STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA14-1934		

4. TITLE AND SUBTITLE

Weave Analysis Matrix and Microsimulation Methodology Refinement

5. REPORT DATE

6/13/2014

6. PERFORMING ORGANIZATION CODE

7. AUTHOR

Alexander Skabardonis, Michael Mauch

8. PERFORMING ORGANIZATION REPORT NO.

UCB-ITS-PRR-2014-05

9. PERFORMING ORGANIZATION NAME AND ADDRESS

California PATH Program Institute of Transportation Studies
University of California Berkeley Richmond Field Station, Building 452
1357 S. 46th Street, Richmond, CA 94804-4648

10. WORK UNIT NUMBER

65-3763

11. CONTRACT OR GRANT NUMBER

65A0477

12. SPONSORING AGENCY AND ADDRESS

California Department of Transportation
Division of Research, Innovation and System Information
1227 O street, MS-83
Sacramento, CA 94814

13. TYPE OF REPORT AND PERIOD COVERED

Final Report
6/15/2012 to 6/30/2014

14. SPONSORING AGENCY CODE

Caltrans DRISI

15. SUPPLEMENTARY NOTES

N/A

16. ABSTRACT

The objectives of this research project were a) evaluation of the existing weaving analysis procedures to determine under which design and operating conditions the “best available” tools are most effective, and b) development of an improved procedure either by modification of existing approaches or a new method as appropriate.

The Highway Capacity Manual 2000 (HCM2000), Leisch and Level D methods were selected for evaluation. A database from 36 real-world weaving sections (189 data points of traffic volumes and speeds) was compiled from previously collected data. The analysis of the results identified the strengths and limitations of each method in predicting the performance of a freeway weaving section for a range of operating conditions. Additional analyses were performed by applying the selected analysis methods to synthetic datasets for the design and operating conditions that field data were not available. A total of 339 datasets were created. The analysis of the results focused on the consistency of the predictions from each analysis method. Additional field data were collected at three California ramp weave sites.

A performance matrix was developed for each weaving analysis method to serve as a guide for Caltrans staff when choosing the “best” analysis method for the weaving section under study. Each cell of the matrix represents a distinct design and operating condition. There are a total of 144 cells for typical weaving sections of two, three, four and five lanes wide. Based on the comparison of the model prediction with field and synthetic data, we show on each cell the performance of the particular method as good (or “green light”), or partially good or often inconsistent (or “yellow light”) or poor (or “red light”) for a particular design and operating condition.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Freeway Weaving Sections, HCM2010, Weaving Analysis	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIFICATION *(of this report)*	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	68	N/A

DISCLAIMER STATEMENT

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Weave Analysis Performance Matrix Refinement

Alexander Skabardonis
Michael Mauch

California PATH Research Report
UCB-ITS-PRR-2014-05

This work was performed as part of the California PATH program of the University of California, in cooperation with the State of California Business, Transportation and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Agreement 65A0477

June 2014

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

ACKNOWLEDGEMENTS

This work is being performed by the California Partners for Advanced Transportation Technology (PATH) Program at the University of California at Berkeley, in cooperation with the State of California Business, Transportation and Housing Agency, Department of Transportation (Caltrans), Division of Research, Information, and System Information (DRISI) (Research Technical Agreement #65A0477). The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California.

The authors wish to thank the project monitors Mr. Fred Yazdan and Tam Nguyen of Caltrans DRISI, and the members of the Caltrans Technical Advisory Group for their guidance and support during the project.

DISCLAIMER STATEMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Weaving sections are common design elements on freeway facilities such as near ramps and freeway-to-freeway connectors. When the traffic demands exceed the capacity at weaving areas congestion may occur, which affects the operation of the entire freeway section. Traffic operational problems also may exist at weaving areas even when traffic demands are less than capacity because of the complexity of vehicle interactions, resulting in poor level of service (LOS) and potential safety problems.

Efforts to develop procedures for the design and analysis of freeway weaving sections began in the 50's. However, the existing procedures have several shortcomings, and their practical application often produces inconsistent results. This is mostly due to the lack of empirical data on weaving operations. Most of the existing methods are based on limited data that are not representative of the entire range of the geometric configurations and traffic volumes and patterns in weaving areas. The systematic evaluation of existing weaving methods and the development of an improved analysis method have been recognized as high priority research needs. Recently, a new weaving analysis method [1] was developed as part of the latest edition of the Highway Capacity Manual (HCM2010) [2].

1.2 Project Objectives

In an earlier PATH project (Task Order 6304) a Weave Analysis Performance Matrix was developed to address some of these issues. Recently a new weaving analysis method was developed as part of the Highway Capacity Manual 2010 (HCM-2010). The objectives of this project are:

1. To upgrade and enhance the Weave Analysis Performance Matrix developed in a previous research project (PATH Task Order 6304) and develop a plan to include it as a design tool for use by Caltrans in the Design Manual.
2. Evaluate the HCM-2010 methodology, compare it with other weave analysis methods, and recommend best use cases for it.

1.3 Overview of the Research

The scope of work consists of the following tasks described below.

Task 1. Technical Literature Review: A comprehensive literature review was performed on weaving analysis methods as part of TO6304. In this Task, the literature review was updated focusing on recent publications and ongoing work still unpublished.

Task 2A. Collect additional field data: Several cells in the weaving analysis performance matrix for each method developed in TO6304 were lacking field data on traffic performance. There was a need to obtain additional data and update these matrices by collecting additional data from a number of selected sites with emphasis on sites (cells) in the performance matrix lacking field data, data collection methods, and time and budget constraints of the project.

Task 2B. HCM2010 weaving analysis method evaluation: Evaluate the new weaving analysis method for HCM 2010, using the same data used in the previous study (TO6304), and the new data collected in Task 2A to determine if it is an appropriate analysis tool to be used by Caltrans staff. Incorporate the results into the weaving analysis performance matrix.

Task 2C. Capacity estimation: The new HCM2010 weaving analysis method provides an estimate of the weaving section capacity. The accuracy of capacity prediction for the HCM2010 as well as the other weaving analysis methods, was evaluated by comparing predicted flow rates against observed queue discharge flow rates at weaving sites that are active bottlenecks.

Task 2D. Evaluation of the proposed matrix: Working closely with the Caltrans Technical Advisory Group (TAG), applied the proposed weaving analysis Performance Matrix on selected real-world case studies and assessed its usability and usefulness in analysis of weaving sections. Updated and refined the Performance Matrix based on the feedback from the Caltrans TAG.

Task 3. Preparation of final report and workshop: A final report was prepared documenting in detail the work performed and presenting the major findings. One workshop was held to present the project findings to the Caltrans TAG and other Caltrans staff.

1.4 Organization of the Report

This document is a final report for the project. Chapter 2 provides background on existing weaving analysis methods and describes the HCM2010 methodology. The evaluation of the HCM2010 methodology on 30 real-world weaving sections is presented in Chapter 3. Chapter 4 describes the field data collection on three weaving sites. The findings from the application of all methods on the field data are described in Chapter 5. Chapter 6 describes the application of the weaving analysis Performance Matrix on the real-world case studies and its usability for the analysis of weaving sections. Chapter 7 summarizes the study's conclusions along with comments on extensions of this work. Appendix A includes the study database (Chapter 3) and Appendix B lists the study database (Chapter 5) for the San Diego sites.

CHAPTER 2
BACKGROUND

2.1 Weaving Analysis Methods

The first formal procedure for analysis of weaving sections appeared in the 1965 edition of HCM [4], based on research conducted by O.K. Normann [5]. The basic model in the 1965 HCM is a relationship between weaving length, total weaving volume, and Level of Service. The 1965 HCM method was widely used and brought some national consistency to the analysis and design of weaving areas. The methodology covered a wide range of situations and configurations in which weaving could exist. However, the method was based on very limited few field data.

The Level D Method was developed in California by Moskowitz & Newman to analyze weaving sections under heavy traffic conditions (Level of Service (LOS) is D or E) [6]. The method is designed for weaving sections with one lane on-ramp followed by off-ramp with a continuous auxiliary lane. The method provides the percentages of on-ramp and off-ramp traffic remaining in the auxiliary lane and the right-most through lane at 500 ft intervals through the weaving section, as well as the proportion of the freeway through traffic remaining in outer through lane in the weaving section. The analyst estimates the traffic volumes in the right most through lane and the auxiliary lane at 500 ft intervals using the provided percentages. These values are compared against the lane capacities in the weaving section. The Level D method was later extended for other types of weaving sections with multiple on- and off-ramps [7].

The Leisch Method was developed by J. Leisch based on data from 48 weaving sections around the country [8]. The method uses concepts similar to the 1965 HCM and a nomograph approach. The primary relationship is between the length of the weaving section and the total weaving volume. The solution of the nomographs results in determination of either the LOS of a weaving section with known design characteristics, or the number of lanes needed to obtain a specified LOS. The method accounts for the difference in operational characteristics between lane-balanced and unbalanced weaving sections. Lane balanced sections have one more lane going away, such as an optional lane at exit; i.e., one weaving movement is not required to change lanes. The advantage of the Leisch method is that it is relatively straightforward to apply, and could be manipulated to produce design and/or operational analysis results. However the development and calibration of nomographs was mostly based on experience and judgment with very limited field data.

The HCM2000 Method [9] was originated from the weaving analysis method developed by the Polytechnic Institute of New York [10] and the research for the development of the 1985 Highway Capacity Manual [11,12]. This method is based on the same field data as the Leisch method, but it explicitly recognizes the geometric configuration of the weaving section, depending on the minimum number of lane changes required by the weaving vehicles. Freeway weaving sections are classified into three configurations, depending on the minimum number of lane changes required by weaving vehicles as illustrated in Figure 2.1.

- Type A: each weaving vehicle must make one lane-change (ramp weaves)
- Type B: major weaving configurations requiring one lane change for the one weaving movement and none for the other weaving movement (balanced sections)
- Type C: major weaving configurations requiring two or more lane changes for one weaving movement and none for the other weaving movement (unbalanced sections)

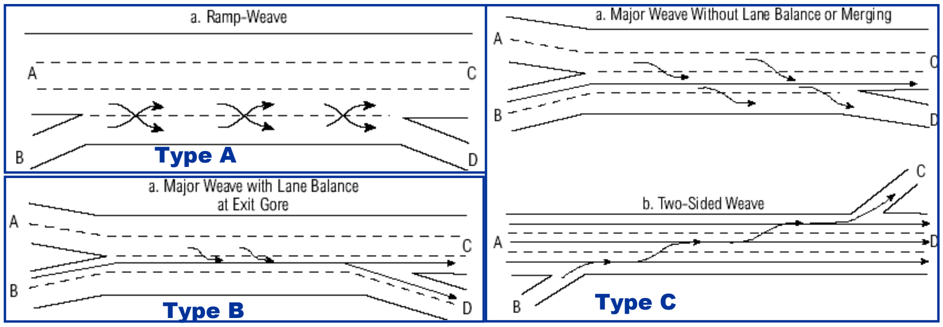


Figure 2.1 Configurations of Freeway Weaving Sections (HCM2000/1985)

The HCM2000 method also introduced the concept of constrained vs. unconstrained operations. Constrained operations occur when the geometry of the section constrains weaving vehicles from using certain freeway lanes. Under constrained operations weaving vehicles occupy a smaller proportion of the roadway than they would without the constraint of geometry; non-weaving vehicles occupy more space, and the difference between non-weaving and weaving vehicle speeds increases. The LOS is defined based on the speeds of weaving and non-weaving vehicles:

Several concerns have been expressed by transportation researchers and professionals regarding the HCM2000 method because a) it could not provide capacity estimates; b) it uses rather complex equations for estimating weaving and non-weaving vehicle speeds to determine LOS, and the logic of these formulae is not readily apparent, and c) often inappropriately reflects impacts created by changes in geometric configuration of the weaving areas.

2.2 The HCM2010 Methodology

The HCM2010 weaving analysis methodology brings important differences compared to the existing HCM2000 procedure; namely, a) it does not classify the weaving sections into different configuration types (A, B, or C), b) it includes a new definition of the weaving section length, c) it explicitly accounts for the number of lane changes, and d) it includes a direct method for estimating weaving section capacity.

2.2.1 Weaving Section Length

The weaving section length is typically measured as the distance between points in the respective gore areas where the left edge of the ramp traveled way and the right edge of the freeway traveled way meet. This is called base length L_B. The HCM2010 methodology uses the short length, L_s which is defined as the distance between the end points of any barrier markings (solid lines) that prohibit or discourage lane changing (Figure 2.2). Based on the data collected as part of the HCM2010 weaving analysis methodology the following relationship exists:

$$L_S = 0.77 L_B \quad (1)$$

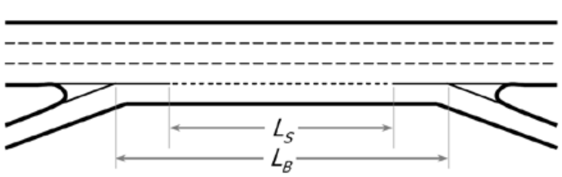


Figure 2.2 Weaving Section Length (source: Exhibit 12-2, HCM2010)

2.2.2 Number of Lane Changes in the Weaving Section

The HCM2010 methodology explicitly considers the number of lane changes in the weaving segment. The total number of lane changes LC_{ALL} consists of the lane changes by the weaving vehicles LC_W plus the number of lane changes by the non-weaving vehicles LC_{NW}:

$$LC_{ALL} = LC_W + LC_{NW} \quad (2)$$

Number of lane changes by weaving vehicles: The total lane-changing rate LC_W for weaving vehicles is the sum of the minimum lane changes LC_{MIN} plus the optional lane changes for weaving vehicles that could occur in the weaving segment:

$$LCw = LC_{MIN} + 0.39\left[(L_s - 0.39)^{0.5} N^2 (1 + ID)^{0.8}\right] \quad (3)$$

where:

$$LC_{MIN} = (LC_{RF} x v_{RF}) + (LC_{FR} x v_{FR}) \quad (4)$$

L_s = weaving section length (ft)
$LC_{RF(FR)}$ = minimum number of lane changes that a freeway to ramp (ramp to freeway) vehicle must make to complete the desired weaving maneuver
N = number of lanes in the weaving section
ID = interchange density (int/mi),
$v_{RF\ (FR)}$ = ramp to-freeway (freeway-to-ramp) demand flow rate in the weaving section (pc/h)

Number of lane changes by non-weaving vehicles: The lane changes performed by non-weaving vehicles are optional. Such lane changes are made to avoid the turbulence created by the lane changing maneuvers of weaving vehicles, and/or to improve vehicle's speed. The estimation of the number of lane changes depend on the "a non-weaving vehicle index" I_{NW} defined below:

$$I_{NW} = \frac{L_S ID v_{NW}}{10{,}000} \quad (5)$$

where v_{NW} is the demand flow rate of the non-weaving vehicles.

