the cycle length is 60 seconds, 90 seconds, and 120 seconds, respectively. The ratio of effective green time to the cycle length is 0.6, 0.7, and 0.8 respectively. The similar figures for the other levels of traffic volume are plotted.

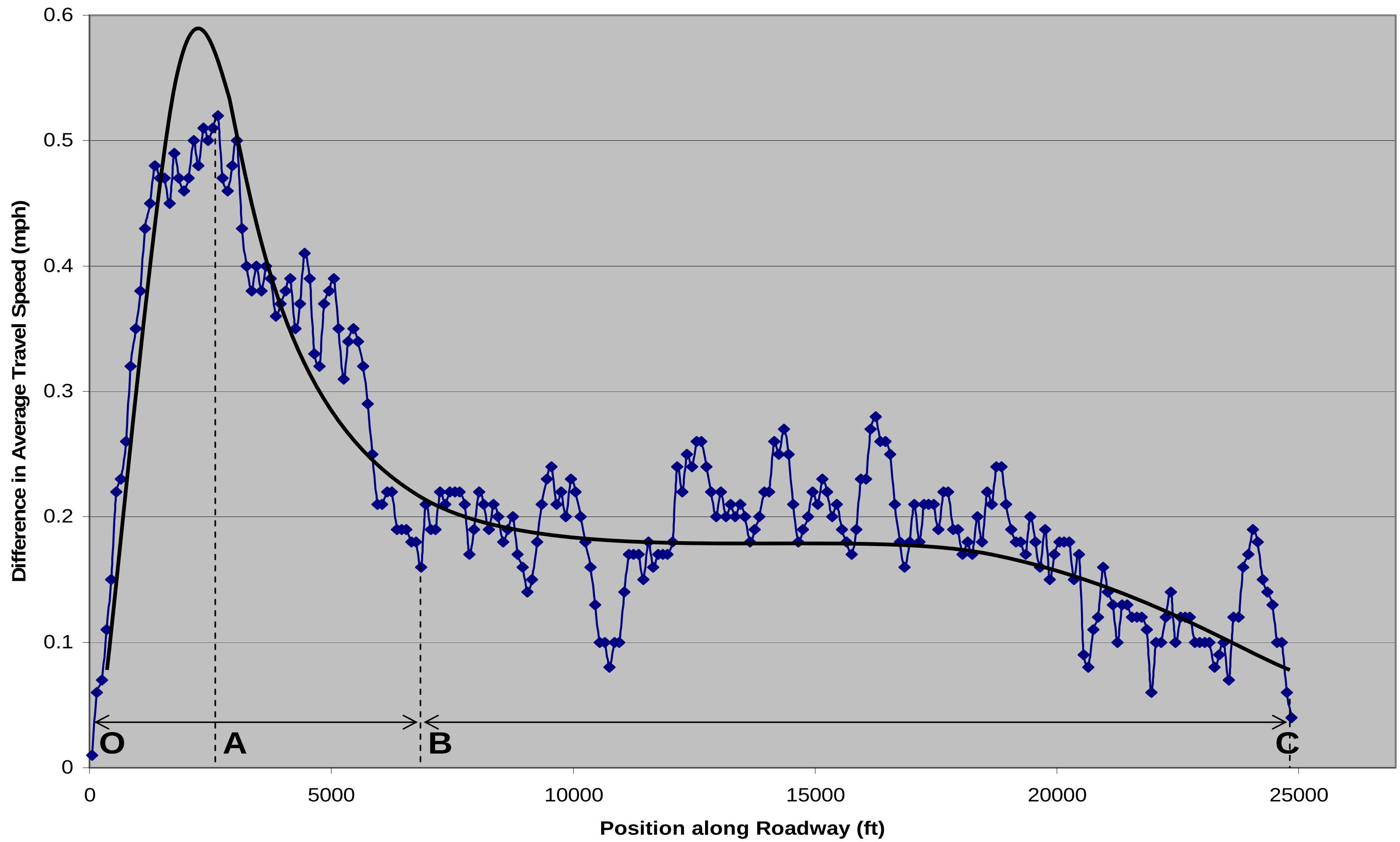

Figure 4-8: Difference in the Average Travel Speed along the Two-Lane Highway with or without Signalized Intersection

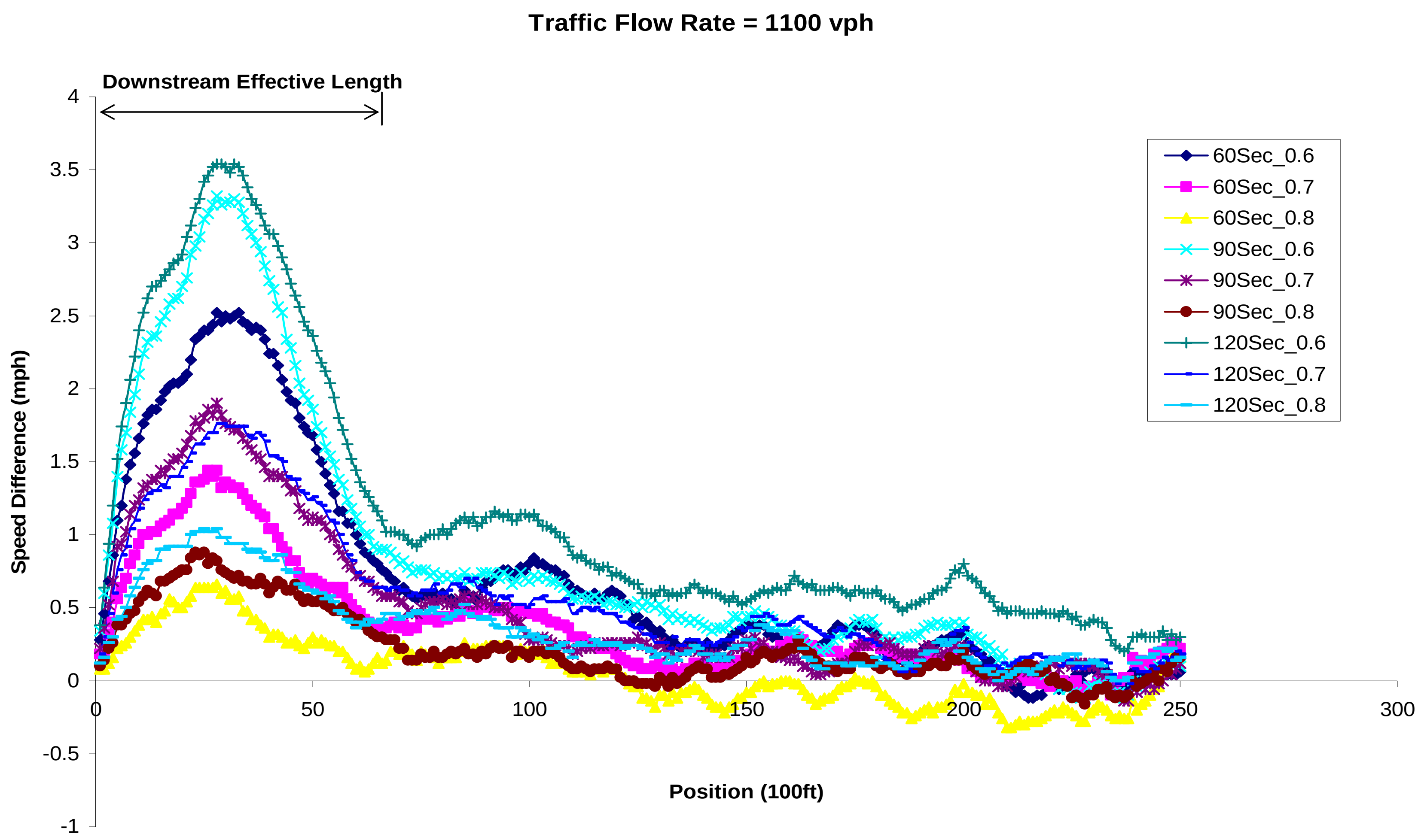

Figure 4-9: Difference in the Average Travel Speed with Traffic Volume = 1100 veh/h

On observing these figures, the following conclusions can be drawn:

- The traffic volume is the decisive factor for the downstream effective length of a signalized intersection. The larger the traffic volume into the downstream segment, the longer the downstream effective length.
- Cycle length and the ratio of effective green time to cycle length also have some effect on the downstream effective length of the signalized intersection influence area, but it is much smaller.

Based on the above analysis, it is was decided to develop a simplified model for the downstream effective length of a signalized intersection, that is, one that is just a function of directional traffic volume being served during the analysis period, as shown in Equation 4-25:

$$Len_{eff\_down} = 2.218584 - 0.122942 \times (V/100) \quad (4\text{-}25)$$

Where:

Len_{eff_down}: Downstream effective length of a signalized intersection, mi, and
V: Directional traffic flow rate, veh/h

Table 4-11: Regression model for the downstream effective length

R^2 = 0.98645; Adj. R^2 = 0.98306		
Variable	**Coeff.**	**t-stat**
Intercept	2.218584	38.8479
Volume/100	-0.122942	-17.0642

From the above model, it can be seen that the downstream effective length is inversely proportional to the traffic volume. As traffic volume increases, the downstream effective length decreases. When the traffic volume is low, the headway between vehicles is relatively large; thus, vehicles are generally not traveling in platoons and the average travel speed is at or very near to the free-flow speed. The presence of a controlled intersection introduces platooning in the traffic stream in the vicinity of the intersection. As the traffic stream discharges from upstream of the intersection into the downstream section beyond the intersection, it will take a relatively longer distance to return to the free-flow state from the platooned state. However, when the traffic flow rate is high, the headway between vehicles is much smaller; thus, a high percentage of vehicles are already in the platooned state and the average travel speed is lower than the free-flow speed. As the traffic stream discharges from upstream of the intersection into the downstream section beyond the intersection, it will take a relatively shorter distance to return to a similar platoon state from the signal queued state.

This method of determining the effective length of an isolated signalized intersection influence area on the downstream two-lane highway segment takes full advantage of TWOPAS's ability to simulate traffic operations on the two-lane highway. It also applies the parameter of Entering Percent Following at the immediate downstream point of a signalized intersection to reflect the potential effect of a signalized intersection on the downstream two-lane highway operation. The evaluation for this methodology will be done in the next section.

4.2.5 Evaluation Based on CORSIM Simulation

TWOPAS is the only simulation software that is able to simulate the passing maneuver operation on the two-lane highway using the opposing lane, and was developed with U.S. data. In this study, TWOPAS was used to study the effects of the signalized intersection on the downstream segment with the reasonable Entering Percent Following input variables. In this section, a simulation approach is used to evaluate the methodology for determining the downstream effective length of a signalized intersection on the two-lane highway.

The CORSIM simulation model was selected as the traffic simulator. It can analyze a wide range of traffic, geometric, and control conditions and produces a relatively rich set of performance measures. CORSIM is not able to simulate the passing operation on the two-lane highway using the opposing lane, but this drawback will be considered in the results analysis.

A two-way, two-lane roadway network with an isolated fixed-time signalized intersection was simulated using CORSIM. It was a total of 5 miles in length, and the isolated intersection was located at the 0.5-mile point. Once the CORSIM base road network was developed, the values for the independent variables were systematically changed to model different scenarios. After simulation, average travel speeds at the interval of 0.025 miles along the two-lane roadway are obtained from the CORSIM output file. The downstream effective length of a signalized intersection based on average travel speed can be determined from its variation trend. Figure 4-10 shows the average travel speed variation along the downstream two-lane highway segment of a signalized intersection and the average travel speed variation under the condition with no signalized intersection, assuming the traffic flow rate is 220 veh/h. The red line represents the average travel speed variation with no signalized intersection. The other lines represent the average travel speed variation with a signalized intersection, which have different cycle lengths and g/C (the ratio of green time to the cycle length).

As observed from this figure, after the signalized intersection, vehicles travel some distance to return to the speed at which they would have traveled under the condition of no signalized intersection. According to the average travel speed variation under the two conditions, the distance of OB in this figure is defined as the downstream effective length due to the influence of the signalized intersection. In addition, it can be observed that with the same traffic flow rate, there is not a large difference in the variation of average travel speed when the signalized intersections have different cycle lengths and g/C ratios. These phenomena are the same with the conclusion drawn from the methodology for determining the downstream effective length of a signalized influence area presented in Section 4.2.4. The similar figures are plotted for other levels of traffic volume. As observed from these figures, the downstream effective lengths from CORSIM simulation are presented in Table 4-12.