The number of lane changes for non-weaving vehicles is:

If $I_{NW} \leq 1{,}300$ $\quad LC_{NW} = L_{NW1} \quad LC_{NW1} = (0.206 v_{NW}) + (0.542 L_S) - (192.6N) \quad (5)$

If $I_{NW} \geq 1{,}950$ $\quad LC_{NW} = L_{NW2} \quad LC_{NW2} = 2135 + 0.223(v_{NW} - 2{,}000) \quad (6)$

If $1{,}300 < I_{NW} \leq 1{,}950$ $\quad LC_{NW} = L_{NW3} \quad LC_{NW3} = L_{NW1} + (LC_{NW2} - LC_{NW1})\left(\frac{I_{NW} - 1{,}300}{650}\right) \quad (7)$

2.2.3 Average Speed of Vehicles in the Weaving Section

The average speed of weaving vehicles S_w is:

$$S_w = 15 + \frac{FFS - 15}{(1 + W)} \qquad (8)$$

where FFS is the freeway free-flow speed and W is the weaving intensity factor which is a function of the total lane-changing rate within the weaving segment:

$$W = 0.226\left(\frac{LC_{ALL}}{L_S}\right)^{0.789} \qquad (9)$$

The average speed of non-weaving vehicles S_{NW} is computed using the following equation:

$$S_{NW} = FFS - (0.0072 LC_{MIN}) - \left(0.0048\frac{v}{N}\right) \qquad (10)$$

where v is the total demand flow rate.

As expected, the speed of non-weaving vehicles decreases with an increase in the weaving turbulence, caused by either increases in the LC_{MIN} or the total demand flow rate per lane.

The average space mean speed of all vehicles in the weaving segment is calculated as follows:

$$S = \frac{v_w + v_{NW}}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{NW}}{S_{NW}}\right)} \qquad (11)$$

where v_W and v_{NW} are the weaving and non-weaving demand flow rates in the weaving segment respectively.

2.2.4 Level of Service (LOS)

Next, the density for the weaving section is computed from the average speed and flow rate. The Level of Service (LOS) is determined from the computed density value based on Table 2.1 below:

Table 2.1 HCM2010 LOS Criteria for Freeway Weaving Sections

LOS	Density (pc/mi/ln)
A	0-10
B	>10-20
C	>20-28
D	>28-35
E	>35
F	Demand Exceeds Capacity

2.2.5 Capacity of the Weaving Section

The HCM 2010 methodology computes two values for the capacity of the weaving section– one based upon a density of 43 pc/mi/ln, which according to the HCM2010 is the value that freeway breakdowns occur, and the other based upon the maximum weaving flow rates. The minimum of the two values is the capacity of the weaving section.

The capacity of a weaving segment determined by the freeway breakdown density is:

$$c_{IWL} = c_{IFL} - \left[438.2(1+VR)^{1.6}\right] + \left[0.0765L_s\right] + \left[119.8N_{WL}\right] \qquad (12)$$

where:
c_{IWL} = capacity of the weaving segment under equivalent ideal conditions (pc/h/ln)
c_{IFL} = capacity of a basic freeway segment with the same free-flow speed as the weaving segment under equivalent ideal conditions (pc/h/ln)
N_{WL} = number of lanes from which weaving maneuvers can be made with one lane change or no lane changes.
VR = volume ratio for weaving demand (= total weaving volume/total volume)

The respective total capacity under prevailing conditions is calculated as follows:

$$c_W = c_{IWL} N f_{HV} f_p \qquad (13)$$

where f_{HV} and f_P are adjustment factors for heavy-vehicle presence and driver population respectively.

The capacity of a weaving segment determined by the total weaving demand is estimated as follows:

$$c_{IW} = \frac{2{,}400}{VR} \quad for\ N_{WL} = 2\ lanes \qquad (14)$$

$$c_{IW} = \frac{3{,}500}{VR} \quad for\ N_{WL} = 3\ lanes \qquad (15)$$

where c_{IW} is the capacity of all lanes in the weaving segment under ideal conditions (pc/h). As before the respective total capacity under prevailing conditions is calculated as follows:

$$c_W = c_{IWL} f_{HV} f_p \qquad (16)$$

The capacity of the weaving segment is defined as the smaller of the values in (13) and (16).

CHAPTER 3
EVALUATION OF THE HCM2010 METHODOLOGY

This Chapter describes the application of the HCM2010 on existing data from weaving sites in California. The data were collected in previous research studies.

3.1 The Study Database

Data from several real-world weaving sections throughout the US (Table 3.1) were assembled covering a range of configurations and design and traffic characteristics. The final database consists of 30 test sites and a total of 228 data points of volumes and speeds. Table 3.1 shows the available datasets per geometric characteristics (number of lanes and configuration) and source. The sources and characteristics of data are further described below:

California Studies —Major Weaving Sections [13]: Data on eight major weaving sections in California were collected in late 1980s using video recording and processed to obtain volumes per traffic movement, speeds of weaving and non-weaving vehicles and lane distribution of component flows. All the sites are major weaving sections with more than one lane on or off-ramps, typical of urban freeway weaving sites. The data were reviewed for accuracy and coded into the study database for further analysis. There are a total of eight test sites and 32 data points of volume and speed conditions (Table 3.2).

Table 3.1 The Study Database

CONFIGURATION	Number of Lanes in the Weaving Section		
	N=3	N=4	N=5 (or more)
RAMP WEAVE **One lane on- and off-ramps**	MD-100EB-1		**SR-91EB** **I-580EB** **I-10EB** *US-101NB** **SR-91WB** **I-110SB** **I-10WB** **SR-60EB** **I-5SB**
MAJOR WEAVE BALANCED **More than one lane on- or off- ramps**	MD-100EB-2 **SR-92WB** SR-217SB	I-405EB SR-102WB I-5SB-1 SR-202EB	*I-80EB* **I-95SB** **I-5SB-2** **I-805NB** **I-10WB_SB** **I-10WB_LA**
MAJOR WEAVE UNBALANCED **More than one lane on- or off-ramps**			**US-101NB** SR-101EB **I-280SB** **US-101SB** **I-10EB_LA***

**six lanes*
xxxx: California Studies
xxxx: NCHRP 3-75 Data
xxxx: NGSIM Data

Table 3.2 Major Weaving Sites—California Studies

TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	V (vph)	VR	S (mph)	D (v/m/l)
SR 92WB	3	1400	1078	3	65	3221	0.43	51.73	20.75
San Mateo						2760	0.41	53.55	17.18
						3035	0.35	59.67	16.95
						4033	0.33	57.44	23.40
I-805NB	5	1371	1056	3	65	7197	0.22	60.69	23.72
San Diego						6663	0.23	60.66	21.97
						6903	0.25	61.04	22.62
						6909	0.23	56.75	24.35
I-10WB	5	1690	1301	3	65	7751	0.31	58.00	26.73
Los Angeles						5986	0.31	62.90	19.03
						5941	0.32	62.03	19.15
						5832	0.33	62.17	18.76
						6427	0.33	60.42	21.27
I-10WB	5	1989	1532	3	65	4020	0.25	59.01	13.62
San Bernardino						3822	0.25	60.16	12.71
						4612	0.25	65.61	14.06
US 101NB	5	787	606	2	65	9684	0.43	48.70	39.77
Los Angeles						9202	0.38	48.72	37.77
I-280SB	5	1347	1037	2	65	5665	0.30	67.80	16.71
San Jose						5130	0.32	67.13	15.28
						4720	0.31	62.74	15.05
						4997	0.31	65.86	15.17
						7092	0.27	64.23	22.08
						7391	0.28	61.36	24.09
I-10EB	6	1437	1106	2	65	4622	0.37	52.70	14.62
Los Angeles						4389	0.40	51.73	14.14
						5800	0.34	57.25	16.88
						6411	0.34	56.93	18.77
						10102	0.37	45.65	36.88

California Studies —Ramp Weaves: Caltrans staff collected data on weaving sections in the early 90's using video recordings, as part of a study to evaluate the accuracy of the Level D method [14]. All the data were collected on urban freeways with a one lane on- and off-ramp connected with an auxiliary lane. Most of the data in each study site consisted of 5 minute volumes per movement. Speeds of weaving and non-weaving vehicles were extracted from eight sites. At the time of the data collection there was a 55 mph posted speed limit on all locations. Table 3.3 shows the final ramp weaves database consisting of eight sites all five lane wide and 84 data points of volumes and speeds.

The NGSIM Data Sets: Detailed data on freeway operations have been collected as part of the of Next Generation Simulation (NGSIM) program sponsored by FHWA [15]. The NGSIM database consists of vehicle trajectories and aggregate loop detector data from two weaving sections in California: I-80EB in San Francisco Bay area and US-101NB in Los Angeles. The Interstate 80 site is Type B weaving section per HCM2000 with a length of 1,650 ft; there are six freeway lanes entering the weaving section with lane 1 an HOV lane. There is a lane drop downstream of the off-ramp. The US-101NB is a typical ramp weave section with five through lanes, one lane on and off ramps and a continuous auxiliary lane. There are a total of eight data points of volumes and speeds in congestion and transition.

The NCHRP 3-75 Database: The data base for the National Cooperative Highway Research Program (NCHRP) Project 3-75 that produced the HCM2010 methodology consisted of 10 sites for 104 data points in four different regions of the country [1]. The data on traffic volumes and speeds were collected using video recordings. Most of the weaving sections are balanced sections with five lanes.

Table 3.3 Ramp Weaving Sites—California Studies

TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	V (vph)	VR	S (mph)	D (v/m/l)
I-580EB	5	1250	963	2	55	6096	0.33	45.0	27.1
Oakland						6264	0.29	46.0	27.2
						6804	0.32	42.0	32.4
						6708	0.31	44.0	30.5
						6108	0.29	47.0	26.0
						7608	0.30	42.0	36.2
						7836	0.31	41.0	38.2
						8328	0.27	42.0	39.7
						9444	0.26	41.0	46.1
						8784	0.26	42.0	41.8
						8208	0.26	43.0	38.2
						8052	0.30	41.0	39.3
						8112	0.29	41.0	39.6
						8532	0.26	42.0	40.6
						8100	0.33	39.0	41.5
						8364	0.29	41.0	40.8
						8340	0.31	40.0	41.7
						8412	0.32	39.0	43.1
						8736	0.27	41.0	42.6
						9984	0.30	37.0	54.0
						8592	0.31	39.0	44.1
						9528	0.31	37.0	51.5
						9252	0.28	40.0	46.3
						8700	0.33	38.0	45.8
						3972	0.33	55.0	14.4
						3972	0.37	55.0	14.4
						3912	0.37	57.0	13.7
I-5SB	5	1255	966	2	55	4284	0.26	55.0	15.6
San Diego						4392	0.21	54.0	16.3
						4620	0.24	55.0	16.8
						5868	0.21	55.0	21.3
						6132	0.21	53.0	23.1
						6240	0.20	53.0	23.5
						5988	0.17	53.0	22.6
						5880	0.19	54.0	21.8
						6108	0.19	54.0	22.6
SR 91WB	5	1895	1459	2	55	5448	0.13	59.0	18.5
Los Angeles						5124	0.12	60.0	17.1
						5592	0.11	58.0	19.3

Table 3.3 Ramp Weaving Sites—California Studies (continued)

SR 60EB Los Angeles	5	1100	847	2	55	9240	0.08	60.0	30.8
						8784	0.09	58.0	30.3
						8568	0.09	59.0	29.0
						5400	0.08	60.0	18.0
						5388	0.10	63.0	17.1
						5052	0.11	60.0	16.8
						5340	0.08	60.0	17.8
						5760	0.09	61.0	18.9
						6168	0.10	61.0	20.2
						6240	0.08	60.0	20.8
						5520	0.10	61.0	18.1
						5880	0.07	61.0	19.3
						6720	0.07	59.0	22.8
						7068	0.08	59.0	24.0
						6708	0.08	59.0	22.7
I-10WB Los Angeles	5	1010	778	2	55	4428	0.17	55.0	16.1
						4524	0.15	56.0	16.2
						4800	0.16	55.0	17.5
						4404	0.18	55.0	16.0
						5244	0.14	54.0	19.4
						4524	0.19	56.0	16.2
						4608	0.14	55.0	16.8
						4992	0.19	54.0	18.5
						4752	0.11	55.0	17.3
						4584	0.13	56.0	16.4
						4980	0.15	55.0	18.1
						5244	0.15	55.0	19.1
I-110SB Los Angeles	5	610	470	2	55	7716	0.07	52.0	29.7
						7488	0.07	50.0	30.0
						7440	0.09	53.0	28.1
SR 91EB Los Angeles	5	845	651	2	65	6612	0.13	58.9	22.5
						6084	0.14	58.4	20.8
						6396	0.10	58.6	21.8
I-10EB Los Angeles	5	950	732	2	55	5244	0.08	57.0	18.4
						5172	0.06	55.0	18.8
						5664	0.08	55.0	20.6
						4980	0.07	59.0	16.9
						6264	0.07	53.0	23.6
						6156	0.08	54.0	22.8
						5508	0.07	55.0	20.0
						6000	0.08	55.0	21.8
						5340	0.12	54.0	19.8
						5340	0.10	55.0	19.4
						5112	0.08	56.0	18.3
						5436	0.11	54.0	20.1

3.2 Application of the HCM2010 Methodology to Weaving Sections

The HCM2010 methodology was applied to the California datasets, a total of 116 data points (Tables 3.2 and 3.3) to predict the density and LOS in the weaving sections. We did not apply the method to the NCHRP and NGSIM test sites, because those data were used to develop the HCM2010 and the emphasis in the evaluation is to determine the methodology's accuracy in analyzing California weaving sections. The datasets from NCHRP and MGSIM were utilized later in the project along new data collected to develop an improved procedure as appropriate.

The HCM2010 method predictions were compared to the field measurements within a site and across all sites to determine the strengths and limitations of the methodology. The findings from the analysis are described below:

The HCM methodology predicts that the traffic demand exceeds the capacity in 15 datasets shown in Table3.4. In this situation the method does not calculate density or LOS. Field measurements indicate that these weaving sections operate below capacity. As it is shown on Table 3.4, all the weaving sections are ramp weaves or unbalanced sections with high weaving ratio VR (fraction of weaving volume to total volume) and appears that HCM2010 underestimates the capacity in these situations.

As it was described in Section 2.2.5 the HCM2010 calculates the capacity as the smaller of two values: the capacity estimate C_D based on the breakdown density for freeways of 43 pc/mi/lane and the capacity estimate C_W based on the total weaving volume. Table 5 shows that the C_D value exceeds the measured volumes, but the C_W is lower in all datasets.

Table 3.4 HCM2010 Predicted Capacity vs. Field Measurements

TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	Vw (vph)	VR	V (vph)	HCM2010		
									C_D (vph)	Cw (vph)	C (vph)
I-580EB Oakland	5	1250	963	2	55	2424	0.31	**7836**	9376	7758	**7758**
						2472	0.26	**9444**	9570	9169	**9169**
						2436	0.30	**8052**	9404	7933	**7933**
						2712	0.33	**8100**	9274	7168	**7168**
						2436	0.29	**8364**	9450	8240	**8240**
						2556	0.31	**8340**	9388	7831	**7831**
						2676	0.32	**8412**	9340	7544	**7544**
						2952	0.30	**9984**	9432	8117	**8117**
						2640	0.31	**8592**	9385	7811	**7811**
						2928	0.31	**9528**	9384	7810	**7810**
						2592	0.28	**9252**	9465	8567	**8567**
						2844	0.33	**8700**	10707	7342	**7342**
US 101NB Los Angeles	5	787	606	2	65	4119	0.43	**9684**	9067	5643	**5643**
						3517	0.38	**9202**	9252	6279	**6279**
I-10EB Los Angeles	6	1437	1106	2	65	3781	0.37	**10102**	11373	6412	**6412**

The HCM2010 methodology predicted in 8 datasets that the traffic demands are below capacity but the calculated densities are higher than the critical density of 43 pc/mi/l (Table 3.5). This is an inconsistency in the methodology because if the weaving section under consideration operates below capacity then the density should be below the critical density value. The issue was brought to the methodology developers and to the members of the Transportation Research Board Highway Capacity and Quality of Service Committee but no response has been received to-date.

Table 3.5 HCM2010 Density Predictions above Critical Density

TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	V (vph)	FIELD DATA S (mph)	FIELD DATA D (veh/m/l)	FIELD DATA LOS	HCM2010 S (mph)	HCM2010 D (veh/m/l)	HCM2010 LOS
I-580EB Oakland	5	1250	963	2	55	7608	42.0	36.2	E	33.1	**46.0**	E
						8328	42.0	39.7	E	32.9	**50.6**	E
						8784	42.0	41.8	E	31.9	**55.1**	E
						8208	43.0	38.2	E	33.3	**49.3**	E
						8112	41.0	39.6	E	32.3	**50.2**	E
						8532	42.0	40.6	E	32.6	**52.3**	E
						8736	41.0	42.6	E	31.6	**55.3**	E
SR 60EB Los Angeles	5	1100	847	2	55	9240	60.0	30.8	D	40.9	**45.2**	E

Figure 3.1 shows the average percentage error and the root mean square error (RMSE) between the observed and HCM2010 predicted densities at all the remaining datasets (a total of 93 datasets). On the average the HCM2010 predicted density is 22% higher than the observed values and the RMSE is 5.1 pc/mi/l. Figure 3.1 also shows a comparison of field and predicted values per configuration type. The HCM2010 method performs best for balanced weaving sections (average difference of 8.3% and RMSE of 2.1 pc/mi/l). HCM2010 over-predicts the densities for ramp weaves and unbalanced weaving sections by 24% on the average.

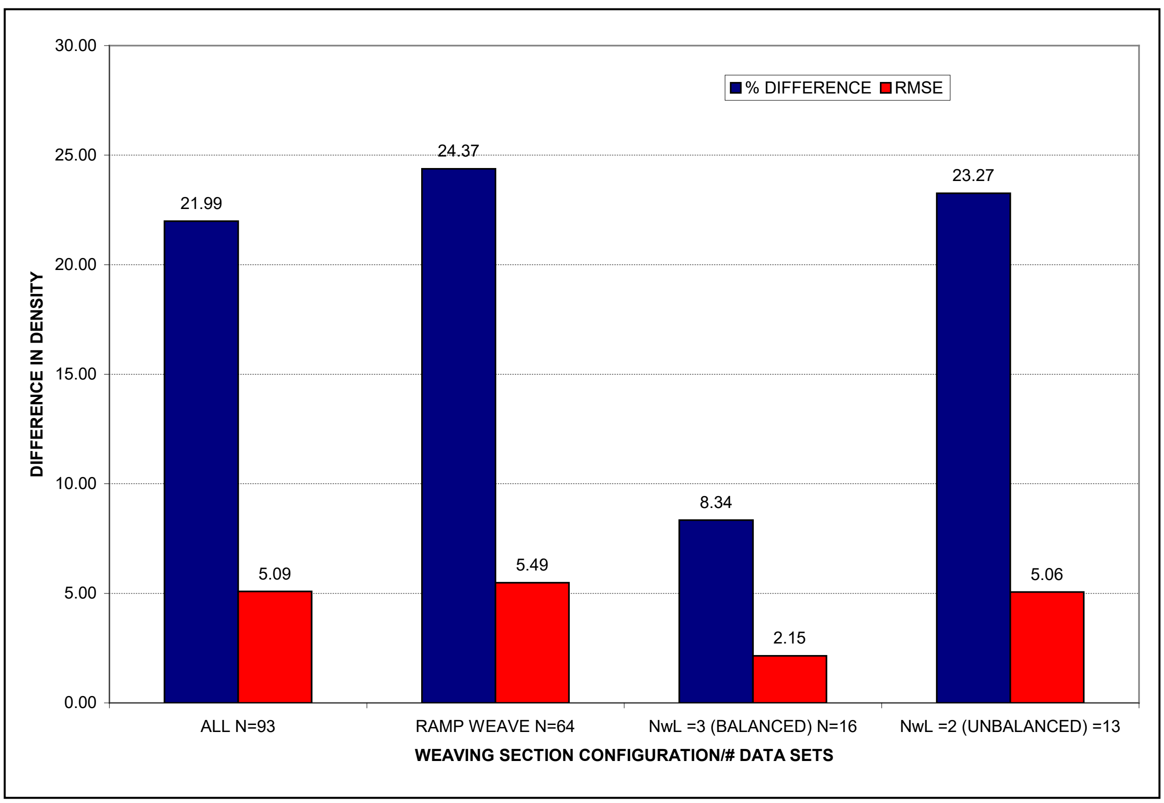


Figure 3.1 Measured vs. HCM2010 Predicted Densities

Figure 3.2 shows in more detail the observed and HCM2010 predicted densities per weaving section configuration. The largest differences are for ramp and unbalanced weaving sections under heavy traffic conditions.

Regarding the LOS, the HCM2010 methodology predicted a worse LOS than observed in 51 out of 93 datasets (55%). The majority of datasets (43) were ramp weaves.

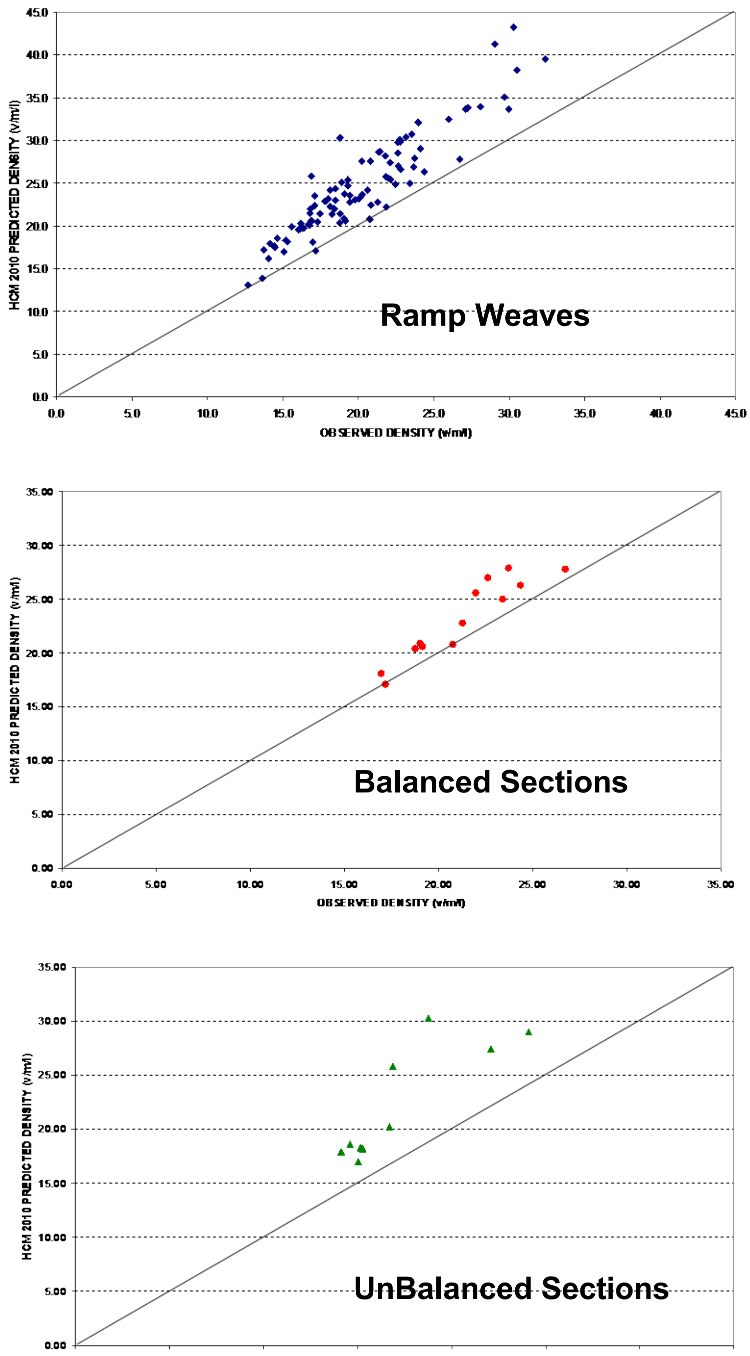


Figure 3.2 Measured vs. HCM2010 Predicted Densities per Weaving Section Configuration

CHAPTER 4
FIELD DATA COLLECTION

This Chapter describes the selection of ramp weaving sites and the collection of new ramp weave field data at the selected sites.

4.1 Selection of Data Collection Sites

The selection of weaving test sites was based on the following criteria:

Test Site is a Bottleneck location: the presence of a weave area bottleneck is characterized by the presence of two observable traits, which are necessary to measure the capacity of the weave area:

1) Upstream demand must be sufficient as to not starve the weave bottleneck. Queueing (congestion) should be present at one or more of the approaches to the weave area.
2) Downstream effects cannot hinder traffic discharging from the weave bottleneck – traffic discharging the weaving area should be freely flowing.

Test Site Characteristics: because the objective is to evaluate the HCM2010 weaving analysis method, the selected site should not include characteristics that may prevent the application of the HCM2010 method. The HCM2010 methodology has the following limitations:

- Special lanes, such as High-occupancy vehicle lanes, within the weaving segment;
- Ramp metering on entrance ramps forming part of the weaving segment;
- Specific operating conditions when oversaturated conditions exist;
- Effects of speed limit enforcement practices on weaving segment operations;
- Effects of intelligent transportation system technologies on weaving segment operations;
- Weaving segments on arterials or other urban streets, including one-way frontage roads;
- Multiple weaving segments.

Availability of Reliable Detector Data: Working freeway mainline loop detectors upstream of the weaving section, within the weaving section, and downstream of the weaving section were desired properties of a weave segment for analysis purposes; as were functional loop detectors at the weave's upstream on-ramp and downstream off-ramp. Weaving sites with regularly spaced detector data archived in the freeway performance measurement system (PeMS) were preferred over sites with poor or no archived loop data.

The PeMS archived loop data was utilized for a few key purposes. First during the selection process to determine if a test site was a regularly active bottleneck (a key criterion for selecting the test site). During the weave analysis, the PeMS data were used to determine when downstream pressure could have been affecting the weave's performance (important for quantifying the performance of weave sections). Finally, the PeMS archived loop data were used to check the accuracy of field data collection equipment.

Possibility for Placement of Data Collection Equipment: the weaving data collection sites needed to be compatible with the proposed data collection methods, i.e., MioVision cameras and Bluetooth units. Both collection devices require poles or other locations for mounting the equipment.

The selection of the test sites was performed as followed:

The members of technical advisory group proposed a total of thirty five test sites in the Districts 3, 5, 6, 7, 11 and 12. Detector data on each site from PeMS were extracted and processed to determine if the potential sites were active bottleneck locations. Next, the sites identified as active bottlenecks were visited. A detailed site investigation was performed on the selected sites to assure that they were compatible with the proposed data collection procedures – for example, field site visits confirmed that the sites had adequate light and/or sign poles along the weave section for to mount the MioVision and other traffic data collection equipment.

Another important consideration in selecting the sites to collect data, was the availability of assistance from the District maintenance departments to safely install and uninstall the data collection equipment on light and/or sign poles along the selected freeway weaving sites.

The following three weaving sites were chosen. All the sites are located in District 11 in San Diego. The sites are shown in Figure 4.1.