Table 4-12: Comparison of Downstream Effective Length

Volume (veh/h)	Effective Downstream Length from CORSIM, (mi)	Effective Downstream Length Equation 4-26, (mi)	Difference (mi)
200	2.05	1.972	0.078
400	1.60	1.728	-0.128
600	1.35	1.480	-0.130
800	1.05	1.234	-0.184
1000	0.65	0.988	-0.338

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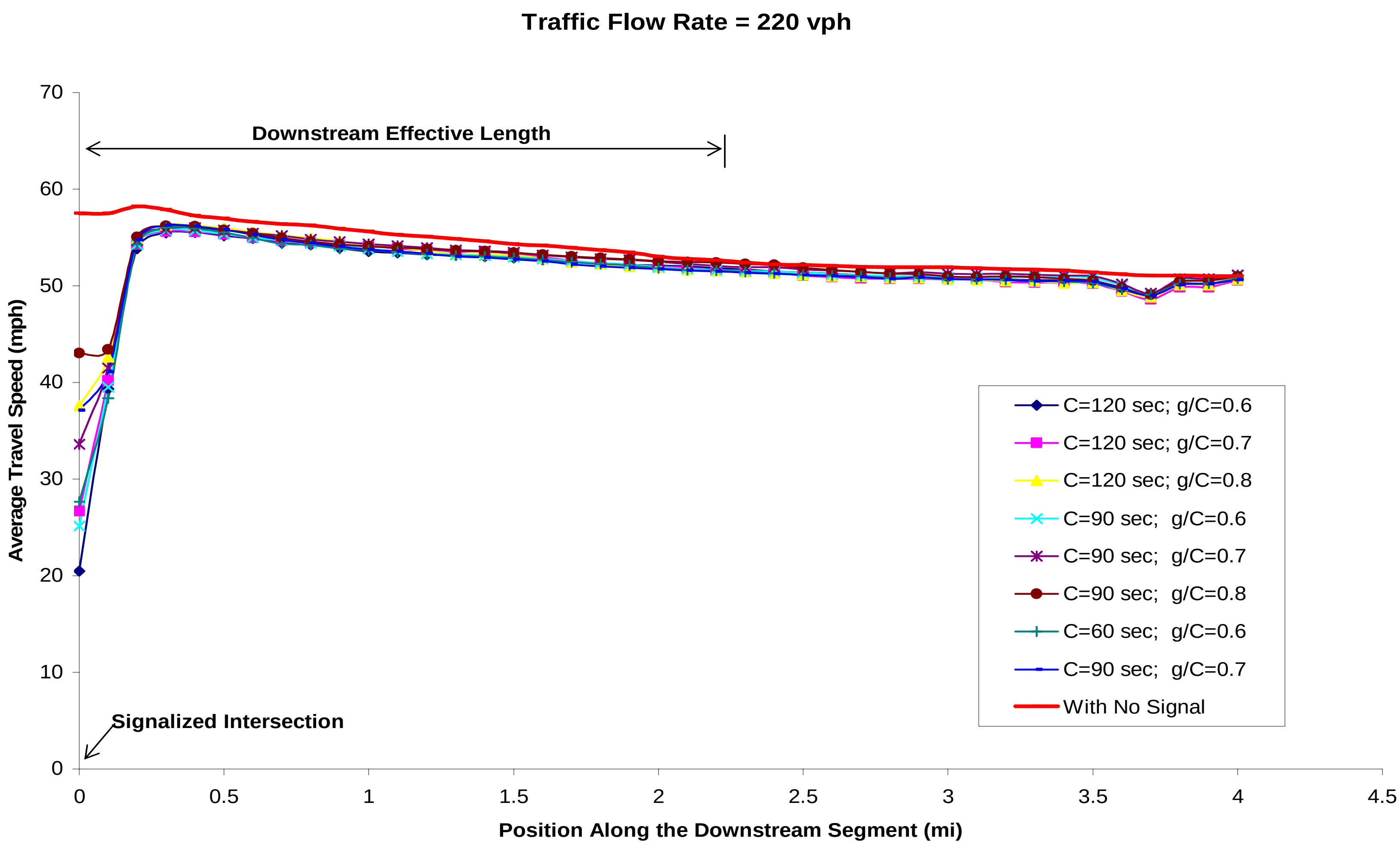


Figure 4-10: Average Travel Speed Variation with Traffic Volume = 220 veh/h

As observed from Table 4-12, the downstream effective length of a signalized intersection from CORSIM simulation is also inversely proportional to the traffic flow rate. Through comparing the results obtained from the TWOPAS methodology with those from CORSIM simulation, it can be seen that when the traffic flow rate is low (such as 200 veh/h, 400 veh/h), the results obtained from the CORSIM simulation is very much in agreement with those obtained from the verified TWOPAS methodology. Although CORSIM has no ability to simulate the passing maneuver on the two-lane highway using the opposing lane, the low passing percentage under the low traffic demand on the two-lane highway weakens the effect of this drawback. When the traffic flow rate increase, the effective length obtained from the CORSIM simulation models are shorter than those obtained from the TWOPAS methodology. As the traffic flow rate increases, the traffic passing percentage also increases. The passing demand on the condition without any signalized intersection is larger than with a signalized intersection. It is CORSIM’s inability of simulating passing maneuvers on the two-lane highway using the opposing lane that makes vehicle speeds drop quickly for the condition without any signalized intersection than for the condition with a signalized intersection. Therefore, the downstream effective lengths obtained from the CORSIM simulation model are shorter than these from TWOPAS when the traffic volume is higher. Based on the above comparison, it can be concluded that the downstream effective lengths obtained from TWOPAS essentially match those obtained from the CORSIM simulation.

CHAPTER 5
ESTIMATION OF SERVICE MEASURE VALUES

Chapter 3 described conceptually the methodological framework for performing a facility level analysis of a two-lane highway that includes occasional signalized intersections. Chapter 4 described the procedures for determining component segment lengths of the facility. This chapter describes the methods for calculating the service measure values of each of these segment types.

This chapter begins with procedures for determining the free-flow speed on the two-lane highway segment. Next, this chapter presents how to determine average travel speed on three kinds of two-lane highway segments: the basic two-lane highway segment that is unaffected by a signalized intersection, the downstream two-lane highway segment within the effects of the installed signalized intersection, and a two-lane highway with a passing lane. Finally, the formulas for calculating control delay at the signalized intersection are presented.

5.1 Free-Flow Speed Estimation

Free-Flow Speed (*FFS*) is the average speed of the traffic stream when the traffic volume is sufficiently low such that drivers are not influenced by the presence of other vehicles and when intersection traffic control is not present or is sufficiently distant as to have no effect on speed choice.

In estimating expected operating conditions of a two-lane highway facility, the free-flow speed is a significant variable. The chosen service measure for this facility analysis methodology, percent time-delayed, is defined as the percentage of the travel time that a vehicle on a given roadway segment must travel at speeds less than their desired speed due to the inability to pass or traffic control during some designed time interval. There is actually no practical method by which to measure drivers' desired speed in the field. In practice, the desired speed, on aggregate, is usually considered to be the free-flow speed. In addition, free-flow speed is a necessary variable when calculating the average travel speed on the two-lane highway segment.

Two general methods are recommended in the HCM 2000 [1] to determine the *FFS* for a two-lane highway: field measurement, and estimation of free-flow speed. They are repeated here for convenience.

5.1.1 Field Measurement of Free-Flow Speed

The Free-flow-speed of a two-lane highway can be determined directly from a speed study conducted in the field. The speed study should be conducted at a representative site within the study section. The best location to measure free-flow speed on the two-lane highway is mid-block and as far as possible from the nearest signalized or stop-controlled intersection. The measurement should be made under low flow conditions (less than 200 veh/h). The most appropriate section for performing a field study for the free-flow speed is the segment which is not affected by the installed signalized intersection.

Free-flow speeds may be directly measured as follows:

- A representative speed sample of 100 or more vehicle should be obtained.
- Total two-way traffic flow should be 200 pc/h or less.
- All vehicle speeds should be observed during the study period, or a systematic sampling should be applied.
- When a two-direction analysis is considered, the speed sample should be selected from both directions of flow; when a one-direction analysis is considered, the speed sample should be selected only from the direction under study.

If field measurements must be made at a total flow level higher than 200 pc/h, the free-flow speed may be estimated as:

$$FFS = S_m + 0.00776\left(\frac{v_f}{f_{HV}}\right) \tag{5-1}$$

Where:

FFS: free-flow speed for the facility, mi/h

S_m: mean speed of the measure sample (where the total flow is greater than 200 veh/h), mi/h

V_f : observed flow rate for the period of the speed sample, veh/h

f_{HV} : heavy vehicle adjustment factor

If field measurement of the highway is not feasible, data taken at a similar facility may be used.

5.1.2 Estimating Free-Flow Speeds

If field observation of free-flow speed is available, the free-flow speed on a two-lane rural highway may be estimated indirectly. Because the free-flow speed of a two-lane highway can range from 45 to 65 mi/h, this is a greater challenge on two-lane highways than on other types of uninterrupted-flow facilities. The free-flow speed can be estimated by applying the adjustments to the base free-flow speed (*BFFS*) using Equation 5-2 [1]:

$$FFS = BFFS - f_{LS} - f_A \tag{5-2}$$

Where:

FFS: estimated free-flow speed for the facility, mi/h

BFFS: base free-flow speed for the facility, mi/h

f_{LS}: adjustment for lane and shoulder width, mi/h

f_A: adjustment for access point density, mi/h

There are three important variables in the above estimating formula; the base free-flow speed (*BFFS*), adjustment for lane and shoulder widths, and adjustment for access point density. Note that because of the broad range of speed conditions on two-lane highways and the importance of local and regional factors that influence drive-desired speeds, the HCM 2000 does not provide any detailed criteria for estimating the *BFFS*. It is limited to a range of 45-65 mi/h. The adjustment factors for lane and shoulder width are shown in Table 5-1. The adjustment factors for access point density are shown in Table 5-2.

Table 5-1: Adjustment (f_{LS}) for Lane Width and Shoulder Width

Lane Width (ft)	Reduction in FFS (mi/h)			
	Shoulder Width (ft)			
	>= 0 < 2	>= 2 < 4	>= 4 < 6	>=6
9 < 10	6.4	4.8	3.5	2.2
>= 10 < 11	5.3	3.7	2.4	1.1
>= 11 < 12	4.7	3.0	1.7	0.4
>= 12	4.2	2.6	1.3	0.0

Source: HCM 2000, Chapter 20

Table 5-2: Adjustment (f_A) for Access-point Density

Access Points per mi	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
40	10.0

Source: HCM 2000, Chapter 20

5.2 Performance Measure on the Unaffected Two-Lane Highway Segment

The HCM 2000 Chapter 16 [1] presents operational analysis methodologies for two-way and directional segments of two-lane highways. On a two-lane highway with different types of segments, such as a signalized intersection, an un-signalized intersection, and/or a passing lane, two-way segments typically do not have homogeneous cross sections or relatively constant demand volumes and vehicle mix proportions in the two directions. Thus, a separate analysis by direction of travel is particularly appropriate. The segment directional methodology for determining the average travel speed on the basic two-lane highway segment is repeated here for convenience.

Determining *FFS*

The first step in the analysis of a directional segment is to determine *FFS*. *FFS* can be determined by field measurement or estimation, which has been reviewed in Section 5.1. Note that these methods should be applied on a directional basis rather than to both directions combined.

Determining Demand Flow Rate

This demand flow rate should be based on the *PHF*, the traffic composition, and the terrain or actual grade in the specific direction of travel. The demand flow rate for the peak 15-min period in the direction analyzed is determined with Equation 5-3 [1]:

$$v_d = \frac{V}{PHF \times f_G \times f_{HV}} \quad (5\text{-}3)$$

Where:

v_d: passenger-car equivalent flow rate for the peak 15-min period in the direction analyzed (pc/h)

V: demand volume for the full peak hour in the direction analyzed (veh/h)

f_G: grade adjustment factor, and

f_{HV}: heavy-vehicle adjustment factor

A directional analysis also requires consideration of the demand flow rate in the opposing direction. The opposing demand flow rate is computed using Equation 5-4 [1].

$$v_o = \frac{V_o}{PHF \times f_G \times f_{HV}} \quad (5\text{-}4)$$

Where:

v_o: passenger-car equivalent flow rate for the peak 15-min period in the opposing direction of travel, and

V_o: demand volume for the full peak hour in the opposing direction of travel.

Determining Average Travel Speed

The average travel speed is estimated from the FFS, the demand flow rate, and an adjustment factor for the percentage of no-passing zones. Average travel speed is then estimated using Equation 5-5 [1].

$$ATS_d = FFS_d - 0.00776(v_d + v_o) - f_{np} \quad (5\text{-}5)$$

Where:

ATS_d : average travel speed in the analysis direction (mi/h)

FFS_d : free-flow speed in the analysis direction (mi/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)

f_{np}: adjustment for percentage of no-passing zones in the analysis direction

The detailed procedure is described in Chapter 20 (*Two-lane Highways*) of the HCM 2000.

5.3 Performance Measure on an Affected Two-Lane Highway Segment

The presence of a signalized intersection on a two-lane highway can significantly affect traffic operations on the downstream two-lane highway segment, such as decreasing travel speed, and increasing percent time-spent-following. In this section, the methodology is described, by which the effects of an isolated signalized intersection on a downstream two-lane highway segment can be estimated in terms of average travel speed. That is, to quantify the decrease of average travel speed within the downstream effective length caused by the upstream signalized intersection. The procedure can be broken down into three steps.

Step 1: Determine the average travel speed for the basic two-lane highway section without the signalized intersection, ATS_1.

Step 2: Determine the adjustment factor for the effect of a signalized intersection on average travel speed within the downstream effective length, f_{ATS}.

Step 3: Determine the average travel speed within the downstream effective length, ATS_2.

Step 1: Determine *ATS* without signalized intersection, ATS_1

Two methods can be used to estimate the directional *ATS* for the two-lane highway. One is by microscopic simulation, and the other is using the HCM 2000 directional analysis procedure. The directional analysis procedure is described in detail in the HCM 2000.

Step 2: Determine the adjustment factor for the effect of a signalized intersection on average travel speed, f_{ATS}

This step can be broken down into three sub-steps. First, divide the downstream effective length of a signalized intersection influence area into multiple short equal-distance intervals, then determine the average travel speed within each interval. Second, divide the two-lane highway segment without an intersection into multiple short equal-distance intervals. Then determine the average travel speed within each interval. Note that the length of each interval is equal to the one above. Third, determine the adjustment factor for the effect of a signalized intersection on the average travel speed of its downstream two-lane highway segment. The first two sub-steps can be performed with TWOPAS simulation. The simulation procedure is similar to the one for deciding the downstream effective length of a signalized intersection described in the last chapter. The characteristics of the highway section used in the simulation are also the same as those used to determine the downstream effective length of a signal influence area. Here the third sub-step is discussed in detail.