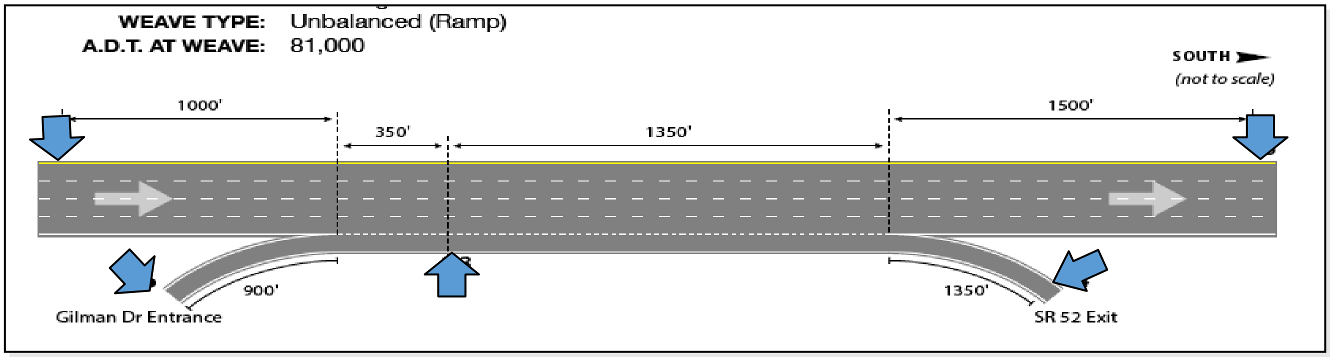
1. I-5 North before Sea World Drive
2. I-5 South before SR-52
3. I-805 North before Governor Drive

4.2 Field Data Collection

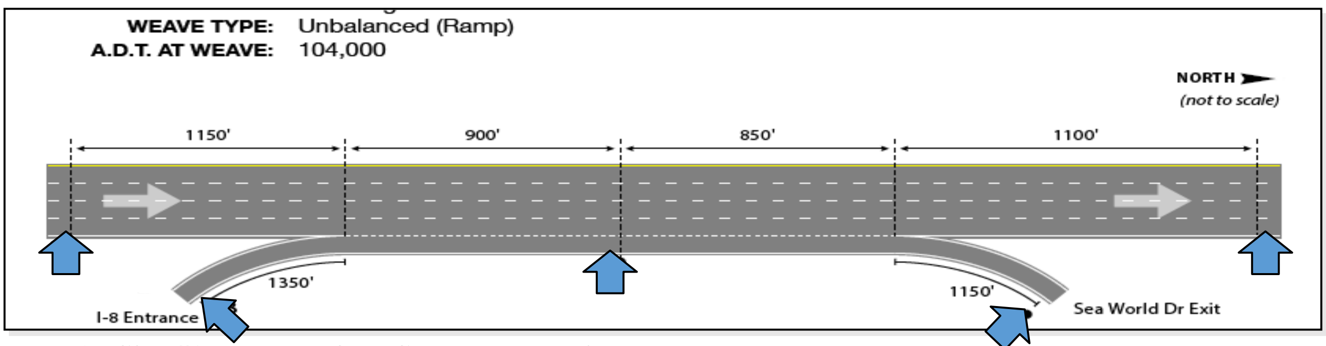
The data to be collected include a) traffic counts and speed per movement, i.e., freeway-to freeway, freeway to ramp, ramp to freeway and ramp to ramp. The speed data are obtained from the travel times measured using Bluetooth sensors. MioVision units were utilized to video record traffic volumes. Figure 4.1 shows the location of Bluetooth and MioVision units in each site.

The data collected were thoroughly checked for accuracy and consistency. Figure 4.2 shows a comparison of traffic volumes from PeMS obtained from the loop detectors at the site and the volumes obtained from processing the MioVision recording. Figure 4.3 shows the travel times for each weaving movement based on the Bluetooth data. It also shows the peak period is the pm period. The speed of weaving and non-weaving vehicles was calculated based on the distance of Bluetooth sensors and recorded travel times. The Bluetooth data gave us also the proportion of each weaving movement in the total volume in the section (Figure 4.4). It can be seen that most of the traffic volume is freeway to freeway.

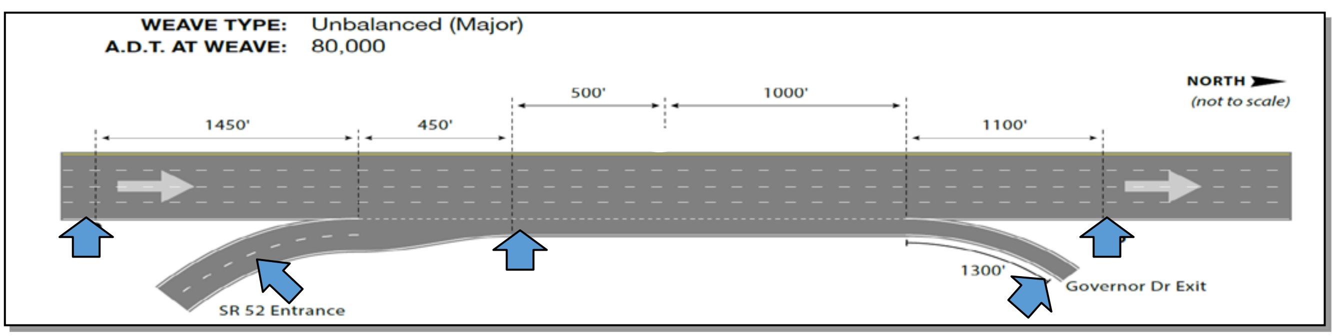
The processing of the data produced a total of 96 data points per day over 5 weekdays for each site consisting of traffic volumes, speeds, and estimated densities.



a) Site #1 I-5 SB before SR 52



b) Site #2 I-5 B before Sea World Drive



c) Site #3 I-805 NB before Governor Drive

Placement of Data Collection Equipment

Figure 4.1 Selected Test Sites for Field Data Collection

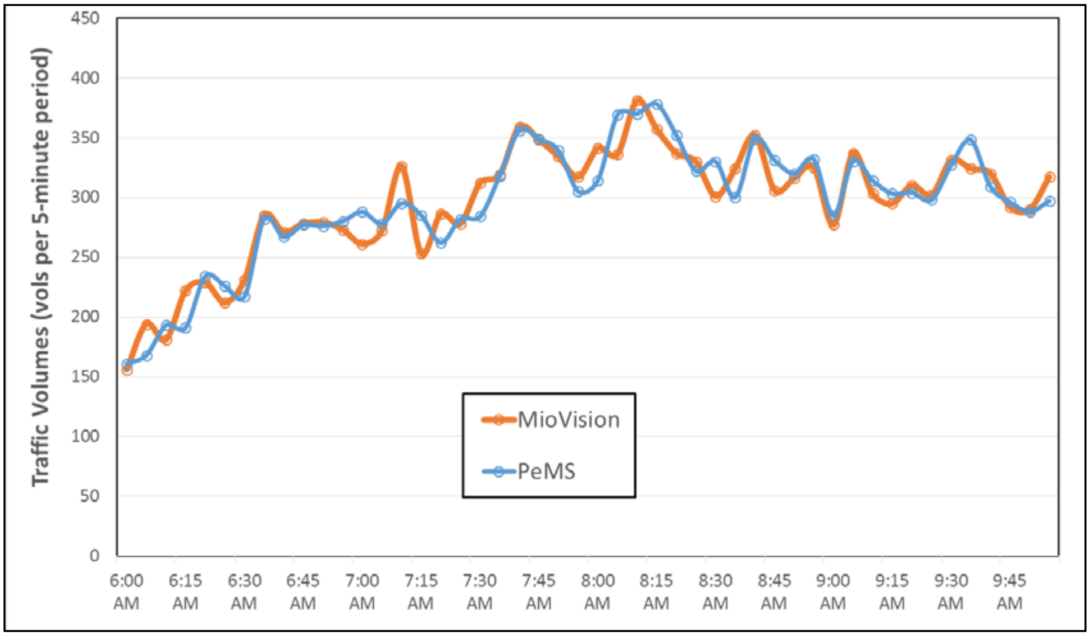


Figure 4.2 Traffic Volumes: PeMS Vs. Miovision—Site #1

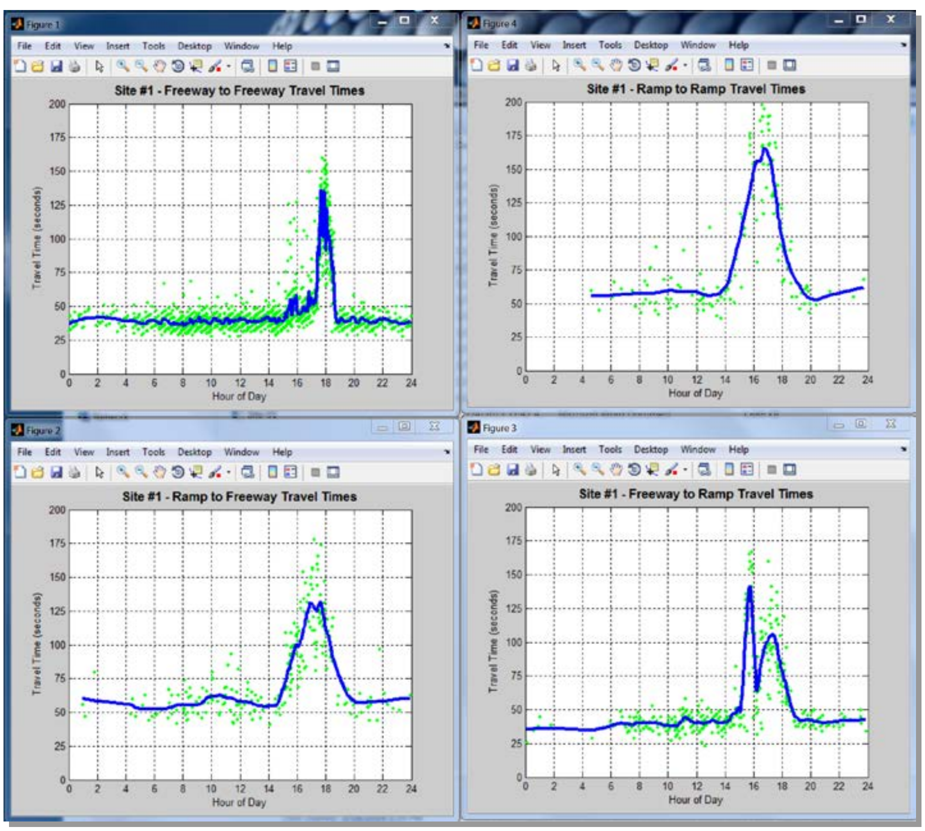


Figure 4.3 Bluetooth Travel Times—Site #1

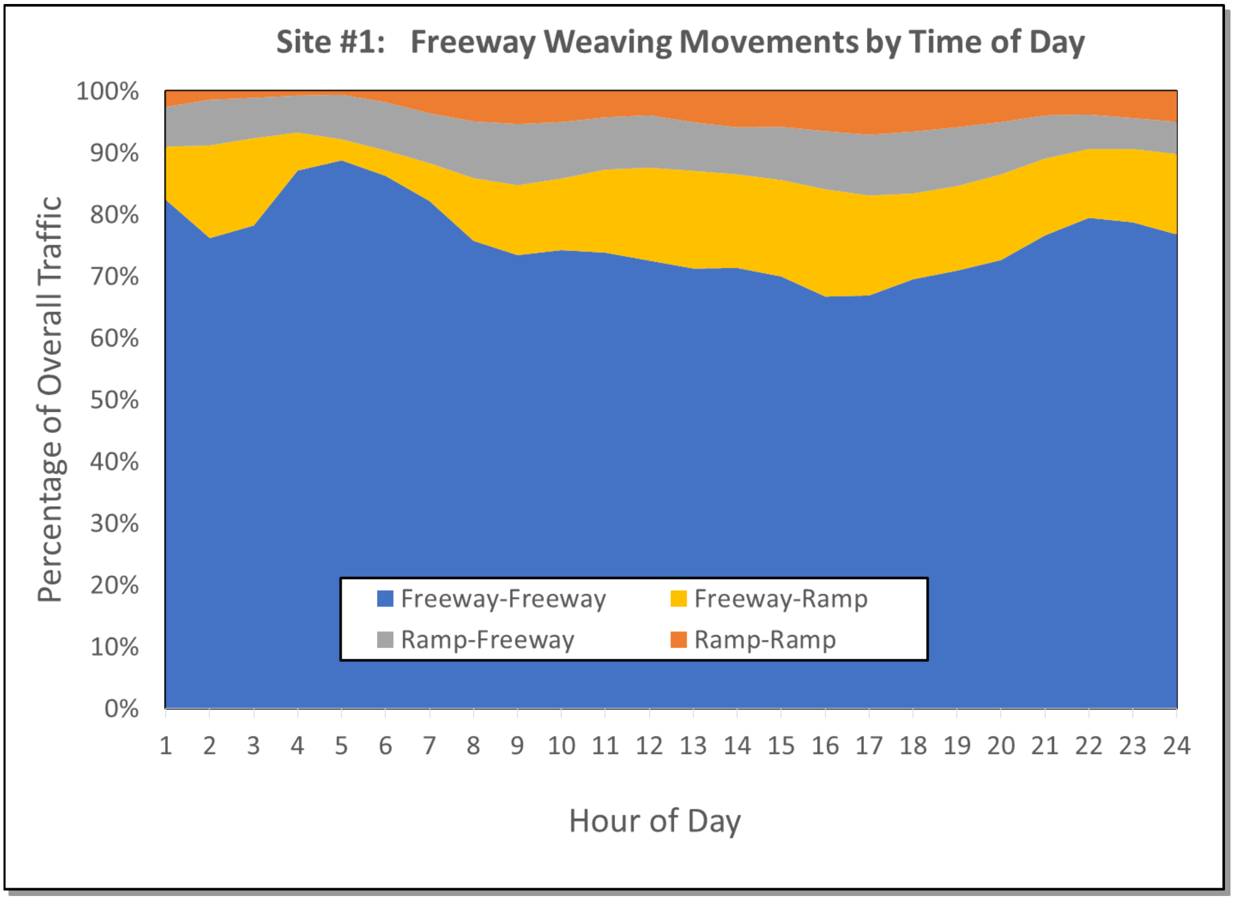


Figure 4.4 O-D Weaving Movements--Bluetooth Data -Site #1

CHAPTER 5
APPLICATION OF WEAVING ANALYSIS METHODOLOGIES TO FIELD DATA

5.1 Density Estimation – Application of Weaving Analysis Methodologies to Field Data

The HCM2010 method was applied to the three San Diego Ramp Weave datasets. Each San Diego dataset contained 15-minute aggregated traffic volume, speed, and empirically estimated densities, totaling 96 data points per day for 5 weekdays.

The HCM2010 method density predictions were compared to the field measurements for each of the three sites to determine the strengths and limitations of the HCM2010 methodology. This analysis procedure was repeated for the 5 weekdays of data at all three San Diego sites using the Caltrans Level D method. Finally, the analysis was repeated using the 5 days of data from San Diego Site #3 using the Leisch Method to gain insights as to how well the Leisch Method's density estimates compared to the field measured densities and those predicted by HCM2010 and Level D methods.

The findings from the analysis are described below:

HCM2010 Method: Study findings using the San Diego weaving sites was largely consistent with the findings presented in Chapter 3 of this report. Using the San Diego Site #3 dataset, the HCM2010 methodology predicted in 4 instances that the traffic demands are below capacity but the calculated densities are higher than the critical density of 43 pc/mi/l (Table 5.1). As was pointed out in Chapter 3, this is an inconsistency in the methodology because if the weaving section under consideration operates below capacity then the density should be below the critical density value. There were no observed data points from San Diego sites #1 and #2 datasets with a density above the critical density of 43 pc/mi/l.

Table 5.1 HCM2010 Density Predictions above Critical Density (San Diego Ramp Weave Sites)

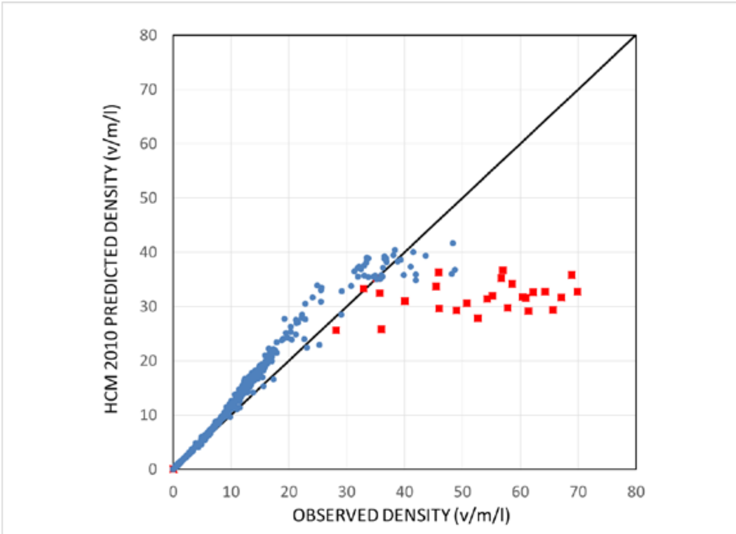
TEST SITE	N	L_S (ft)	N_{WL}	FFS (MPH)	V (vph)	FIELD DATA			HCM2010		
						S (mph)	D (veh/m/l)	LOS	S (mph)	D (veh/m/l)	LOS
San Diego Site #3 I-805 Northbound between SR 52 & Govenor Drive	5	1670	2	65	9,616	26.4	72.8	E	42.4	45.4	E
					9,538	27.5	69.3	E	42.7	44.7	E
					9,476	25.4	74.6	E	41.9	45.2	E
					9,352	23.4	80.0	E	42.4	44.1	E

Figure 5.1 shows the observed and HCM2010 predicted densities for each of the three San Diego weave site. The largest differences between the observed densities and the HCM2010 predicted densities are for heavy traffic conditions. It can be seen from Figure 5.1 that HCM2010 nominally over predicts densities for low volume traffic conditions and tends to under predict densities as the observed densities approach the range of 30 – 40 veh/m/l.

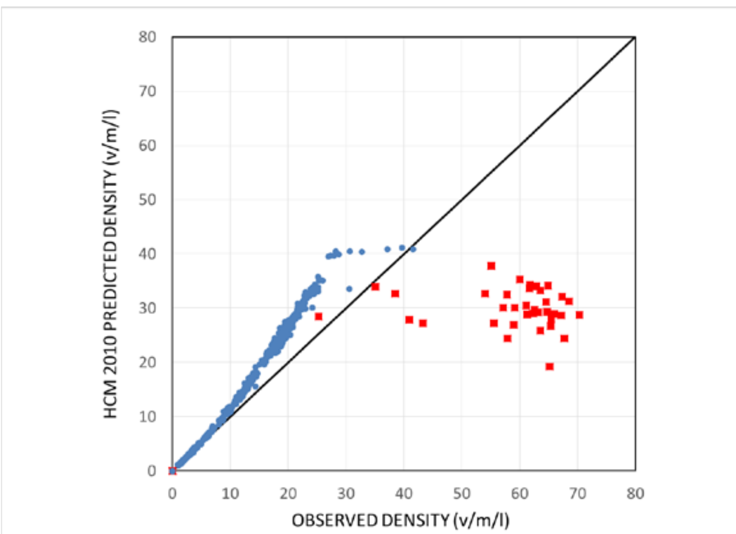
The data points represented as red colored squares in Figure 5.1 are where downstream conditions could have been affecting the traffic conditions within the weave segments. Traffic speeds at a nearby downstream PeMS station was monitored. The data points (observations) were flagged and coded RED when the downstream traffic speeds dropped below 50 mph – that is when free flow traffic conditions could not be confirmed just downstream of the merge segment. The observed density vs. HCM2010 predicted density patterns were similar at all three San Diego weaving sites.

Level D Method: Next, the Caltrans Level D method was applied to the datasets from the three San Diego weaving sites. Figure 5.2 shows the measured and Level D predicted densities for the three San Diego weaving datasets. The data points represented as red colored squares in Figure 5.2 are where the observed speeds was below 50 mph at the closest downstream PeMS station – as was done in Figures 5.1.

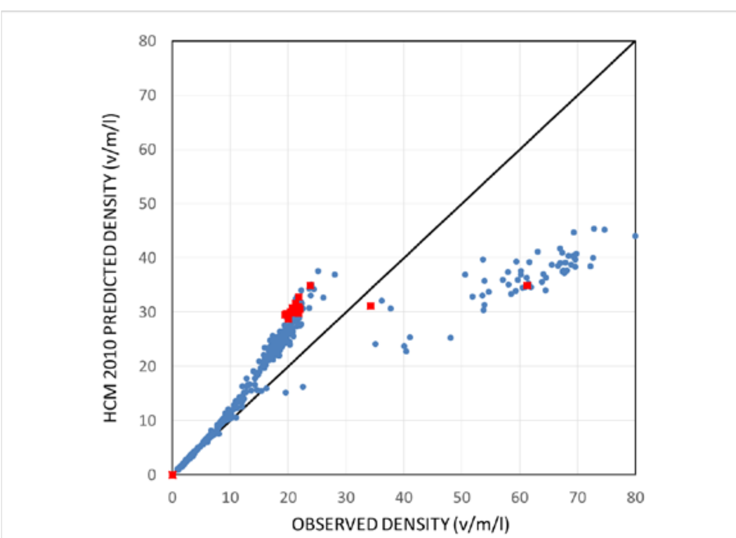
The measured vs. Level D predicted density patterns are similar across the three San Diego weaving sites, and similar to those displayed in Figure 5.1. At the three San Diego weaving sites, the Level D method slightly over predicted densities for low volume traffic conditions and tended to under predict densities where the observed densities were above the 30 – 40 veh/m/l range.



Site #1: Interstate 5 SB in San Diego between Gilman Drive (on) & SR 52 (off)



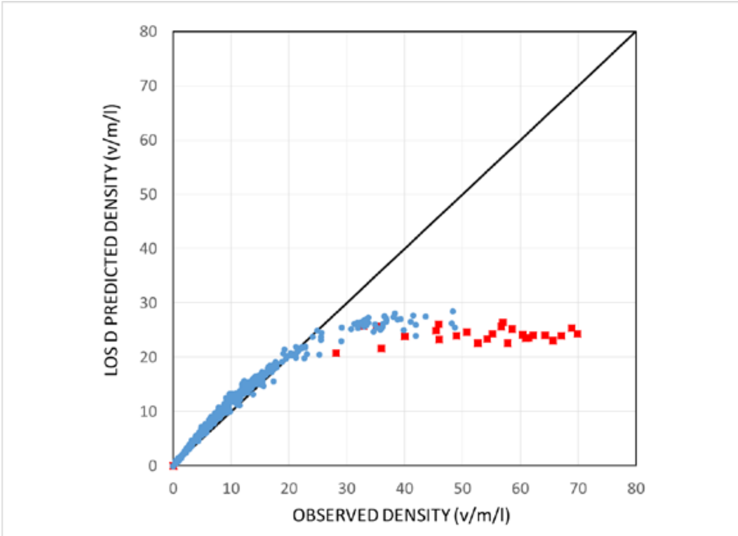
Site #2: Interstate 5 NB in San Diego between I-8 (on) & Sea World Drive (off)



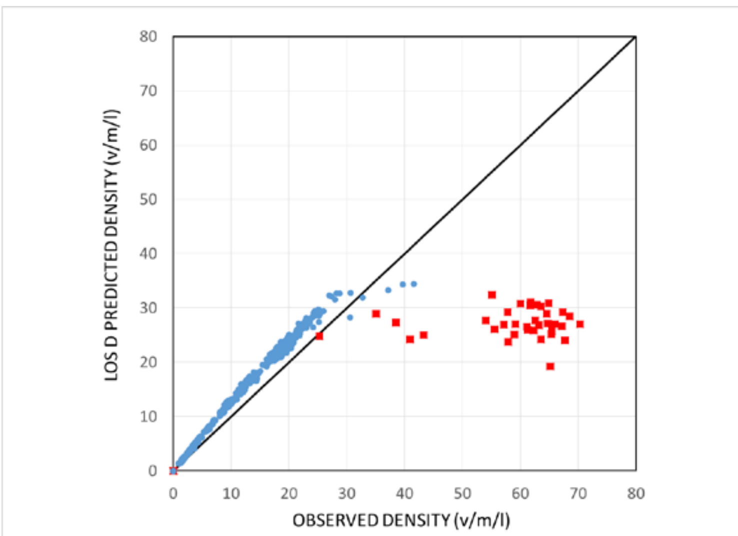
Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off)

Figure 5.1 Measured vs. HCM2010 Predicted Densities per Ramp Weave Site

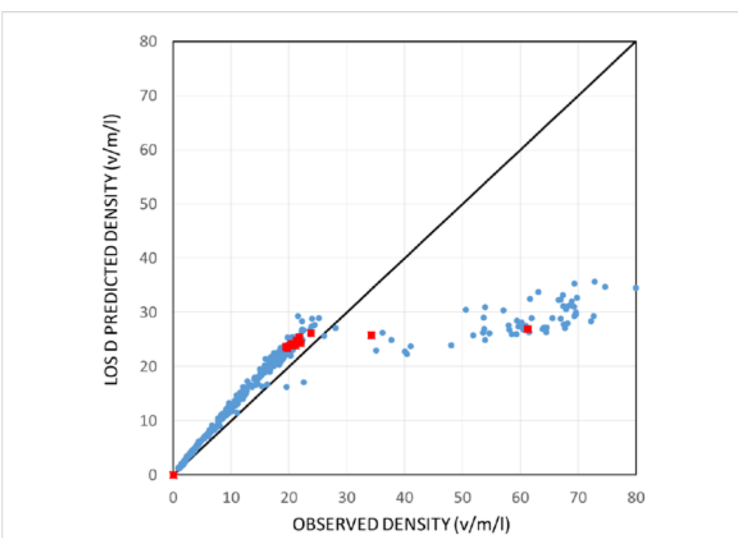
(RED squares are times when downstream congestion could be affecting weave performance.)



Site #1: Interstate 5 SB in San Diego between Gilman Drive (on) & SR 52 (off)



Site #2: Interstate 5 NB in San Diego between I-8 (on) & Sea World Drive (off)



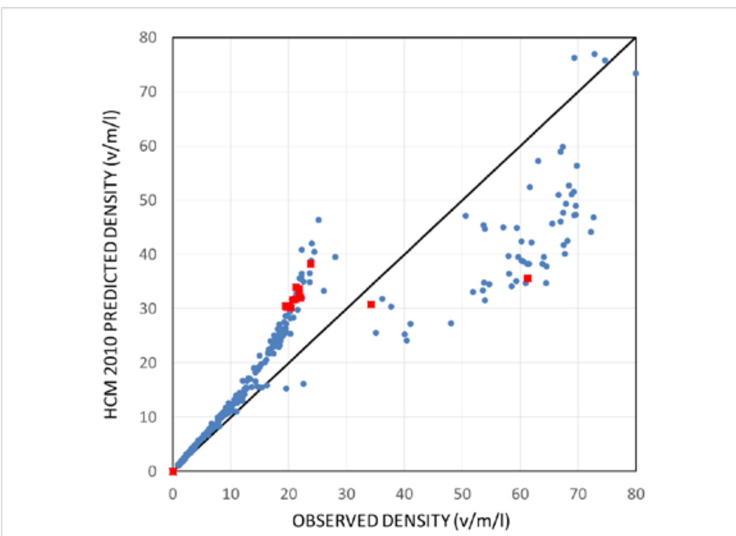
Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off)

Figure 5.2 Measured vs. Level D Predicted Densities per Ramp Weave Site

(RED squares are times when downstream congestion could be affecting weave performance.)

Leisch Method: For comparative purposes, the Leisch Method was applied to the dataset from Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off). Figure 5.3 displays the observed (measured) and Leisch Method predicted densities for the 15-minute periods in Site #3 dataset. The data points represented as red colored squares in Figure 5.3 are where the observed speeds was below 50 mph at the closest downstream PeMS station.

Similar to HCM2010 and Level D methods, the Leisch Method nominally over predicted densities for low traffic conditions. For congested traffic conditions, the Leisch method significantly under predicted density for some 15-minute periods and significantly over predicted density for other 15-minute periods. The average of the Leisch predicted densities were in the range of the average of the measured congested traffic conditions.



Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off)

Figure 5.3 Measured vs. Leisch Predicted Densities for Ramp Weave Site #3

(RED squares are times when downstream congestion could be affecting weave performance.)