Figure 1 shows the difference between $ATS_{1,i}$ and $ATS_{2,i}$ along the facility. This figure is from the output of TWOPAS runs. $ATS_{1,i}$ denotes the average travel speed of the *i*th interval within a two-lane highway with no signalized intersection. $ATS_{2,i}$ denotes the average travel speed of the *i*th interval within a two-lane highway segment downstream of a signalized intersection. The line AB in this figure represents the downstream effective length of a signal influence area, which is divided into multiple equal-distance small intervals. The adjustment factor for ATS is calculated as the average difference between $ATS_{1,i}$ and $ATS_{2,i}$ along the facility, that is

$$f_{ATS} = \frac{1}{n}\sum_{i=1}^{n}(ATS_{1,i} - ATS_{2,i}) \qquad (5\text{-}6)$$

Where"

f_{ATS} : adjustment factor for the effect of a signalized intersection on average travel speed within the downstream effective length of the signal influence area,

$ATS_{1,i}$: average travel speed of the *i*th section of a two-lane highway without a signalized intersection, mph,

$ATS_{2,i}$: average travel speed of the ith section of a two-lane highway downstream of a signalized intersection, mph, and

n: number of sections within the downstream effective length of a signal influence area.

The difference in average travel speed (Δv) between a two-lane highway with a signalized intersection and without a signalized intersection of ith interval, lying between the ith observing station i and the (i+1)th observing station, can be simplified to the following formula:

$$\Delta v(i+\frac{1}{2}) = \frac{\Delta v(i) + \Delta v(i+1)}{2}$$

And can be donated in Figure 5-1 as the line, $\Delta v(i+\frac{1}{2})$.

Note that the assumption is that the average travel speed variation curve is a straight line over the interval between the ith observing station and the (i+1)th observing station . This approximate solution is acceptable when the distance interval of Δx is small. The adjustment factor for average travel speed can be calculated using Equation 5-7 or Equation 5-8,

$$f_{ATS} = \frac{1}{n}\left(\frac{(\Delta v_1 + \Delta v_2)}{2} + \frac{(\Delta v_2 + \Delta v_3)}{2} + \cdots\cdots + \frac{(\Delta v_{n-1} + \Delta v_n)}{2} + \frac{(\Delta v_n + \Delta v_{n+1})}{2}\right) \quad (5\text{-}7)$$

or

$$f_{ATS} = \frac{1}{2n}\left(\sum_{i=1}^{n+1} \Delta v_i - (\Delta v_1 + \Delta v_{n+1})\right) \quad (5\text{-}8)$$

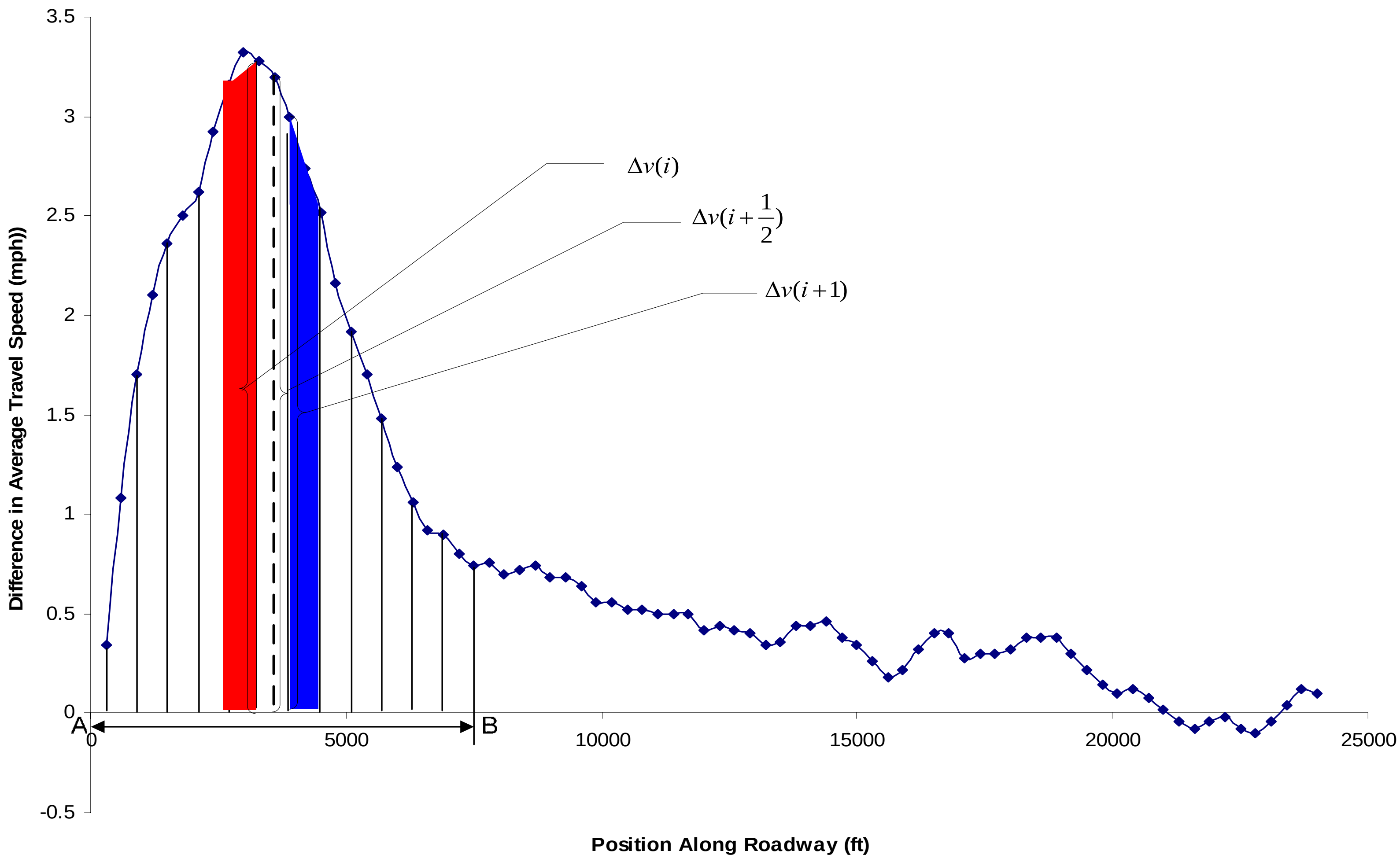


Figure 5-1: Downstream Operational Effects of a Signalized Intersection on ATS

Step 3: Determine the average travel speed for the downstream highway section within the downstream effective length, ATS_2.

Average travel speed within the downstream effective length of a signalized intersection is generally lower than the average travel speed without a signalized intersection. The effect varies as a function of the directional flow rate and the timing plan of the signalized intersection. The adjustment factors are presented in Table 5-3. Within the downstream effective length, average travel speed is assumed to decrease evenly to the value without the effect of the upstream signalized intersection. Thus, the average travel speed within the downstream effective length of a signalized intersection can be computed using Equation 5-9:

$$ATS_2 = ATS_1 - f_{ATS} \tag{5-9}$$

Where:

ATS_2: average travel speed within the downstream effective length of the upstream signalized intersection, mi/h,

ATS_1: average travel speed without the effect of a signalized intersection, mi/h, and

f_{ATS}: adjustment factor for the effect of a signalized intersection on the average travel speed within the downstream effective length, mi/h.

Table 5-3: Adjustment factor, f_{ATS}, to Average Travel Speed for a Segment Downstream of a Signalized Intersection

Directional Demand Flow Rate, (pc/h)	Average Travel Speed (mi/h)			
	60	55	50	45
Cycle Length=60, g/C=0.6				
<=220	0.908	0.835	0.762	0.689
440	1.051	0.978	0.905	0.832
660	1.437	1.284	1.130	0.976
880	1.824	1.589	1.354	1.119
1100	2.210	1.894	1.579	1.263
Cycle Length=60, g/C=0.7				
<=220	0.676	0.599	0.522	0.445
440	0.741	0.664	0.587	0.510
660	0.921	0.806	0.691	0.575
880	1.102	0.948	0.794	0.641

1100	1.282	1.090	0.898	0.706
Cycle Length=60, g/C=0.8				
<=220	0.382	0.321	0.260	0.198
440	0.484	0.423	0.361	0.300
660	0.595	0.530	0.466	0.402
880	0.705	0.638	0.571	0.503
1100	0.816	0.746	0.675	0.605
Cycle Length=90, g/C=0.6				
<=220	1.135	1.006	0.878	0.749
440	1.320	1.191	1.062	0.933
660	1.800	1.573	1.345	1.117
880	2.281	1.954	1.628	1.302
1100	2.761	2.336	1.911	1.486
Cycle Length=90, g/C=0.7				
<=220	0.814	0.703	0.592	0.482
440	0.912	0.801	0.691	0.580
660	1.107	0.964	0.821	0.678
880	1.303	1.127	0.952	0.777
1100	1.498	1.290	1.083	0.875
Cycle Length=90, g/C=0.8				
<=220	0.432	0.371	0.310	0.248
440	0.534	0.473	0.411	0.350
660	0.645	0.580	0.516	0.452
880	0.755	0.688	0.621	0.553
1100	0.866	0.796	0.725	0.655
Cycle Length=120, g/C=0.6				
<=220	1.229	1.060	0.892	0.724
440	1.485	1.317	1.148	0.980
660	1.945	1.709	1.472	1.236
880	2.404	2.100	1.797	1.493
1100	2.864	2.492	2.121	1.749
Cycle Length=120, g/C=0.7				
<=220	0.855	0.812	0.769	0.726
440	0.929	0.886	0.843	0.800
660	1.128	1.043	0.959	0.874
880	1.326	1.200	1.074	0.948
1100	1.525	1.357	1.190	1.022
Cycle Length=120, g/C=0.8				
<=220	0.505	0.454	0.403	0.352
440	0.583	0.532	0.481	0.430
660	0.718	0.648	0.578	0.508
880	0.852	0.763	0.675	0.587
>=1100	0.986	0.879	0.772	0.665

5.4 Service Measure on a Two-Lane Highway with a Passing Lane

When traffic operational problems occur on a two-lane highway, one method for alleviating these problems is to provide passing lanes at regular intervals. Passing lanes cannot increase the capacity of a two-lane highway but can improve its level of service [1]. A passing lane is a lane added in one direction of travel on a conventional two-lane highway to improve opportunities for passing. The addition of a passing lane to a two-lane highway provides a three-lane cross section with two lanes in one direction of travel and one lane in the other.

Chapter 20 in the HCM 2000 provides an operational analysis procedure for a passing lane on a two-lane highway. Here the procedure to determine average travel speed on the two-lane highway with a passing lane is presented.

The first step in the operation analysis of a passing lane is to apply the procedure for directional segment to the normal cross section without the passing lane. The result is the average travel speed, ATS_d, for the normal two-lane cross section. Installation of a passing lane provides operational benefits for some distance downstream before average travel speed returns to its former level. Thus, the effective length of a passing lane is greater than its actual length. The second step is to divide the analysis segment into four regions. Figure 5-2 shows the segment division and variation in average travel speed in a two-lane highway segment with a passing lane. These divided regions are:

1. Upstream of the passing lane
2. The passing lane
3. Downstream of the passing lane but with its effective length
4. Downstream of the passing lane but beyond its effective length

These four lengths add up to the total length of the analysis segment. The HCM 2000 provides a table on the downstream length of roadway affected by passing lanes on directional segment, L_{de}. The lengths of other regions can be determined by the actual placement of the passing lane within the analysis section. Table 5-4 shows the downstream length of two-lane highway affected by a passing lane, based on the average travel speed.