Table 5.2.a lists the average percentage error and the root mean square error (RMSE) between the observed and HCM2010 predicted densities for the three San Diego weaving sites. For the three San Diego ramp weave sites, the average HCM2010 predicted density is 13.40% higher than the observed values (as compared to 24.4% higher for the ramp weaves shown earlier in Figure 3 in Section 3.2 of this report). The average RMSE is 5.76 pc/mi/l for the San Diego sites (the average RSME was 5.5 for ramp weaves shown previously in Figure 3 of Section 3.2 of this report). Table 5.2.b shows the average percentage error and RMSE for the Level D method, and Table 5.2.c lists the same for the Leisch method.

The HCM2010 method has a significantly larger average percentage difference than the Level D or Leisch method. The HCM2010, Level D and Leisch methods aggregate performance on predicting densities for ramp weaves was similar using the RMSE measure.

Table 5.2 Measured vs. Predicted Densities (San Diego Ramp Weave Sites)

(a) HCM2010 Method

SITE	AVERAGE % DIFFERENCE	RSME
SITE #1	13.71	2.65
SITE #2	27.73	4.83
SITE #3	-1.24	9.80
AVERAGE	13.40	5.76

(b) Level D Method

SITE	AVERAGE % DIFFERENCE	RSME
SITE #1	0.59	3.62
SITE #2	20.16	3.10
SITE #3	-10.55	11.96
AVERAGE	3.40	6.23

(c) Leisch Method

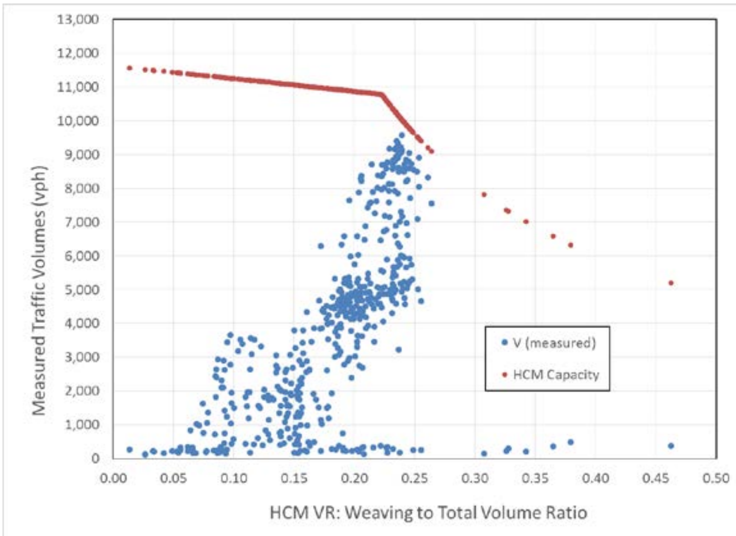
SITE	AVERAGE % DIFFERENCE	RSME
SITE #1	n/a	n/a
SITE #2	n/a	n/a
SITE #3	-2.07	8.68
AVERAGE	-2.07	8.68

5.2 Capacity Estimation – Application of Weaving Analysis Methodologies to Field Data

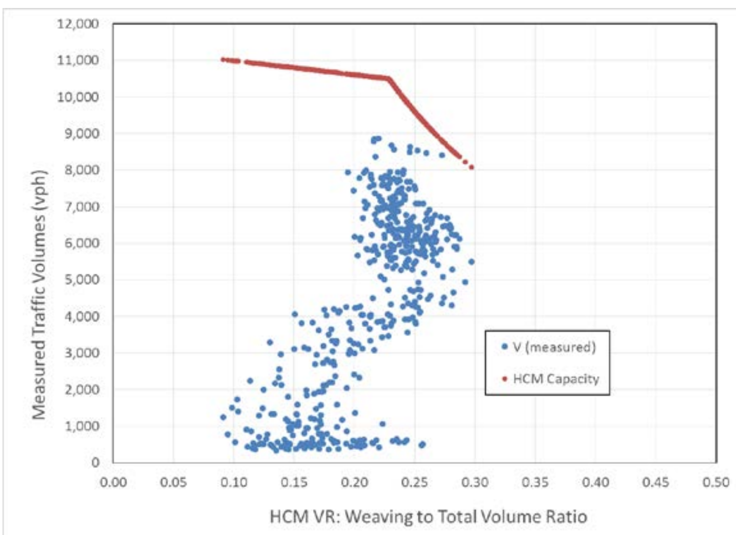
The HCM2010 method estimates the capacity of a freeway weave section for a given geometric information (e.g., number of lanes and weave length) and the total hourly volume rate and the HCM weaving volume to total volume ratio (VR).

The HCM2010 predicted capacities were plotted as a function of the HCM2010 VR parameter, along with the field measured total hourly traffic volume rate (in vehicles per hour) using the San Diego weaving datasets to see if any of the measured hourly traffic volumes exceeded the HCM2010 predicted weaving capacities (see Figure 5.4). The measured hourly volumes were below the HCM2010 predicted capacity for all 15-minute periods observed at Site #1 and Site #2. However, for Site #3, there were several 15-minute observed data points where the measured hourly volumes exceeded the HCM2010 predicted hourly capacities.

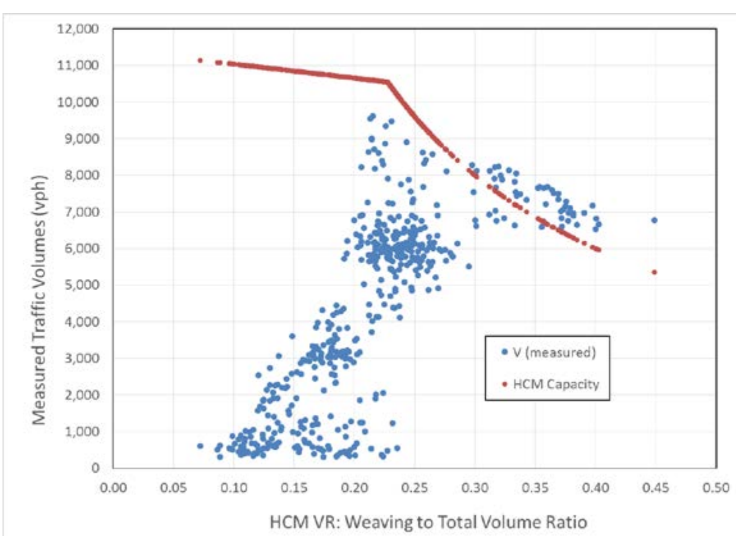
The vast majority of the observations where the weaving section discharge flows exceeded the HCM2010 predicted capacities occurred at a relatively high weaving volume to total volume ratio (VR) – where weaving volumes were in the range of 30% to 40% of the total volumes in the weave segment. In this VR range and above the HCM2010 predicted capacities are considerably reduced to account for the turbulence caused by high lane changing caused by the weaving maneuvers.



Site #1: Interstate 5 SB in San Diego between Gilman Drive (on) & SR 52 (off)



Site #2: Interstate 5 NB in San Diego between I-8 (on) & Sea World Drive (off)



Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off)

Figure 5.4 Measured Hourly Volumes and HCM2010 Predicted Capacities

5.3 Discussion

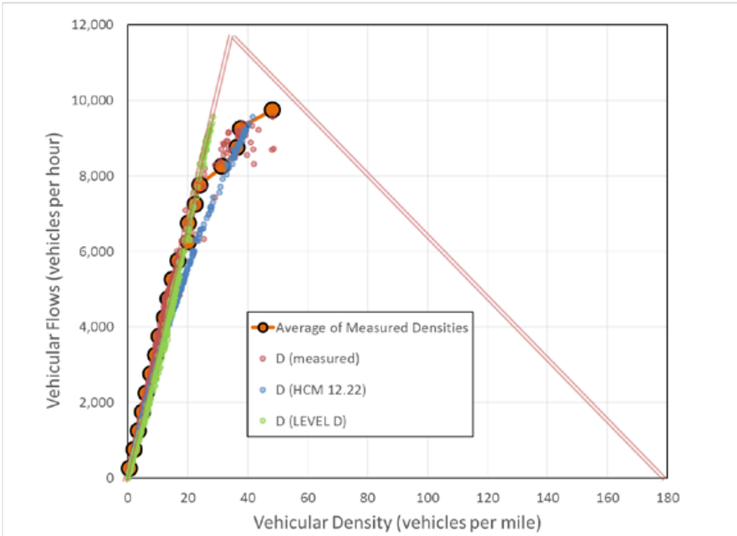
To form more complete explanations for the density trends presented in the preceding Section 5.1, additional analysis were performed. The 15-minute average measured volumes and densities were graphed to form a traditional fundamental traffic flow diagram with densities on the horizontal axis and traffic volumes (sometimes called traffic flows) on the vertical axis. Figure 5.4 shows the measured densities and traffic volumes, along with the HCM2010 and Level D predicted densities for San Diego sites #1, #2 and #3. The Leisch Method predicted densities were also added to the density-flow figure for Site #3. The data points where downstream congestion might have been affecting the weave's performance (those data points with downstream speeds below 50 mph) were omitted from this analysis.

The density-flow diagrams for all three San Diego sites show that measured traffic speeds remain constant with traffic at free flow speeds for all traffic flows under about 7,500 vehicles per hour; and free flow speeds prevailed up to flows of about 8,000 vph at sites #1 and #2. As can be seen in Figure 5.5, densities could be very easily estimated for these weaving sites for flows below 1,500 vehicles-per-hour-per-lane by knowing no more than the free flow speeds within the weave and the measured traffic flows. It should be noted that these three weaving sites have relatively similar geometries. All are 5 lane ramp weaves with HCM2010 weave length (L_S) between 1,500 feet and 1,700 feet.

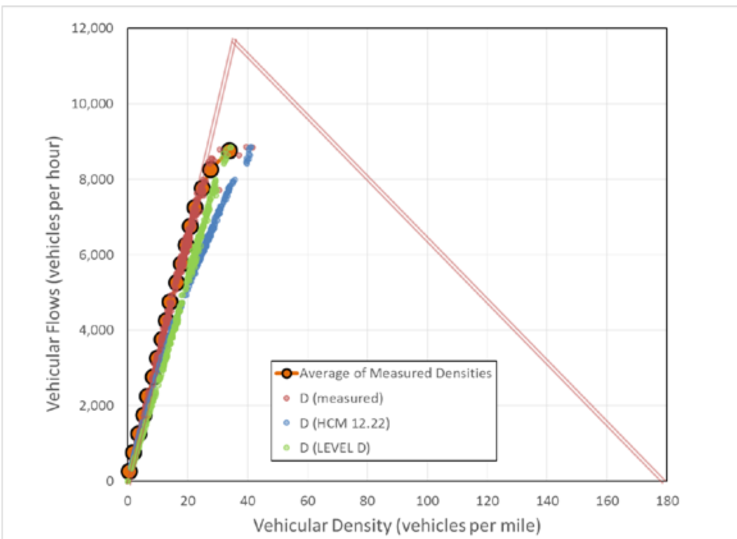
The HCM2010, Level D and Leisch methods are all deterministic methods designed to predict average density for a given geometry and volume set of conditions. With this in mind, average density trend lines were estimated and compared to the average of the measured densities. Figure 5.6 shows the average trend lines for the measured and predicted densities.

To summarize the findings from analyzing the San Diego ramp weaving sites, the HCM2010 weaving method and the other two methods analyzed tend to overestimate densities when the weaving sections are uncongested and operating at free flow speeds. Conversely, these methods can under estimate densities when the weaving sites are heavily congested. The Leisch method performed better than the HCM2010 and better than the Level D method under the highly congested traffic conditions measured at Site #3.

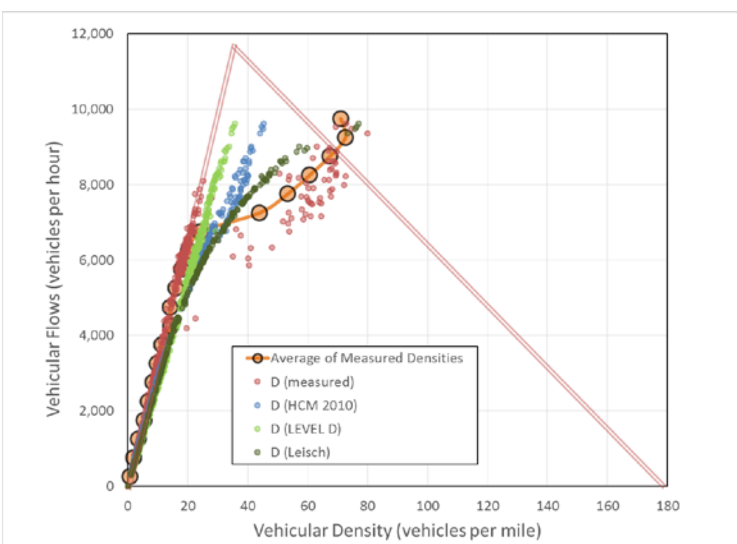
Further, the HCM2010 method may underestimate capacities when ramp weave sites serve relatively high weaving volumes.