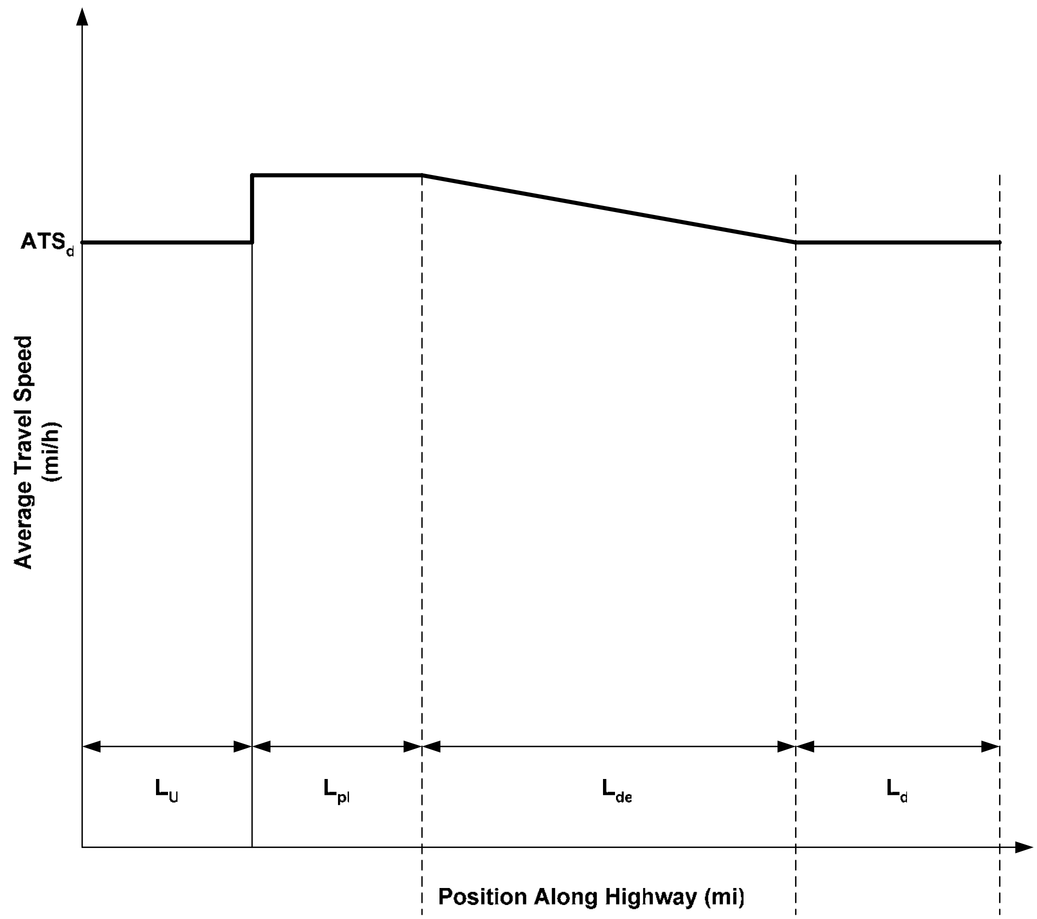


Figure 5-2: Effect of a Passing Lane on Average Travel Speed

Table 5-4: Downstream Length of Roadway Affected by Passing Lane

Directional Flow Rate (pc/h)	Downstream Length of Roadway Affected, L_{de} (mi)
	Average Travel Speed
<= 200	1.7
400	1.7
700	1.7
>=1000	1.7

Source: HCM 2000, Chapter 20

The next step is to determine the average travel speed. Average travel speed with lengths L_u and L_d is assumed to equal ATS_d, as predicted by the directional segment procedure. Within the passing lane, average travel speed is generally 8 to 11 percent higher than its upstream value. This effect varies as a function of directional flow rate, as shown in Table

5-5. Within the downstream length, L_{de}, average travel speed is assumed to decrease linearly with distance from the within-passing lane value to its normal upstream value. Thus, the average travel speed with the passing lane in place can be computed using equation 5-10 [1].

$$ATS_{pl} = \frac{ATS_d \times L_t}{L_u + L_d + \dfrac{L}{f_{pl}} + \dfrac{2L_{de}}{1 + f_{pl}}} \qquad (5\text{-}10)$$

Where

ATS_{pl}: average travel speed for the entire segment including the passing lane (mi/h)

ATS_d: average travel speed for the entire segment without the passing lane

f_{pl}: factor for the effect of a passing lane on average travel speed

Table 5-5: Factors for Estimation of Average Travel Speed within a Passing Lane

Directional Flow Rate (pc/h)	Average Travel Speed
0 – 300	1.08
> 300 – 600	1.10
> 600	1.11

Source: HCM 2000, Chapter 20

5.5 Service Measure at a Signalized Intersection

The HCM 2000 uses control delay as the service measure for a signalized intersection. Control delay includes "movements at slower speed and stops on intersection approaches as vehicles move up in queue position or slow down upstream of an intersection".

The delay model incorporated in the HCM 2000 includes the uniform delay, a version of Akcelik's [1] overflow delay model, and a term covering delay from an existing or residual queue at the beginning of the analysis period. The control delay per vehicle for a given lane group is given by the following formulas, directly from the HCM 2000. Equation 5-12 gives an estimate of control delay assuming uniform arrivals and stable flow. It is based on the first term of Webster's delay formulation. Equation 5-13 gives an estimate of the incremental delay due to non-uniform arrivals and individual cycle failures, as well as delay caused by sustained periods of over-saturation. Equation 5-14 gives an estimate of the initial queue delay from the previous period at the start of the analysis.

$$d = d_1(PF) + d_2 + d_3 \tag{5-11}$$

$$d_1 = \frac{0.5C(1-\frac{g}{C})^2}{1-[\min(1,X)\frac{g}{C}]} \tag{5-12}$$

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8klX}{cT}}\right] \tag{5-13}$$

$$d_3 = \frac{1800Q_b(1+u)t}{cT} \tag{5-14}$$

Where:

d: control delay per vehicle, s/veh

d_1: uniform control delay, s/veh

d_2: incremental delay, s/veh

d_3: initial queue delay, s/veh

PF: progression adjustment factor

T: analysis period, h

X: v/c ratio

C: cycle length, s

k: incremental delay factor for actuated controller settings

I: upstream filtering/metering adjustment factor

c: capacity, veh/h

Q_b: initial queue at the start of analysis period

u: delay parameter

t: duration of unmet demand in analysis period

The progression adjustment factor is an important factor in calculating the control delay. It is an empirically calibrated adjustment to uniform delay that accounts for the effect of platooned arrival patterns or signal coordination. Progression primarily affects uniform delay, so the progression adjustment factor is applied only to d_1. The value of PF can be determined by Equation 5-15.

$$PF = \frac{(1-P)f_{PA}}{1-\frac{g}{C}} \quad (5\text{-}15)$$

Where:

PF: progression adjustment factor

P: proportion of all vehicles arriving during green

g/C: effective green to cycle length ratio

f_{PA}: supplemental adjustment factor for platoon arrival during the green

The procedure of calculating control delay at a signalized intersection is described in detail in the HCM 2000, Chapter 16, *Signalized Intersections*.

5.6 Level of Service Thresholds

To complete a level of service (LOS) methodology, it is necessary to define values of the service measure that serve to delineate between the various levels of service, A-F. The selected values, or thresholds, should be chosen such that they correspond to drivers' level of satisfaction with the operating conditions for the given level of the service measure.

However, without the benefit of research that directly investigates driver satisfaction on these facilities under varying levels of the service measure, there is no way to be sure that the chosen thresholds correlate with driver expectations. Nonetheless, threshold values must still be chosen such that a level of service value can be assigned to the analysis results.

Although the selection of these threshold values is somewhat arbitrary without the benefit of driver perception-based research, there is some existing information that can be used to guide the threshold value selection. This information is the existing LOS thresholds for basic two-lane highway segments. It is important to recognize that adding a signalized intersection along a two-lane highway should not result in an improvement to the LOS that would be estimated for an equivalent two-lane highway with no signalized intersection(s) present.

Preliminary LOS threshold values have been selected and are shown in Table 5-6. The application of these thresholds is demonstrated in the example problems of Chapter 6.

Table 5-6: LOS Criteria for Two-Lane Highway Facilities

Level of Service	Percent Time-Delayed
A	< 7.5%
B	7.5%-15%
C	15%-25%
D	25%-35%
E	35%-45%
F	> 45%

5.7 Application of Methodology to Multilane Highways

Multilane highway segments and freeway segments currently share the same service measure, density. Given the similarity in operational features of these segments, this makes some sense. However, in some respects, multilane highways that include the presence of signalized intersections have more in common with signalized arterials or two-lane highways (with occasional signals) than freeways. Since freeways, by definition, are always uninterrupted, it becomes more difficult to make comparisons between an interrupted facility and one that includes occasional interruptions.

Combining multilane highway segments, that use density for the service measure, with signalized intersections, that use delay as the service measure, poses the same challenge as that for two-lane highways and signalized intersections. That is, the service measures for each facility type are somewhat disparate, but even more so in the case of multilane highways and signals, as the density measure has no time component to it, whereas the signal delay measure is strictly time-based.

As was done for this two-lane facility analysis methodology, a speed/delay measure can be implemented for multilane highways. However, as indicated by current empirical evidence, average speeds on multilane highways (as well as freeways) are relatively constant up to fairly high flow rates, and thus LOS based upon speed does not reflect the likely discomfort experienced by travelers for increasing flow rates. Density, on the other hand, always increases with increasing flow rate (for under-saturated conditions) and thus reflects traveler discomfort more adequately. To some extent, the use of speed for two-lane highways has the same limitations (compared to percent time-spent-following); however, speed is more readily impacted by flow rate on two-lane highways due to the need to use the oncoming lane for passing maneuvers.

Percent time-spent-following may be more applicable than speed on multilane highways, as it correlates better with increasing density (decreasing headways) at lower volumes. Although this measure has a time component to it, it would still require some manipulation to be compatible with the delay measure of signalized intersections. Alternatively, the signal delay measure might be manipulated to be yield a comparable *PTSF* value. While these manipulations may also have been possible for the two-lane highway facility methodology, it should be noted again that one of the recognized drawbacks of the *PTSF* measure was its potential lack of applicability to certain types of two-lane highways. Furthermore, these manipulations of either the *PTSF* measure or the signal delay measure would potentially lead to a less intuitive level of service methodology.

CHAPTER 6
APPLICATION EXAMPLES

The methodologies developed in this research can be used to assess the operational performance of an extended length of a two-lane highway facility, comprised of multiple segments, with segment delineations occurring with a change in either roadway or control attributes. A common application of the methodologies is to compute the LOS of a current or a changed facility in the near term or in the future. The primary outputs are the performance measure values of delay time and percent time-delayed, as well as a level of service ranking.

This report focuses the efforts on developing the methodology for operational analysis of a two-lane highway with an isolated signalized intersection at the facility level. Nonetheless, it is intended that this research will also provide a model for the basic structure of a facility level analysis that will be amenable to the incorporation of a variety of segment types. In this chapter, two examples are provided to illustrate the application of the developed methodology.

6.1 Example 1

The Facility: A rural two-lane highway facility extends 7 miles with an isolated signalized intersection at the 3-mile point. Figure 6.1(a) illustrates the components of the facility.

The Question: What is the percent time-delayed and level of service of this two-lane highway facility for the peak hour?

The Facts:

- ***Roadway Data***

➢ Level terrain	➢ 60 mi/h base FFS
➢ 6-ft shoulder width	➢ 12-ft lane width
➢ 5 access points/mi	➢ 50% no-passing zones
➢ Downstream with 4-mile length	➢ Upstream with 3-mile length

- ***Traffic Data***

➢ 1000 veh/h (two-way volume) ➢ 3 percent trucks and buses ➢ 0.95 PHF	➢ 60/40 split ➢ 2 percent RVs

- ***Control Data***

➢ EB and WB HV=5 percent ➢ 0.95 PHF ➢ EB-WB green=54 s, NB-SB green=26 s ➢ Cross street has one lane in each direction ➢ 6-ft shoulder width ➢ No parking at intersection	➢ NB and SB HV=5 percent ➢ Two-phase signal ➢ Yellow=4 s ➢ Main street has one lane and a left-turn bay in each direction. ➢ Movement lost time=5 s ➢ 12-ft lane width ➢ Level terrain

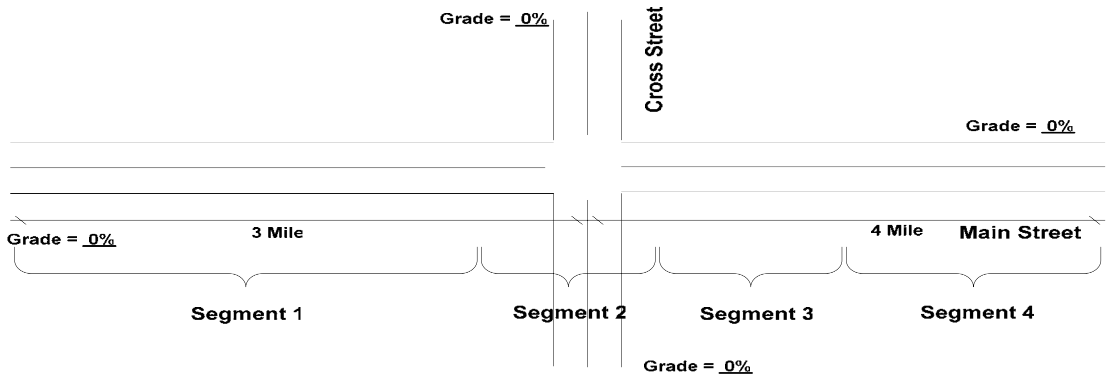
Outline of Solution:

1. Divide the facility into segments.
2. Determine segment lengths.
3. Calculate the free-flow speed.
4. Calculate the average travel speed on the two-lane highway segment upstream of the signal influence area.
5. Calculate control delay at the signalized intersection influence area.
6. Determine average travel speed on the affected downstream segment.
7. Determine average travel speed on the unaffected downstream segment.
8. Determine the delay of every segment.
9. Determine the percent time-delayed of the entire facility.

INPUT WORKSHEET

General Information		Site Information	
Analyst	____________ .	Intersection	____________ .
Date Performed	____________ .	Area Type	____________ .
Analysis Time Period	____________ .	Analysis Year	____________ .

Facility Geometry



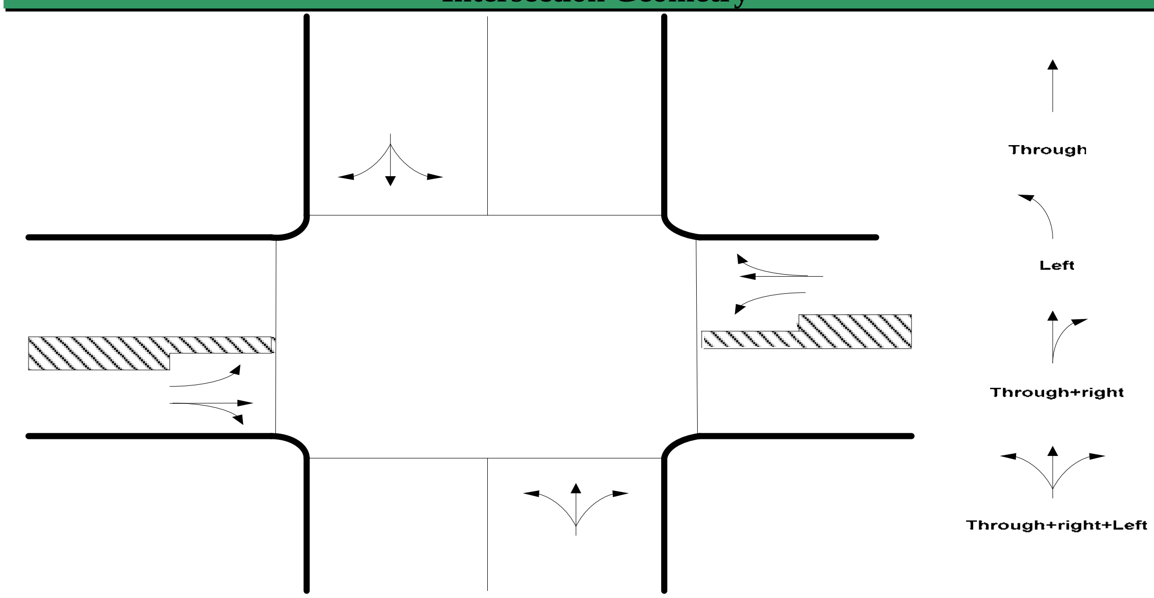
Input Data of Two-Lane Highways

Class II highway

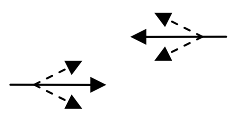
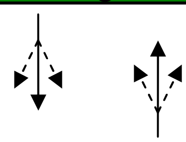
Two-way hourly volume	1000 veh/h	Directional split	60/40
Peak-hour factor, PHF	0.95	Access points/mi	5 /mi
% Trucks	3 %	Base FFS	60 mi/h
% Recreational vehicles	2 %	Shoulder width	6 ft
% No-passing zone	50 %	Lane width	12 ft
Upstream segment length	3 mi	Downstream segment length	4 mi
Terrain	Level		

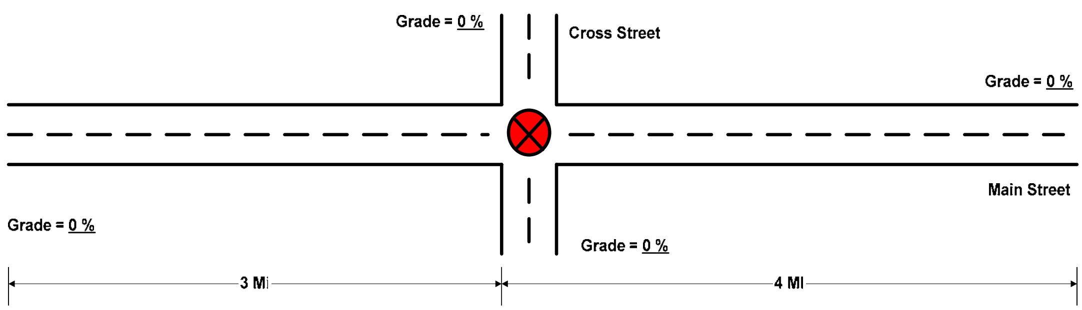
Input Data of Signalized Intersection

Intersection Geometry

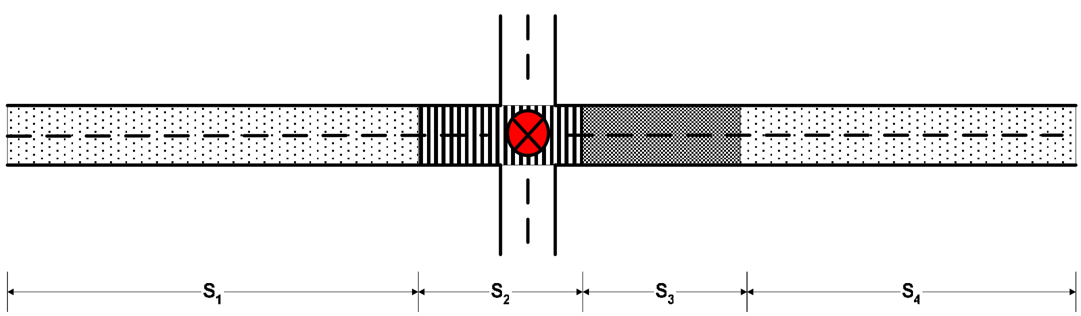


Volume and Signal Timing Input												
	EB			WB			NB			SB		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Volume, V (veh/h)	50	500	50	50	300	50	50	100	50	50	100	50
% heavy vehicle, %HV	5	5	5	5	5	5	5	5	5	5	5	5
Peak-hour factor, PHF	0.95			0.95			0.95			0.95		
Pretimed(P), Actuated (A)	P			P			P			P		
Start-up Lost time, l (s)	2			2			2			2		
Arrival type, AT	3			3			3			3		
Parking (Y or N)	N			N			N			N		
Parking maneuvers,	0			0			0			0		
Bus stopping	0			0			0			0		

Signal Phasing Plan			
Diagram	 Phase 1	 Phase 2	
Time	G= 54.0 Y+R=5.0	G= 26.0 Y+R=5.0	Cycle Length, C = 90.0 s



(A)



(B)

Figure 6-1: A Two-lane Highway with an Isolated Signalized Intersection

Step 1: Divide the facility into segments

The first step is to divide the facility into uninterrupted and interrupted flow segments. Each segment has homogenous characteristics. Figure 6-1 (B) shows the segmentation of a two-lane highway with an isolated signalized intersection. The whole two-lane highway facility is divided into four segments. These segments are:

- Segment 1: the basic two-lane highway segment. It is located upstream of the signalized intersection. This segment is not affected by the downstream signalized intersection.
- Segment 2: the influence area of the signalized intersection. It is composed of not only its own actual length, but also the deceleration distance, stopped distance and acceleration distance.
- Segment 3: the affected downstream two-lane highway segment. It is located downstream of the signalized intersection, and affected by the upstream signalized intersection. Note that this segment length does not include the acceleration distance of the signal influence area.
- Segment 4: the basic two-lane highway segment, it is located downstream of the signalized intersection. Just like Segment 1, this segment is not affected by the upstream signalized intersection.

These four lengths add up to the total length of the analysis facility.

Step 2: Determine segment lengths

The length of the signalized intersection influence area, L_2, is calculated as the sum of upstream effective length and acceleration length.

The upstream effective length is calculated using Equation 4-17.

$$\begin{aligned} Len_{eff\_up} &= 43.2463 + 4.2688 \times (V/100)^2 + 5.2178 \times Cycle \\ &\quad - 57.3041 \times (V/100) \times \%LT - 5.2444 \times Cycle \times g\_C \\ &= 43.2463 + 4.2688 \times (600/100)^2 + 5.2178 \times 90 \\ &\quad - 57.3041 \times (600/100) \times 8.3\% - 5.2444 \times 90 \times 0.6 \\ &= 355 \text{ ft} \end{aligned}$$

The acceleration length can be determined using the linearly-decreasing acceleration model, or obtained from the reference table in *Transportation and Traffic Engineering Handbook*, which is presented in Chapter 4, Table 4-2. Here the acceleration distance uses the value from this reference table.

L_A = 574 ft

The length of Segment 2, L_2, is:

$$L_2 = L_{eff\_up} + L_A$$
$$= 355 + 574 = 929 \text{ ft} = 0.18 \text{ mi}$$

The length of the conventional two-lane highway segment upstream of the signalized intersection, L_1, is calculated by subtracting the upstream part of the signalized intersection influence area from the length of the two-lane highway upstream of the signalized intersection. That is,

$$L_1 = L_{U1} - L_{eff\_up}$$
$$= 3.0 - 355/5280 = 2.93 \text{ mi}$$

The length of the affected downstream segment of the signalized intersection, L_3, is calculated by subtracting the acceleration length of the signal influence area from the downstream effective length. The downstream effective length is calculated using Equation 4-25.

$$Len_{eff\_down} = 2.218584 - 0.122942 \times (V/100)$$
$$= 2.218584 - 0.122942 \times (600/100)$$
$$= 1.48 \text{ mi}$$

The length of Segment 3, L_3, is,

$$L_3 = Len_{eff\_down} - L_A$$
$$L_3 = 1.48 - (574/5280) = 1.37 \text{ mi}$$

Segment 4 is located downstream of the signalized intersection. The length of Segment 4 can be calculated by subtracting the total length of Segment 1, 2 and 3 from the total length of the facility. The length of Segment 4, L_4, is,

$$L_4 = L_T - (L_1 + L_2 + L_3)$$

$$L_4 = (3.0 + 4.0) - (2.93 + 0.18 + 1.37) = 2.52 \text{ mi}$$

Step 3: Calculate the free-flow speed

$$\begin{aligned} FFS &= BFFS - f_{LS} - f_A \\ &= 60 - 0 - 1.3 \\ &= 58.7 \text{ mi/h} \end{aligned}$$

The above equation is Equation 20-2 in the HCM 2000. The f_{LS} and f_A values are from Exhibits 20-5 and 20-6, respectively, in Chapter 20 of the HCM 2000.

Step 4: Calculate the average travel speed on the unaffected upstream segment.

Use the HCM 2000 methodology to calculate the *ATS* (Chapter 20)

ATS_1 = 48.4 mi/h

Step 5: Calculate control delay at the signalized intersection influence area.

Use the HCM 2000 methodology to calculate the control delay (Chapter 16)

Control Delay = 12.8 sec/veh

Step 6: Determine average travel speed on the unaffected downstream segment

Use the 2000 HCM methodology to calculate the average travel speed.

ATS_4 = 48.4 mi/h

Step 7: Determine average travel speed on the affected downstream segment.

For the affected downstream segment of the signalized intersection, an adjustment factor for the effect of a signalized intersection on average travel speed will be applied to the average travel speed without a signalized intersection to compute the average travel speed on the affected downstream segment of the signalized intersection. The adjustment factors can be obtained from Table 5-3 based on the traffic flow rate. The adjustment factor for Segment 4 can be interpolated as

$$f_{ATS} = 1.32 + (600 - 440) \times \frac{1.800 - 1.320}{660 - 440} = 1.669 \text{ mi/h}$$

So the average travel speed of Segment 4 is

$$\begin{aligned} ATS_2 &= ATS_4 - f_{ATS} \\ &= 48.4 - 1.669 = 46.73 \text{ mi/h} \end{aligned}$$

Step 8: Determine the delay of every segment.

The delay at Segment 1, D_1, is

$$L_1 = 2.93 \text{ mi}$$
$$S_1 = 48.4 \text{ mi/h}$$
$$FFS_1 = 58.7 \text{ mi/h}$$
$$D_1 = \frac{L_1}{S_1} - \frac{L_1}{FFS_1} = (\frac{2.93}{48.4} - \frac{2.93}{58.7})(3600) = 38.24 \text{ sec/veh}$$

The delay at segment 2, D_2, is

$$L_2 = 0.18 \text{ mi}$$
$$D_2 = 12.8 \text{ sec/veh}$$

The delay at Segment 3, D_3, is

$$L_3 = 1.37 \text{ mi}$$
$$S_3 = 46.73 \text{ mi/h}$$
$$FFS_3 = 58.7 \text{ mi/h}$$
$$D_3 = \frac{L_3}{S_3} - \frac{L_3}{FFS_3} = (\frac{1.37}{46.73} - \frac{1.37}{58.7})(3600) = 21.52 \text{ sec/veh}$$

The delay at Segment 4, D_4, is

$$L_4 = 2.52 \text{ mi}$$
$$S_4 = 48.4 \text{ mi/h}$$
$$FFS_4 = 58.7 \text{ mi/h}$$
$$D_4 = \frac{L_4}{S_4} - \frac{L_4}{FFS_4} = (\frac{2.52}{48.4} - \frac{2.52}{58.7})(3600) = 32.89 \text{ sec/veh}$$

Step 9: Determine the percent time-delayed of the entire facility.

1. The total length of the facility

Length of Segment 1, L_1	2.93 miles
Length of Segment 2, L_2	0.18 miles
Length of Segment 3, L_3	1.37 miles
Length of Segment 4, L_4	2.52 miles
Total Length, L_t	$L_t = L_1 + L_2 + L_3 + L_4$ $L_t = 2.93 + 0.18 + 1.37 + 2.52 = 7$ miles

2. The total delay of the facility

Delay of Segment 1 D_1	38.24 sec
Delay of Segment 2, D_2	12.80 sec
Delay of Segment 3, D_3	21.52 sec
Delay of Segment 4, D_4	32.89 sec
Total Delay, D_T	$D_T = D_1 + D_2 + D_3 + D_4$ $= 38.24 + 12.8 + 21.52 + 32.89 = 105.45$ sec/veh

3. Calculate the total travel time of the facility based on the free flow speed

$$T_{tFFS} = \frac{L}{FFS} = \frac{7}{58.7}(3600) = 429 \text{ sec/veh}$$

4. Calculate the percent time-delayed of the facility

$$PTD = \frac{\sum_{H,S}(D_H + D_S)}{\sum_{H,S}\left(\frac{L_H}{FFS_H} + \frac{L_S}{FFS_S}\right)} = \frac{D_T}{\frac{L_t}{FFS}}$$

$$= \frac{105.45}{429} = 24.58\%$$

From Table 5-6, this value of percent time-delayed gives an LOS value of ‘C’, albeit barely, as the value of 24.6% is just under the ‘C/D’ threshold of 25.0%. By comparison, an average travel speed of 48.4 mph, for a two-lane highway with no signalized intersection, would also yield an LOS of ‘C’ using the criteria in Exhibit 20-2 of the HCM 2000 (for *ATS* only). The LOS ‘C’ range in this table is 45-50 mph. Although the level of service is the same in this situation, as opposed to being made worse due to the presence of the signal, it is still reasonable given that the average signal delay is only 12.8 seconds over a 7-mile length of highway. Thus, the relatively good signal conditions in this case are probably having a very minor impact on the overall trip quality over this length of highway.