Site #1: Interstate 5 SB in San Diego between Gilman Drive (on) & SR 52 (off)



Site #2: Interstate 5 NB in San Diego between I-8 (on) & Sea World Drive (off)



Site #3: Interstate 805 NB in San Diego between SR 52 (on) & Governor Drive (off)

Figure 5.5 Density-Flow Diagrams with Measured and Predicted Densities

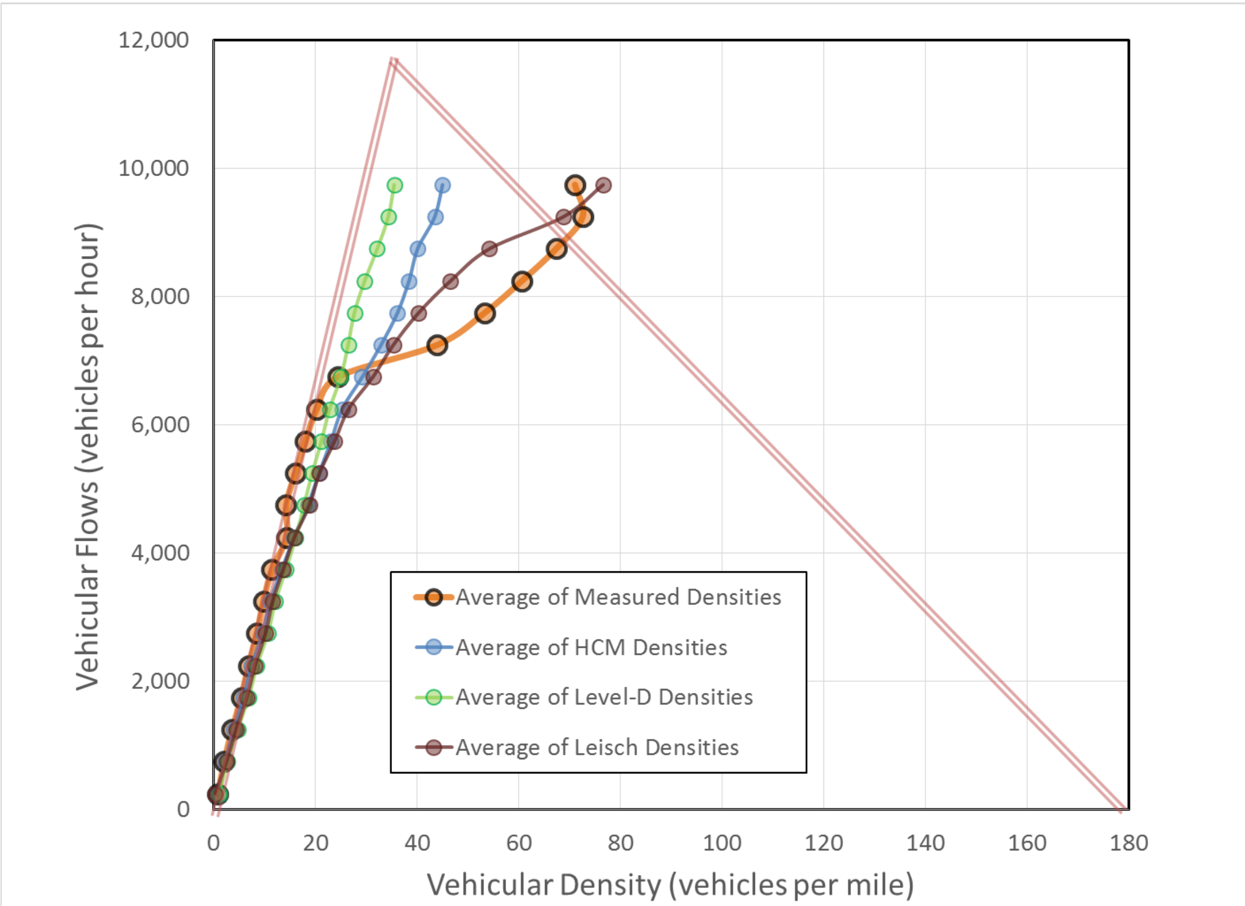


Figure 5.6 Site #3, Density-Flow-Diagram with Trend-lines for Measured and Predicted Densities

CHAPTER 6
WEAVING ANALYSIS PERFORMANCE MATRICES

Currently, the Caltrans Highway Design Manual includes two methodologies for determining the capacity and/or Level of Service of weaving sections: the Level D method and the Leisch method. Although the HCM2010 method is not officially recommended for use, it is often applied to check whether other analysis results are reasonable.

To determine how well each of the three methods predicts operations at weaving sections, for each study site the analysis results of the three methods were compared to the actual operating conditions that correspond to each data set. The results were then further analyzed to determine which of three existing methods predicts best the operating characteristics of a weaving section under certain geometric and operational conditions.

Working closely with the Caltrans Technical Advisory Group (TAG), the weaving analysis Performance Matrix was updated using the findings from the Chapter 3 and Chapter 5 real-world case studies. Its usability and usefulness in analysis of weaving sections was evaluated. Finally, the Performance Matrix was updated and refined based on the feedback from the Caltrans TAG.

6.1 Development of the Weaving Methods Performance Matrices

The weaving analysis performance matrix was created to serve as a guide for Caltrans design engineers when choosing the "best" weaving analysis method for the weaving section under study, based on comparisons with field data. A method that works well for a given geometric/operational mix will be given a "green light", a satisfactory method a "yellow light" and poor one a "red light".

Each cell represents a distinct design and operating condition. For a given number of lanes in the weaving section, the matrix has 48 cells; operational characteristics are reported by row while geometric characteristics are reported by column. There are a total of 192 possible cells for typical weaving sections of two, three, four and five lanes wide. Shaded cells indicate infeasible conditions. For example, it is not possible to have a two lane weaving section with more than one on- or off ramps. Therefore, the proposed matrix includes a total of 144 cells.

Table 6.1 shows the general format of the weaving analysis performance matrix. Through this and previous work efforts, a performance matrix was developed for each analysis method.

Table 6.1 Format of the Weaving Analysis Performance Matrix

No. of Lanes in Weaving Section, N =	2											
Configuration* --->	No Auxiliary Lane, 1-lane on & off ramps			With Aux. Lane 1-lane on/off ramps (Type A)			Balanced >1-lane on & off ramps (Type B)			Unbalanced >1-lane on & off ramps (Type C)		
Operational Conditions(vols) **	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	3											
Configuration* --->	No Auxiliary Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps (Type A)			Balanced >1-lane on & off ramps (Type B)			Unbalanced >1-lane on & off ramps (Type C)		
Operational Conditions(vols) **	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	4											
Configuration* --->	No Auxiliary Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps (Type A)			Balanced >1-lane on & off ramps (Type B)			Unbalanced >1-lane on & off ramps (Type C)		
Operational Conditions(vols) **	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	5											
Configuration* --->	No Auxiliary Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps (Type A)			Balanced >1-lane on & off ramps (Type B)			Unbalanced >1-lane on & off ramps (Type C)		
Operational Conditions(vols) **	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000-2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

The following sections describe the classification of design and operational conditions for developing the performance matrix.

6.2 Weaving Section Classification

6.2.1 Geometric Characteristics

The weaving sections geometric characteristics include the total number of lanes in the weaving section, the number of auxiliary lanes, and the length of weaving section. First, we consider the total number of lanes in the weaving section: two, three, four, or five lanes wide. Next, for a given number of lanes, we consider the presence and number of auxiliary lanes:

1. *No Auxiliary Lane, single lane on- & off-ramps*
2. *With Auxiliary Lane, single -lane on & off-ramps*: These are weaving sections consisting of two-lane on or off-ramps in which each weaving movement is required to make one lane change. These are also called ramp weaves.
3. *Balanced*, >1 lane on- & off-ramps (Type B): These are weaving sections consisting of two-lane on or off-ramps in which one weaving movement is not required to make a lane

change, and the other weaving movement is required to make one lane change. It also includes balanced sections, i.e., weaving sections with an optional lane at exit, i.e., "one more lane going away. Note balanced sections include weaving sections with a single lane on- or off-ramp (Figure 6.1).

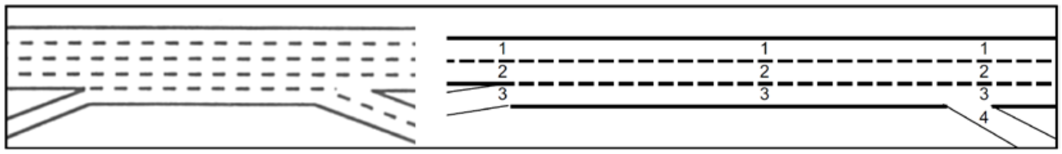


Figure 6.1 Typical Balanced Weaving Sections

4. *Unbalanced, >1-lane on-& off-ramps*: These are weaving sections consisting of two-lane on or off-ramps in which one weaving movement is required to make two lane changes, and the other weaving movement is not required to make a lane change. It also includes unbalanced sections, i.e., weaving sections without an optional lane at exit (Figure 6.2)

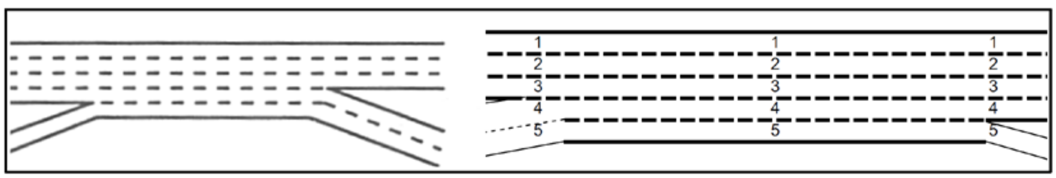


Figure 6.2 Typical Unbalanced Weaving Sections

Under each of these groups, a weaving section can further be classified according to its length as short, medium or generous, as follows:

1. Short Weave Length (<1,000 feet)
2. Medium Weave Length (1,000- 2,500 feet)
3. Generous Weave Length (>2,500 feet)

These thresholds were assumed to be reasonable in that weaving sections in each group would exhibit similar traffic behavior given certain traffic volumes.

6.2.2 Operational Conditions

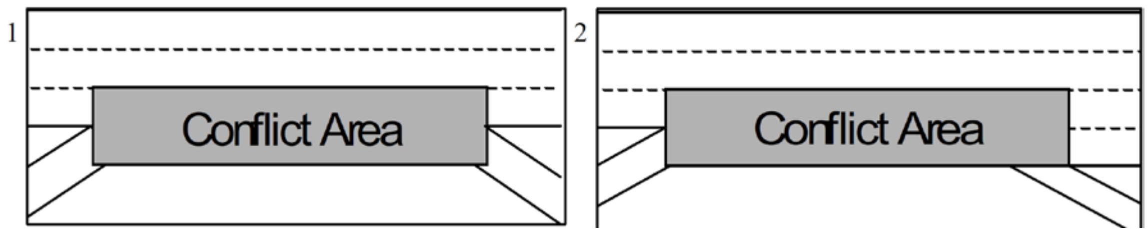
The operational conditions are grouped based on the total weaving and non-weaving traffic volumes in the weaving section as follows:

1. Non-Weaving Volumes: Heavy, Weaving Volumes: Heavy
2. Non-Weaving Volumes: Heavy, Weaving Volumes: Mid to Low
3. Non-Weaving Volumes: Mid to Low, Weaving Volumes: Heavy
4. Non-Weaving Volumes: Mid to Low, Weaving Volumes: Mid to Low

The non-weaving volume includes all traffic traveling through a weaving section (freeway-to freeway) and from the on-ramp to off-ramp. The weaving volume consists of the on-ramp to freeway volume and the volume from the freeway to the off-ramp. It was determined that volumes could be grouped in this way because it does not appear that performance estimates from the existing analysis methods would differ if, for instance, one weaving section had high on-ramp to freeway volumes and another had high freeway to off-ramp volumes. The analysis methods do not recognize the difference between these two groups of traffic, and two scenarios would yield the same analysis results.

The non-weaving and weaving volumes are classified as “heavy” or “mid to low” based on the number of lanes in the “conflict area” of the weaving section. The term conflict area is used to indicate the travel lanes where most of the turbulence occurs due to merging and diverging traffic. Most turbulence occurs in the lanes adjacent to the on- and off-ramps, and as a result the conflict area is defined as follows, based on “A Proposed Analytical Technique for the Design and Analysis of Major Freeway Weaving Sections” [16]:

1. (Conflict Area 1) The area of the weaving section extending from the right-most auxiliary lane to the lane directly to the left of the diverge gore, or
2. (Conflict Area 2) The area of the weaving section extending from the right-most auxiliary lane to the lane directly to the left of the merge gore.



Whichever of the above descriptions encompasses more lanes of the weaving area will govern as the conflict area. The lanes in the conflict area are those “reserved” for weaving volumes, and the remaining lanes of the weaving section are those “reserved” for non-weaving volumes. The table below indicates the criteria by which weaving and non-weaving volumes are classified as “heavy” or “mid to low”.

(A) Criteria for "Non-weaving" Traffic

Volume (vph)	N – [# lanes in conflict area]	“Heavy” Criteria	“Mid to Low” Criteria
Non-weaving	1 lane	Heavy = >1,800	Mid to Low < 1,800
	2 lanes	Heavy = >3,600	Mid to Low < 3,600
	3 lanes	Heavy = >5,400	Mid to Low < 5,400
	4 lanes	Heavy = >7,200	Mid to Low < 7,200

(B) Criteria for "Weaving" Traffic

Volume (vph)	# lanes in conflict area	“Heavy” Criteria	“Mid to Low” Criteria
All weaving	1 lane	Heavy = >1,000	Mid to Low < 1,000
	2 lanes	Heavy = >2,000	Mid to Low < 2,000
	3 lanes	Heavy = >3,000	Mid to Low < 3,000

(A) + (B) = N (number of lanes in weaving section)

For example, for the second “conflict area” figure, there are two lanes in the conflict area and (4-2) = two lanes designated for non-weaving traffic.

The thresholds for "heavy" and "mid to low" traffic for non-weaving volumes were determined by assuming that a freeway lane is operating at or near capacity if volumes are 1,800 vehicles per hour (vph) or greater. The thresholds for "heavy" and "mid to low" traffic for weaving volumes were determined by assuming that a freeway on- or off-ramp lane is operating at or near capacity if volumes are 1,000 vph or greater.

The resulting HCM2010, Level D and Leisch Method Weaving Analysis Matrices are presented next.

6.3 Resulting Weaving Analysis Performance Matrices

The final HCM2010 Weaving Analysis Performance Matrix is presented in Tables 6.2. The Level D Weaving Analysis Performance Matrix is in Table 6.3 and Leisch Method Weaving Analysis Performance Matrix is shown in Table 6.4.

The following legend and the hourly volume categories shown below apply to all three Weaving Analysis Performance Matrices (Table 6.2 HCM2010, Table 6.3 Level D and Table 6.4 Leisch Method).

LEGEND: Methodology's prediction of performance

= Poor, inconsistent results
= Fair; sometimes inconsistent results
= Good and consistent results

Notes for Table 6.2 HCM2010, Table 6.3 Level D and Table 6.4 Leisch Method:

* For the Weaving Analysis Performance Matrices presented in the following tables, the "Configuration" for all weaving sections considered are single side, right side configurations (i.e., does not include left side or two sided weave configurations).