6.2 Example 2

The Facility:

A rural two-lane highway facility extends 20 miles with two isolated signalized intersections, and a passing lane. The first isolated signalized intersection is installed at a location 3 miles downstream from the beginning of the 20-mile two-lane highway in the analysis direction; the second one is at the 16-mile point. A 1.5-mile passing lane is also added at the 7-mile point. Figure 6.2-(a) illustrates the components of the facility.

The Question:

What is the percent time-delayed and level of service for this two-lane highway facility for the peak hour?

The Facts:

- ***Two-lane highway segments***
  - 1200 veh/h (two-way volume)
  - 60/40 split
  - 5 percent trucks and buses
  - 3 percent RVs
  - 0.90 PHF
  - 60 mi/h base FFS
  - Level terrain
  - 12-ft lane width
  - 6-ft shoulder width
  - 40% no-passing zones
  - 5 access points/mi
  - 20-mile roadway Length
  - The first signalized intersection at a location 3 miles downstream
  - A 1.5-mile length of passing lane including tapers at a location 7 mi downstream from the beginning of the 20-mile two-lane highway in the analysis direction
  - The second signalized intersection at a location 16 miles downstream

- ***The First Signalized intersection:***
  - EB and WB HV = 8 percent
  - NB and SB HV = 8 percent
  - 0.90 PHF
  - Two-phase signal
  - EB-WB green = 54 s
  - Yellow = 4 s

- NB-SB green = 26 s
- Cross street has one lane in each direction
- 6-ft shoulder width
- No parking at intersection
- Main street has one lane in each direction
- Movement lost time = 5 s
- 12-ft lane width
- Level terrain

- ***The Second Signalized Intersection:***
  - EB and WB HV = 8 percent
  - 0.90 PHF
  - EB-WB green = 63 s
  - NB-SB green = 17 s
  - Cross street has one lane in each direction
  - 6-ft shoulder width
  - No parking at intersection
  - NB and SB HV = 8 percent
  - Two-phase signal
  - Yellow = 4 s
  - Main street has one lane and a left-turn bay in each direction
  - Movement lost time = 5 s
  - 12-ft lane width
  - Level terrain

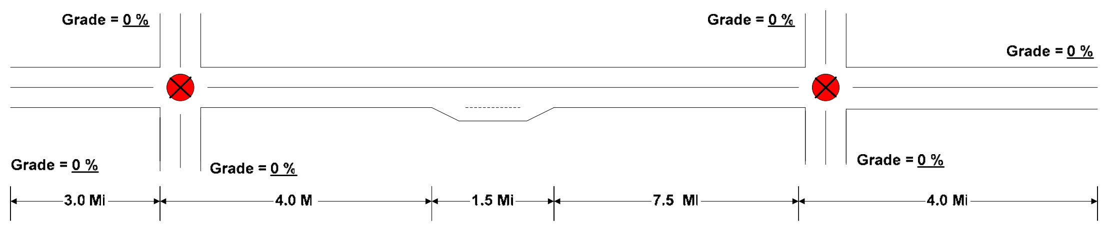
Outline of Solution:

1. Divide the facility into segments.
2. Determine segment lengths.
3. Calculate the free-flow speed.
4. Determine the average travel speed on the unaffected basic two-lane segments (**Segment 1, Segment 4, Segment 7, and Segment 10)**.
5. Determine the average travel speed on the affected downstream two-lane segments of the signalized intersection **(Segment 3, Segment 9)**.
6. Determine the average travel speed within the passing lane and its affected downstream segment **(Segment 5 and Segment 6)**.
7. Determine the control delay of the signalized intersection influence areas **(Segment 2, and Segment 8)**.
8. Determine the delay of every segment.
9. Determine the percent time-delayed of the entire facility.

INPUT WORKSHEET

General Information		Site Information	
Analyst	________________ .	Intersection	________________ .
Date Performed	________________ .	Area Type	________________ .
Analysis Time Period	________________ .	Analysis Year	________________ .

Facility Geometry



(A)

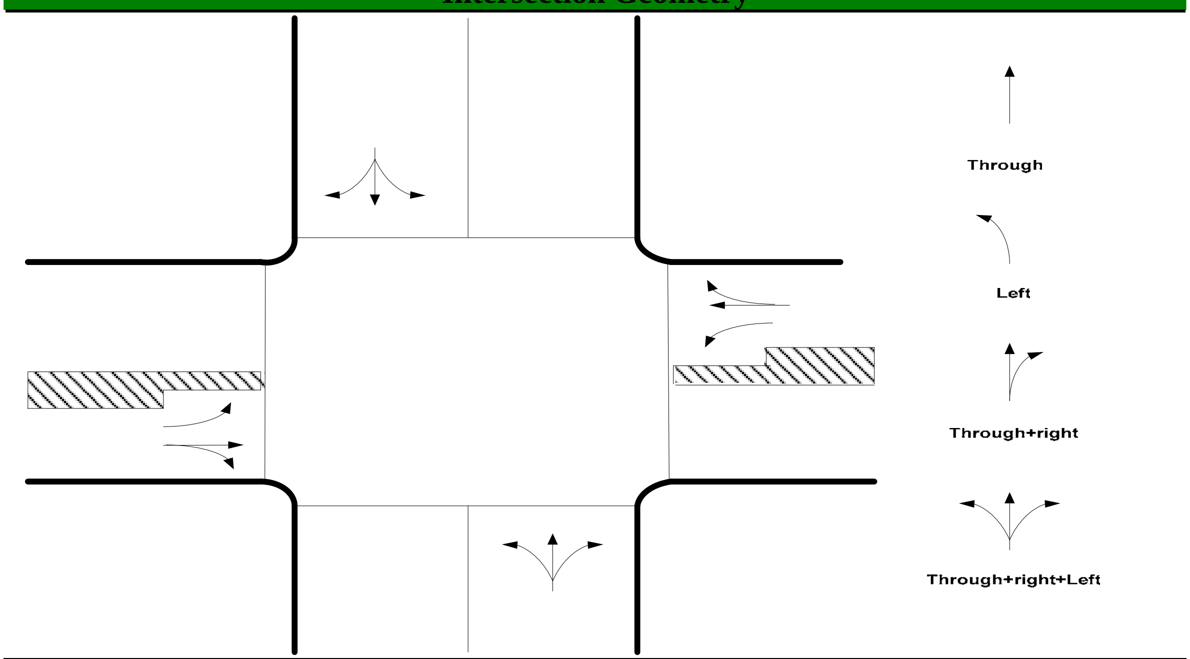
Input Data of Two-Lane Highways

Class I highway

Two-way hourly volume	1200 veh/h	Directional split	60/40
Peak-hour factor, PHF	0.90	Access points/mi	5 /mi
% Trucks	5 %	Base FFS	60 mi/h
% Recreational vehicles	3 %	Shoulder width	6 ft
% No-passing zone	40 %	Lane width	12 ft
segment length	20 mi	Terrain	Level

Input Data of the First Signalized Intersection

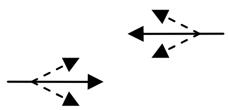
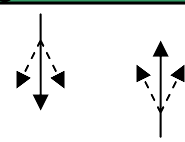
Intersection Geometry



Volume and Signal Timing Input

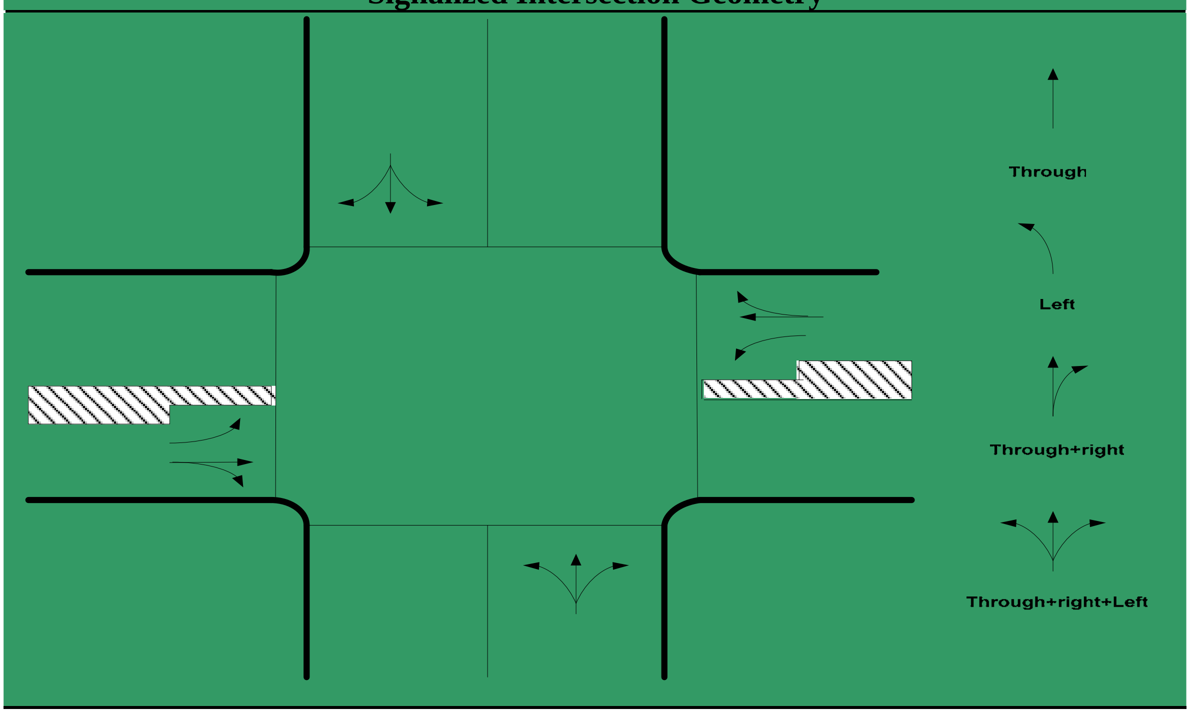
	EB			WB			NB			SB		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Volume, V (veh/h)	50	620	50	50	400	50	50	50	115	50	90	115
% heavy vehicle, %HV	8	8	8	8	8	8	8	8	8	8	8	8
Peak-hour factor, PHF	0.90			0.90			0.90			0.90		
Pretimed(P), Actuated (A)	P			P			P			P		
Start-up Lost time, l (s)	2			2			2			2		
Arrival type, AT	3			3			3			3		
Parking (Y or N)	N			N			N			N		
Parking maneuvers,	0			0			0			0		
Bus stopping	0			0			0			0		

Signal Phasing Plan

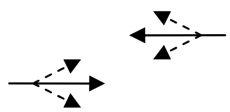
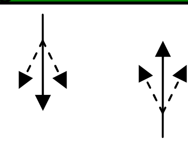
Diagram	 Phase 1	 Phase 2	
Time	G= 54.0 Y+R=5.0	G= 26.0 Y+R=5.0	Cycle Length, C = 90.0 s

Input Data of the Second Signalized Intersection

Signalized Intersection Geometry



Volume and Signal Timing Input												
	EB			WB			NB			SB		
	LT	TH	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Volume, V (veh/h)	100	700	50	60	360	60	60	100	60	60	120	60
% heavy vehicle, %HV	8	8	8	8	8	8	8	8	8	8	8	8
Peak-hour factor, PHF	0.90			0.90			0.90			0.90		
Pretimed(P), Actuated (A)	P			P			P			P		
Start-up Lost time, l (s)	2			2			2			2		
Arrival type, AT	3			3			3			3		
Parking (Y or N)	N			N			N			N		
Parking maneuvers,	0			0			0			0		
Bus stopping	0			0			0			0		

Signal Phasing Plan			
Diagram	 Phase 1	 Phase 2	
Time	G= 63.0 Y+R=5.0	G= 26.0 Y+R=5.0	Cycle Length, C = 90.0 s

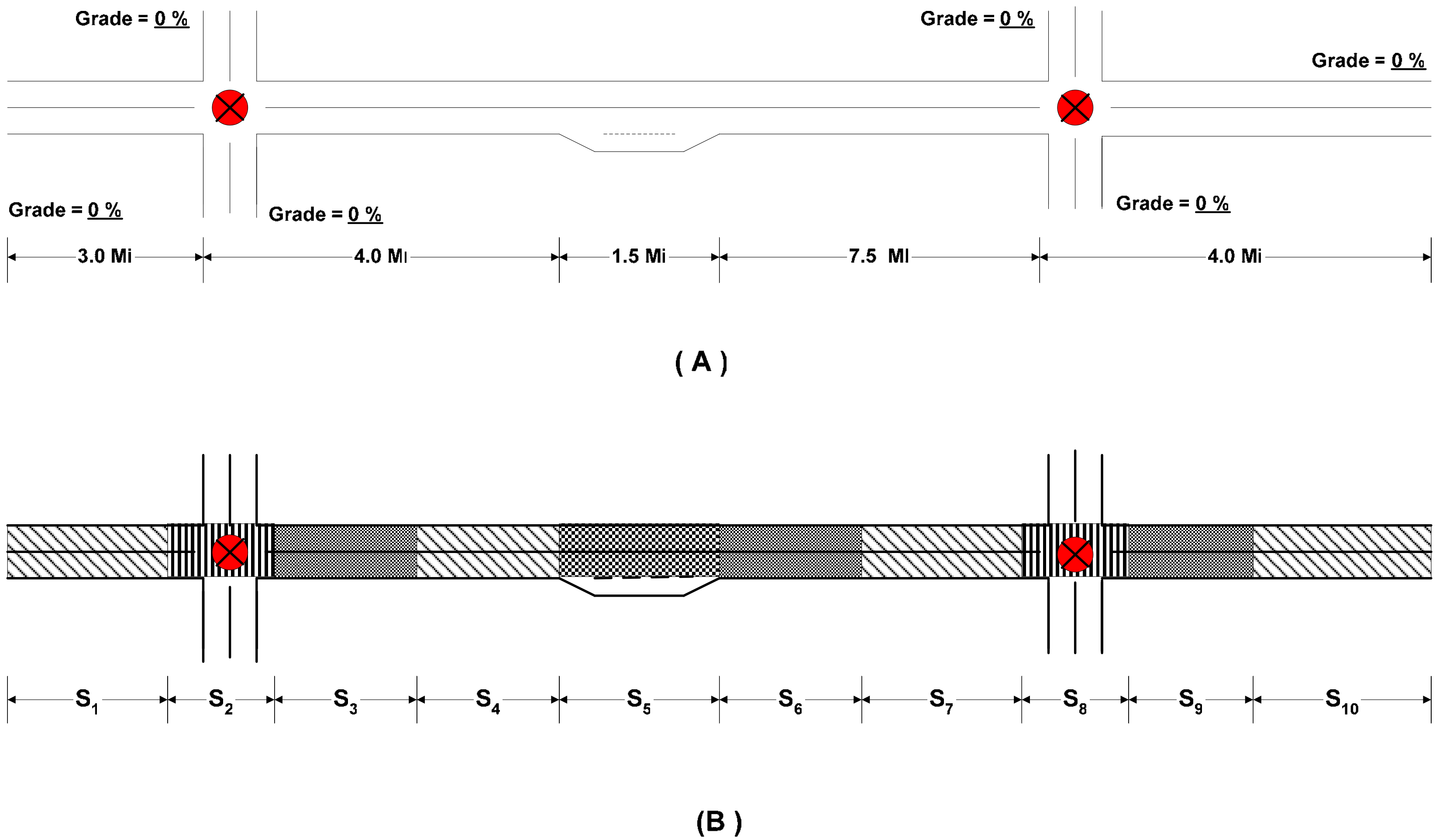


Figure 6-2: Segmentation for a two-lane highway facility

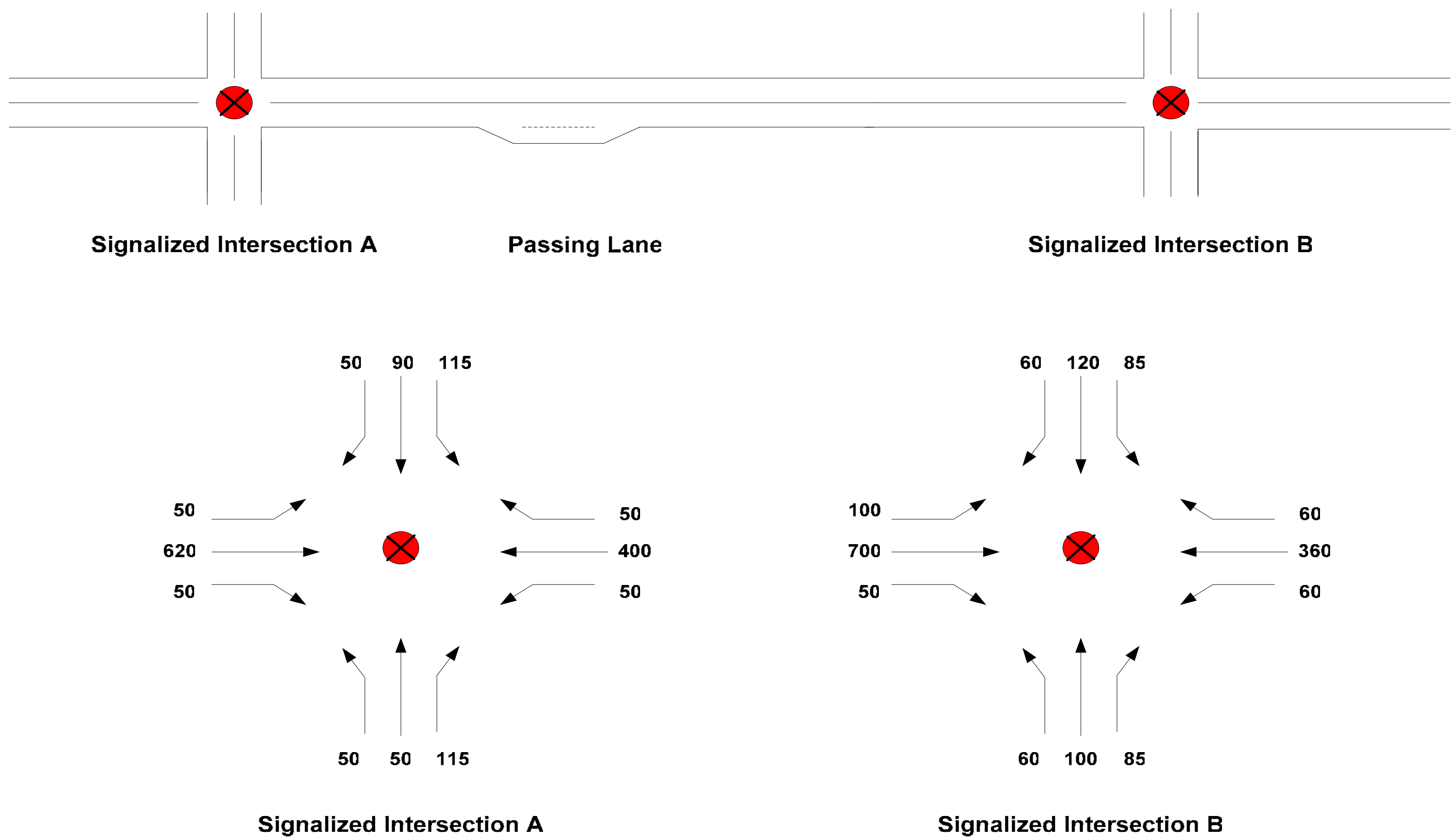


Figure 6-3: Traffic flow rates at two intersections

Step 1: Divide the facility into segments

To a two-lane highway with two isolated signalized intersections, and a passing lane, the signalized intersections affect the operations of the upstream and downstream two-lane highway segments; the added passing lane also has effects on the downstream two-lane highway segment. The first step is to divide the facility into uninterrupted and interrupted flow segments. Each segment has homogenous characteristics. Figure 6-2 (B) shows the division of a two-lane highway with two isolated signalized intersections, and one passing lane. The whole two-lane highway facility is divided into ten segments. These segments are:

- Segment 1: the unaffected two-lane highway segment. It is located upstream of the first signalized intersection. This segment is not affected by the downstream signalized intersection.
- Segment 2: the influence area of the first signalized intersection. It is composed of not only its own actual length, but also the deceleration distance, stopped distance and acceleration distance, which is needed for the vehicles through the first signalized intersection.
- Segment 3: the affected downstream two-lane highway segment. It is located downstream of the first signalized intersection, and affected by the upstream signalized intersection. Potential operational effects on this segment are produced by the first signalized intersection and traffic flows coming from the cross street at the first signalized intersection. Note this segment length does not include the acceleration length of the first signal influence area.
- Segment 4: the unaffected two-lane highway segment, it is located downstream of the first signalized intersection. This segment is not affected by the upstream signalized intersection, and the downstream passing lane.
- Segment 5: the passing lane. The passing lane length should include the length of the lane addition and lane drop tapers.
- Segment 6: the affected downstream segment. It is the downstream segment of the passing lane but within its effective length.

- Segment 7: the unaffected two-lane highway segment. It is located upstream of the second signalized intersection, and downstream of the passing lane. This segment is not affected by the upstream passing lane or the downstream signalized intersection.
- Segment 8: the influence area of the second signalized intersection. It is composed of not only its own actual length, but also the deceleration lengths, stopped lengths and acceleration lengths, which is needed for the vehicles through the second signalized intersection.
- Segment 9: the affected downstream segment. It is located downstream of the second signalized intersection, and affected by the upstream signalized intersection. Note this segment length does not include the acceleration length of the second signal influence area.
- Segment 10: the unaffected two-lane highway segment. It is located downstream of the second signalized intersection. This segment is not affected by the upstream signalized intersection.

The lengths of these ten segments add up to the total length of the analysis facility.

Step 2: Determine segment lengths

The length of the signalized intersection influence area, L_2, is calculated as the sum of upstream effective length, and acceleration length.

Because there is not a left-turn bay present at the first signalized intersection, the upstream effective length of the first signalized intersection, Len_{eff_up1}, is calculated using Equation 4-18.

$$\begin{aligned}
Len_{eff_up1} &= 3074.49 + 5.89 \times (V/100)^2 - 440.00 \times DFactor \\
&\quad + 1.69 \times C - 7336.59 \times g_C + 4758.52 \times (g_C)^2 \\
&\quad + 1171.01 \times (V/100) \times (\%LT)^2 \\
&= 3074.49 + 5.89 \times (720/100)^2 - 440.00 \times 0.6 \\
&\quad + 1.69 \times 90 - 7336.59 \times 0.6 + 4758.52 \times (0.6)^2 \\
&\quad + 1171.01 \times (720/100) \times (50/720)^2 \\
&= 620 \text{ ft}
\end{aligned}$$

The acceleration length can be determined using the linearly-decreasing acceleration model, or obtained from the reference table in *Transportation and Traffic Engineering Handbook*, which is presented in Chapter 4, Table 4-2. Here the acceleration distance uses the value from this reference table.

L_A = 574 ft

The length of Segment 2, L_2, is:

$$L_2 = L_{eff\_up1} + L_A$$
$$= 620 + 574 = 1194\text{ ft} = 0.23\text{ mi}$$

The length of the unaffected two-lane highway segment upstream of the first signalized intersection, L_1, is calculated by subtracting the upstream part of the first signalized intersection influence area from length of the two-lane highway upstream of the first signalized intersection.

$$L_1 = L_{UFS} - L_{eff\_up1}$$
$$= 3.0 - 620/5280 = 2.88\text{ mi}$$

The length of the affected downstream segment of the first signalized intersection, L_3, is calculated by subtracting the acceleration length of the first signal influence area from the downstream effective length of the first signalized intersection. The downstream effective length, Len_{eff_down1} is calculated using Equation 4-25.

Len_{eff_down1} = 2.218584 – 0.122942 × (V/100)

= 2.218584 – 0.122942 × (820/100)

= 1.17 mi

The length of Segment 3, L_3, is:

$$L_3 = Len_{eff\_down1} - L_A$$
$$L_3 = 1.17 - (574/5280) = 1.06\text{ mi}$$

Segment 4 is located in the downstream of the first signalized intersection, and the upstream of the passing lane. The length of Segment 4 can be calculated by subtracting the total length of Segment 1, 2 and 3 from the total upstream length of the passing lane as shown in Equation 6-1.

$$L_4 = (L_{UFS} + L_{UP}) - (L_1 + L_2 + L_3) \quad (6\text{-}1)$$

Where:

L_{UFS}: upstream length of the first signalized intersection, mi, and

L_{UP}: the length between the stop line of the first signalized intersection and the beginning point of the passing lane, mi

So the length of Segment 4, L_4, is:

$$L_4 = (3.0 + 4.0) - (2.88 + 0.23 + 1.06)$$
$$= 2.83\,\text{mi}$$

The length of the passing lane, L_5, includes the lengths of the lane addition and lane drop tapers. A typical passing lane is shown in Figure 6-4.

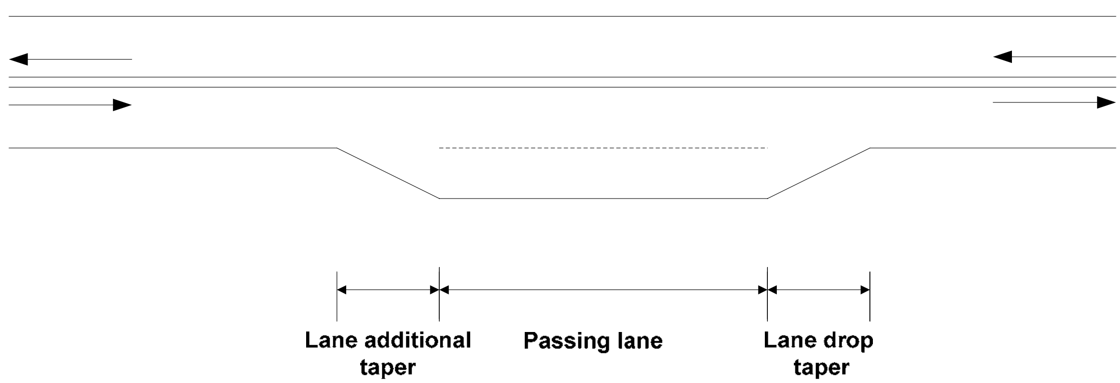


Figure 6-4: A view of a typical passing lane

In this analysis, the passing lane length, L_5, is:

L_5 = 1.5 mi

The length of the downstream highway segment within the effective length of the passing lane, L_6, is determined from Table 5-4. From this table, the downstream length of roadway affected by the upstream passing lane, L_6, is:

L_6 = 1.7 mi

The length of the second signalized intersection influence area, L_8, is also calculated as the sum of upstream effective length and acceleration length. Because there is a left-turn bay present at the second signalized intersection, the upstream effective length of the second signalized intersection, Len_{eff_up2}, is calculated using Equation 4-17.

$$
\begin{aligned}
Len_{eff\_up2} &= 43.2463 + 4.2688 \times (V/100)^2 + 5.2178 \times Cycle \\
&\quad - 57.3041 \times (V/100) \times \%LT - 5.2444 \times Cycle \times g\_C \\
&= 43.2463 + 4.2688 \times (850/100)^2 + 5.2178 \times 90 \\
&\quad - 57.3041 \times (850/100) \times (100/850) - 5.2444 \times 90 \times 0.7 \\
&= 434\text{ft}
\end{aligned}
$$

L_A = 574 ft

The length of Segment 8, L_8, is:

$$
\begin{aligned}
L_8 &= L_{eff\_up2} + L_A \\
&= 434 + 574 = 1008\text{ft} = 0.19\text{ mi}
\end{aligned}
$$

Segment 7 is an unaffected two-lane highway segment, located downstream of the passing lane and upstream of the second signalized intersection. The length of Segment 7 can be calculated by subtracting the upstream effective length of the second signal influence area from the upstream length of the second signalized intersection, the distance from the ending point of the passing lane to the stop line of the second signalized intersection. The length of Segment 7 can be calculated using Equation 6-2.

$$L_7 = L_{USS} - L_6 - Len_{eff\_up2} \tag{6-2}$$

Where:

L_{USS}: the upstream length of the second signalized intersection from the ending point of the passing lane to the stop line of the second signalized intersection, mi

The length of Segment 7, L_7, is:

$$
\begin{aligned}
L_7 &= L_{USS} - L_6 - Len \\
&= 7.5 - 1.7 - \frac{434}{5280} \\
&= 5.72\text{ mi}
\end{aligned}
$$

The length of the affected downstream segment of the signalized intersection, L_9, is calculated by subtracting the acceleration length of the second signal influence area from the downstream effective length. The downstream effective length, Len_{eff_down2}, is calculated using Equation 4-25.

$$Len_{eff\_down2} = 2.218584 - 0.122942 \times (V/100)$$
$$= 2.218584 - 0.122942 \times (870/100)$$
$$= 1.15 \text{ mi}$$

The length of Segment 9, L_9, is:

$$L_9 = Len_{eff\_down2} - L_A$$
$$L_9 = 1.15 - (574/5280) = 1.04 \text{ mi}$$

Segment 10 is located downstream of the second signalized intersection. The length of Segment 10 can be calculated by subtracting the downstream effective length of the second signalized intersection from the distance between the stop line of the second signalized intersection and the ending point of the analyzed facility. The length of Segment 10 can be calculated using Equation 6-3.

$$L_{10} = L_{DSS} - Len_{eff\_down2} \qquad (6\text{-}3)$$

Where:

L_{DSS} : the downstream length of the second signalized intersection from the stop line of the second signalized to the ending point of the facility, mi

The length of Segment 10, L_{10}, is:

$$L_{10} = L_{DSS} - Len_{eff\_down2}$$
$$= 4.0 - 1.15 = 2.85 \text{ mi}$$

Step 3: Calculate the free-flow speed

$$FFS = BFFS - f_{LS} - f_A$$
$$= 60 - 0 - 1.3$$
$$= 58.7 \text{mi/h}$$

The above equation is Equation 20-2 in the HCM 2000. The f_{LS} and f_A values are from Exhibits 20-5 and 20-6, respectively, in Chapter 20 of the HCM 2000.

Step 4: Determine the average travel speed on the unaffected two-lane segments (*Segment 1, Segment 4, Segment 7, and Segment 10*)

Use the HCM 2000 methodology to calculate the average travel speeds on the unaffected two-lane segments. The average travel speeds of these basic two-lane segments are summarized in the Table 6-1.

Table 6-1: Average Travel Speed for the Unaffected Two-lane Segments.

	Average Travel Speed (mi/h)
Segment 1	ATS_1 = 46.9 mi/h
Segment 4	ATS_4 = 45.7 mi/h
Segment 7	ATS_7 = 45.7 mi/h
Segment 10	ATS_{10} = 45.6 mi/h

Step 5: Determine the average travel speed of the affected downstream segments of the signalized intersection (Segment 3 and Segment 9)

For the affected downstream segment of the signalized intersection, an adjustment factor for the effect of a signalized intersection on average travel speed will be applied to the average travel speed without a signalized intersection to compute the average travel speed on the affected downstream segment of the signalized intersection. The adjustment factors can be obtained from Table 5-3 based on the traffic flow rate. The adjustment factor for Segment 3 can be interpolated as

$$f_{ATS} = 1.8 + (850 - 660) \times \frac{2.281 - 1.800}{880 - 660} = 2.215 \text{ mi/h}$$

So the average travel speed of Segment 3 is

$$\begin{aligned} ATS_3 &= ATS_4 - f_{ATS} \\ &= 45.7 - 2.215 = 43.5 \text{ mi/h} \end{aligned}$$

The adjustment factor for Segment 9 can be interpolated as

$$f_{ATS} = 1.8 + (870 - 660) \times \frac{2.281 - 1.800}{880 - 660} = 2.259 \text{ mi/h}$$

So the average travel speed of Segment 9 is

$$ATS_9 = ATS_{10} - f_{ATS}$$
$$= 45.6 - 2.259 = 43.3 \text{ mi/h}$$

The average travel speeds of these affected downstream segments of the signalized intersection are summarized in Table 6-2.

Table 6-2: Average Travel Speed for the Affected Downstream Two-lane Segments

Segment No.	Average Travel Speed (mi/h)
Segment 3	ATS_3 = 43.5mi/h
Segment 9	ATS_9 = 43.3 mi/h

Step 6: Determine the average travel speed within the passing lane and its affected downstream segment (Segment 5 and Segment 6)

Equation 20-21 in the HCM 2000 is used to compute the average travel speed with the passing lane and its affected downstream two-lane highway. The average travel speeds of Segment 5 and Segment 6 are summarized in Table 6-3.

Table 6-3: Average Travel Speed for the Affected Passing Lane Segments

Segment No.	Average Travel Speed (mi/h)
Segment 5	ATS_5 = 49.4mi/h
Segment 6	ATS_6 = 49.4 mi/h

Step 7: Determine the control delay of the signal influence areas (Segment 2 and Segment 8)

Use the HCM 2000 methodology to calculate the control delay (Chapter 16). The control delays of the signalized intersection influence areas are summarized in Table 6-4.

Table 6-4: Control Delays at Signalized Intersection

Segment No.	Control Delay (sec/veh)
Segment 2	D_2 = 22.0 sec/veh
Segment 8	D_8 = 19.0 sec/veh

Step 8: Determine the delay of every segment.

The delay at Segment 1, D_1, is:

$L_1 = 2.88$ mi

$S_1 = 46.9$ mi/h

$FFS_1 = 58.7$ mi/h

$$D_1 = \frac{L_1}{S_1} - \frac{L_1}{FFS_1} = (\frac{2.88}{46.9} - \frac{2.88}{58.7})(3600) = 44.44 \text{ sec/veh}$$

The delay at Segment 2, D_2, is:

$L_2 = 0.23$ mi

$D_2 = 22.0$ sec/veh

The delay at Segment 3, D_3, is:

$L_3 = 1.06$ mi

$S_3 = 43.5$ mi/h

$FFS_3 = 58.7$ mi/h

$$D_3 = \frac{L_3}{S_3} - \frac{L_3}{FFS_3} = (\frac{1.06}{43.5} - \frac{1.06}{58.7})(3600) = 22.72 \text{ sec/veh}$$

The delay at Segment 4, D_4, is:

$L_4 = 2.83$ mi

$S_4 = 45.7$ mi/h

$FFS_4 = 58.7$ mi/h

$$D_4 = \frac{L_4}{S_4} - \frac{L_4}{FFS_4} = (\frac{2.83}{45.7} - \frac{2.83}{58.7})(3600) = 49.37 \text{ sec/veh}$$

The delay at Segment 5 and Segment 6 is:

$L_5 = 1.50$ mi

$L_6 = 1.70$ mi

$S_5 = 49.4$ mi/h

$S_6 = 49.4$ mi/h

$FFS_5 = 58.7$ mi/h

$FFS_6 = 58.7$ mi/h

$$D_{5,6} = \frac{L_5 + L_6}{S_{5,6}} - \frac{L_5 + L_6}{FFS_{5,6}} = (\frac{1.5 + 1.7}{49.4} - \frac{1.5 + 1.7}{58.7})(3600) = 36.96 \text{ sec/veh}$$

The delay at Segment 7 is:

$$L_7 = 5.72 \text{ mi}$$

$$S_7 = 45.7 \text{ mi/h}$$

$$FFS_7 = 58.7 \text{ mi/h}$$

$$D_7 = \frac{L_7}{S_7} - \frac{L_7}{FFS_7} = (\frac{5.72}{45.7} - \frac{5.72}{58.7})(3600) = 99.79 \text{ sec/veh}$$

The delay at segment 8 is:

$$L_8 = 0.19 \text{ mi}$$

$$D_8 = 19.0 \text{ sec/veh}$$

The delay at Segment 9 is:

$$L_9 = 1.04 \text{ mi}$$

$$S_9 = 43.3 \text{ mi/h}$$

$$FFS_9 = 58.7 \text{ mi/h}$$

$$D_9 = \frac{L_9}{S_9} - \frac{L_9}{FFS_9} = (\frac{1.04}{43.3} - \frac{1.04}{58.7})(3600) = 22.68 \text{ sec/veh}$$

The delay at segment 10 is:

$$L_{10} = 2.85 \text{ mi}$$

$$S_{10} = 45.6 \text{ mi/h}$$

$$FFS_{10} = 58.7 \text{ mi/h}$$

$$D_{10} = \frac{L_{10}}{S_{10}} - \frac{L_{10}}{FFS_{10}} = (\frac{2.85}{45.6} - \frac{2.85}{58.7})(3600) = 50.21 \text{sec/veh}$$

Step 9: Determine the percent time-delayed of the entire facility.

1. The total length of the facility

Length of Segment 1, L_1	2.88 miles
Length of Segment 2, L_2	0.23 miles
Length of Segment 3, L_3	1.06 miles
Length of Segment 4, L_4	2.83 miles
Length of Segment 5, L_5	1.50 miles
Length of Segment 6, L_6	1.70 miles
Length of Segment 7, L_7	5.72 miles
Length of Segment 8, L_8	0.19 miles
Length of Segment 9, L_9	1.04 miles
Length of Segment 10, L_{10}	2.85 miles
Total Length	$L_t = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8 + L_9 + L_{10}$ $L_t = 2.88 + 0.23 + 1.06 + 2.83 + 1.50 + 1.70 + 5.72 +$ $0.19 + 1.04 + 2.85 = 20 \text{ miles}$

2. The total delay of the facility

Delay of Segment 1, D_1	44.44 sec
Delay of Segment 2, D_2	22.00 sec
Delay of Segment 3, D_3	22.72 sec
Delay of Segment 4, D_4	49.37 sec
Delay of Segment 5, D_5	36.96 sec
Delay of Segment 6, D_6	
Delay of Segment 7, D_7	99.79 sec
Delay of Segment 8, D_8	19.00 sec
Delay of Segment 9, D_9	22.68 sec
Delay of Segment 10, D_{10}	50.21 sec
Total Delay	$D_t = D_1 + D_2 + D_3 + D_4 + D_5 + D_6$ $+ D_7 + D_8 + D_9 + D_{10}$ $D_t = 44.44 + 22.00 + 22.2 + 49.37 + 36.96 + 99.79 + 19.00 +$ $22.68 + 50.21 = 366 \text{ sec/veh}$

3. Calculate the total travel time of the facility based on the free flow speed

$$T_{tFFS} = \frac{L}{FFS} = \frac{20}{58.7}(3600) = 1226 \text{ sec/veh}$$

4. Calculate the percent time-delayed of the facility

$$PTD = \frac{\sum_{H,S}(D_H + D_S)}{\sum_{H,S}(\frac{L_H}{FFS_H} + \frac{L_S}{FFS_S})} = \frac{D_T}{\frac{L_t}{FFS}}$$

$$= \frac{366}{1226} = 29.85\%$$

From Table 5-6, this value of percent time-delayed gives an LOS value of 'D'. By comparison, if the two signalized intersections were removed, an average travel speed of 46.9 mph would be estimated with the HCM 2000 Chapter 20 methodology, which would result in an LOS of 'C', again using the criteria in Exhibit 20-2 of the HCM 2000 (for *ATS* only). So in this case, the LOS is one grade worse due to the presence of the signals. Even though the operations of the signals are still relatively good, with borderline LOS B/C (from LOS criteria in HCM 2000 Exhibit 16-2), they are adding just enough of a penalizing effect to reduce the LOS over the length of the facility.

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