** Hourly Volumes for "Non-weaving" Traffic

Volume (vph)	**N – [# lanes in conflict area]**	**"Heavy" Criteria**	**"Mid to Low" Criteria**
Non-weaving	1 lane	Heavy = >1,800	Mid to Low < 1,800
	2 lanes	Heavy = >3,600	Mid to Low < 3,600
	3 lanes	Heavy = >5,400	Mid to Low < 5,400
	4 lanes	Heavy = >7,200	Mid to Low < 7,200

** Hourly Volumes for "Weaving" Traffic

Volume (vph)	**# lanes in conflict area**	**"Heavy" Criteria**	**"Mid to Low" Criteria**
All weaving	1 lane	Heavy = >1,000	Mid to Low < 1,000
	2 lanes	Heavy = >2,000	Mid to Low < 2,000
	3 lanes	Heavy = >3,000	Mid to Low < 3,000

(A) + (B) = N (number of lanes in weaving section)

Table 6.2 Weaving Analysis Performance Matrix – HCM2010 Method

No. of Lanes in Weaving Section, N = 2

Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N = 3

Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Lengh (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

Table 6.2 Weaving Analysis Performance Matrix – HCM2010 Method (continued)

No. of Lanes in Weaving Section, N = **4**

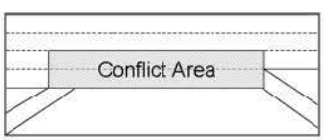
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy	Green	Green	Green	Red	Red	Red	Yellow	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Heavy Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Yellow	Green	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Mid to Low Weaving: Heavy	Green	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Mid to Low Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Yellow	Yellow

No. of Lanes in Weaving Section, N = **5**

Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy	Green	Green	Green	Red	Red	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Heavy Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Mid to Low Weaving: Heavy	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow
Non-Weaving: Mid to Low Weaving: Mid to Low	Green	Green	Green	Yellow	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow

LEGEND: Methodology's prediction of performance

- (Red) = Poor, inconsistent results
- (Yellow) = Fair; sometimes inconsistent results
- (Green) = Good and consistent results



Notes

* All weaving sections considered are single side, right side configurations (i.e. does not include left side or two sided configurations)

Non-weaving Vols in vph: **N [# lanes in conflict area] =

- 1 lane: Heavy = >1,300; Mid to Low < 1,800
- 2 lanes: Heavy = >3,600; Mid to Low < 3,600
- 3 lanes: Heavy = >5,400; Mid to Low < 5,400
- 4 lanes: Heavy = >7,200; Mid to Low < 7,200

Weaving Vols in vph: **[# lanes in conflict area] =

- 1 lane: Heavy = >1,000; Mid to Low < 1,000
- 2 lanes: Heavy = >2,000; Mid to Low < 2,000
- 3 lanes: Heavy = >3,000; Mid to Low < 3,000

Table 6.3 Weaving Analysis Performance Matrix – Level D Method

No. of Lanes in Weaving Section, N =	2											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	3											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

METHOD NOT DESIGNED FOR MULTIPLE ON / OFF RAMPS

Table 6.3 Weaving Analysis Performance Matrix – Level D Method (continued)

No. of Lanes in Weaving Section, N = 4

Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy	Green	Green	Green	Yellow	Yellow	Yellow	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Heavy Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Yellow	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Mid to Low Weaving: Heavy	Green	Green	Green	Yellow	Yellow	Yellow	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Mid to Low Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Yellow	Blue	Blue	Blue	Blue	Blue	Blue

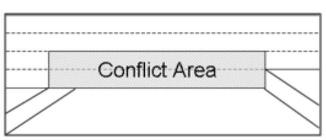
No. of Lanes in Weaving Section, N = 5

Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy	Green	Green	Green	Yellow	Red	Green	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Heavy Weaving: Mid to Low	Green	Green	Green	Yellow	Yellow	Green	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Mid to Low Weaving: Heavy	Green	Green	Green	Yellow	Yellow	Green	Blue	Blue	Blue	Blue	Blue	Blue
Non-Weaving: Mid to Low Weaving: Mid to Low	Green	Green	Green	Yellow	Green	Green	Blue	Blue	Blue	Blue	Blue	Blue

LEGEND: Methodology's prediction of performance

- Red = Poor, inconsistent results
- Yellow = Fair; sometimes inconsistent results
- Green = Good and consistent results

Blue: METHOD NOT DESIGNED FOR MULTIPLE ON / OFF RAMPS



Notes

* All weaving sections considered are single side, right side configurations (i.e. does not include left side or two sided configurations)

Non-weaving Vols in vph: **N – [# lanes in conflict area] =

1 lane:	Heavy = >1,800; Mid to Low < 1,800
2 lanes:	Heavy = >3,600; Mid to Low < 3,600
3 lanes:	Heavy = >5,400; Mid to Low < 5,400
4 lanes:	Heavy = >7,200; Mid to Low < 7,200

Weaving Vols in vph: **[# lanes in conflict area] =

1 lane:	Heavy = >1,000; Mid to Low < 1,000
2 lanes:	Heavy = >2,000; Mid to Low < 2,000
3 lanes:	Heavy = >3,000; Mid to Low < 3,000

Table 6.4 Weaving Analysis Performance Matrix – Leisch Method

No. of Lanes in Weaving Section, N =	2											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	3											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

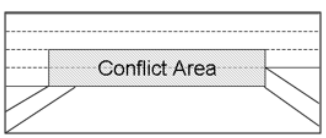
Table 6.4 Weaving Analysis Performance Matrix – Leisch Method (continued)

No. of Lanes in Weaving Section, N =	4											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

No. of Lanes in Weaving Section, N =	5											
Configuration* --->	No Aux. Lane, 1-lane on & off ramps			With Aux. Lane, 1-lane on/off ramps			Balanced >1-lane on & off ramps			Unbalanced >1-lane on & off ramps		
Operational Conditions (vols) **	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')	Short Weave Length (<1000')	Medium Weave Length (1000- 2500')	Generous Weave Length (>2500')
Non-Weaving: Heavy Weaving: Heavy												
Non-Weaving: Heavy Weaving: Mid to Low												
Non-Weaving: Mid to Low Weaving: Heavy												
Non-Weaving: Mid to Low Weaving: Mid to Low												

LEGEND: Methodology's prediction of performance

- = Poor, inconsistent results
- = Fair; sometimes inconsistent results
- = Good and consistent results



Notes

* All weaving sections considered are single side, right side configurations (i.e. does not include left side or two sided configurations)

Non-weaving Vols in vph: **N – [# lanes in conflict area] =

1 lane:	Heavy = >1,800; Mid to Low < 1,800
2 lanes:	Heavy = >3,600; Mid to Low < 3,600
3 lanes:	Heavy = >5,400; Mid to Low < 5,400
4 lanes:	Heavy = >7,200; Mid to Low < 7,200

Weaving Vols in vph: **[# lanes in conflict area] =

1 lane:	Heavy = >1,000; Mid to Low < 1,000
2 lanes:	Heavy = >2,000; Mid to Low < 2,000
3 lanes:	Heavy = >3,000; Mid to Low < 3,000

CHAPTER 7
CONCLUSIONS

This final report describes the work performed and the findings from the evaluation of the HCM2010 analysis methodology on 16 real-world freeway weaving sections in California covering a range of design and traffic characteristics.

From lessons learned from these analysis, new data were collected at three additional ramp weave sections in San Diego California. The San Diego candidate weaving locations were identified and selected in collaboration with Caltrans TAG.

7.1 Summary of the Study Findings

The finding of the study indicate that the HCM2010 method provides reliable estimates for balanced major weaving sections. However, it can significantly over-predict the traffic densities and associated HCM Level of Service (LOS) for ramp and unbalanced weaving sections. On average, the difference between observed and predicted densities was 8% for balanced weaving sections and 24% for ramp and unbalanced weaving sections (findings from US weave databases, Chapter 3).

For the three San Diego sites presented in Chapter 5, HCM2010 aggregately tended to over predict densities by about 13.4% (average percentage difference), while the Level D method aggregately over predicted by about 3.4% and the Leisch method's aggregate percentage error was only about 2%. Looking at the average of the RSME as a goodness of fit, HCM2010 average error term was 5.76, Level D's average error term was 6.23 and the Leisch method's was 8.68. However, these aggregate statistics hide important details.

- The **HCM2010** method tends to slightly over predict densities for low traffic volume (i.e., low density) traffic conditions. The HCM2010 density over prediction tends to increase as volumes increase – up to the point where traffic volumes become sufficient to induce congestion within the weave section. Under moderate congestion, HCM2010 appears to produce density predictions in the range of measured densities. Under heavily congested conditions, the HCM2010 method can significantly under predict traffic densities. These conclusions also largely hold for the Level D method.

- The **Level D** method, much like the HCM2010 method, tends to fairly reliably predict densities with a slight over predict densities for low traffic conditions (low volumes with freely flowing traffic). And like the HCM2010 method, the Level D density over prediction increases as traffic volumes increase – for freely flowing traffic. In light and moderately congested traffic conditions, Level D's density predictions were in the range of those measured. Under heavy congestion, Level D under predicted traffic densities.

- The **Leisch** method, for San Diego Site #3, performed relatively well with a slight over prediction of densities when traffic volumes were low enough for traffic to remain freely flowing, very similar to how HCM2010 and Level D performed in light traffic. The Leisch method was more responsive than HCM2010 and Level D and performed relatively well under moderate and heavily congested traffic conditions.

These trends can be seen in Figures 5.1 HCM2010, 5.2 Level D and 5.3 Leisch density plots, and the trends are repeated in Figure 5.6 which displays the data on a density-flow diagram.

As for capacity, the HCM2010 methodology can under predict the capacity of ramp weaving sections. The method predicted lower maximum discharge flows than were observed at three of the study's sites (Chapter 3), and at one of the three San Diego sites (Chapter 5).

7.2 Future Research

Most of the existing methods for analyzing the performance of freeway weaving sections are based on limited data that are not representative of the entire range of the geometric characteristics and traffic patterns in weaving areas, especially for California conditions. The systematic evaluation of existing weaving methods and the development of an improved analysis method have been recognized as high priority research needs.

Further, bottleneck activation and capacity at weaving sections are still not fully understood. As such, current even best practice methods for predicting the performance of freeway weaving sections have limited success in matching real world (measured) performance. This research found four weaving sites where the measured traffic volumes were higher than the HCM2010 predicted capacity (three described in Chapter 3, one in Chapter 5).

The three San Diego weaving sites (Chapter 5) have appreciably similar geometries. All are 5 lane ramp weaves with HCM2010 weave length (L_S) between 1,500 feet and 1,700 feet, no horizontal or vertical curve elements. Sites #1 and #2 had almost all 15-minute observations with freely flowing traffic up to about 8,000 vph. At site #3, congestion tended to occur at volumes in the 6,500 vph range. The HCM2010 and Level-D methods were not sufficiently responsiveness to these operational differences. Findings like this and the differences between model estimated and real-world densities shown if Chapters 3 and 5 highlight that there is still room for improvements to these methodologies.

The wide variations in the physical characteristics (number of lanes, weave length, geometric details) of weave segments combined with widely varying traffic volumes and origin-destination (O-D) patterns compound the complexity of quantifying the capacity and performance of weave segments. Simple datasets measuring aggregate (across all lanes) traffic volumes and average 15-minute average travel times might not suffice for gaining necessary insights to develop more reliably weaving models and better methods of predicting the performance of freeway weaving segments. Additional empirical research, possibly combined with micro-simulation modeling, leading to a better understanding of how weaving volumes impact freeway performance and capacity is warranted.

REFERENCES

1. Roess, R. et al, "Analysis of Freeway Weaving Sections," Final Report, NCHRP Project 3-75, Transportation Research Board, January 2008.
2. *Highway Capacity Manual,* Transportation Research Board, Washington DC, 2010
3. Skabardonis, A. and A. Kim, "Weaving Analysis Evaluation and Refinement," PATH Research Report UCB-ITS-PRR-2010-19, April 2010.
4. Highway Capacity Manual," *Special Report 87*, Transportation Research Board, Washington DC, 1965.
5. Normann, O.K., "Operation of Weaving Areas," *Highway Research Bulletin 167*, Transportation Research Board, Washington DC, 1957.
6. Moskowitz, K., and Newman, L., *Notes on Freeway Capacity*, Traffic Bulletin 4, California Department of Highways, Sacramento CA, July 1962.
7. Cassidy M, and A.D., May, "Proposed Analytic Technique for Estimating Capacity and Level of Service of Major Freeway Weaving Sections," Transportation Research Record #1320, Journal of the Transportation Research Board, Washington DC, 1991.
8. Leisch, J., "Completion of Procedures for Analysis of and Design of Traffic Weaving Areas," Final Report, U.S. Department of Transportation, Federal Highway Administration, Washington DC, 1983.
9. *Highway Capacity Manual,* 4th Edition, Transportation Research Board, Washington DC, 2000.
10. Pignataro, L, et al, "Weaving Areas – Design and Analysis," National Cooperative Highway Research Report 159, Transportation Research Board, Washington DC, 1975.
11. Reilly, W., et al, "Weaving Analysis Procedures for the New Highway Capacity Manual," Final Report, Contract DTFH-61-83-C-00029, Federal Highway Administration, Washington DC, 1984.
12. *Highway Capacity Manual*, Special Report 209, Transportation Research Board, Washington DC, 1985.
13. Skabardonis A., M. Cassidy and A.D. May, "Operation of Major Freeway Sections: Findings from the Application of Existing Analytical Techniques and Simulation Modeling," Working Paper UCB-ITS-WP-88-12, Institute of Institute of Transportation Studies, University of California, Berkeley, November 1988.
14. Fong, H.K., and F.D. Rooney, "Weaving Areas Near One Lane Ramps," Division of Traffic Operations, California Department of Transportation, Sacramento, 1990.
15. Skabardonis A., and V. Alexiadis, "Traffic Data through the Berkeley Highway Laboratory," Proceedings, Traffic Modeling Workshop, Federal Highway Administration, Sedona, AZ, Sept. 2005.
16. Cassidy, M., et al, "A Proposed Technique for the Design and Analysis of Major Freeway Weaving Sections", Research Report UCB-ITS-RR-90-16, Institute of Transportation Studies, University of California Berkeley, Berkeley CA, 1990.

APPENDIX A.
THE (CHAPTER 3) STUDY DATABASE

Figure A.1 Major Weaving Sites — California

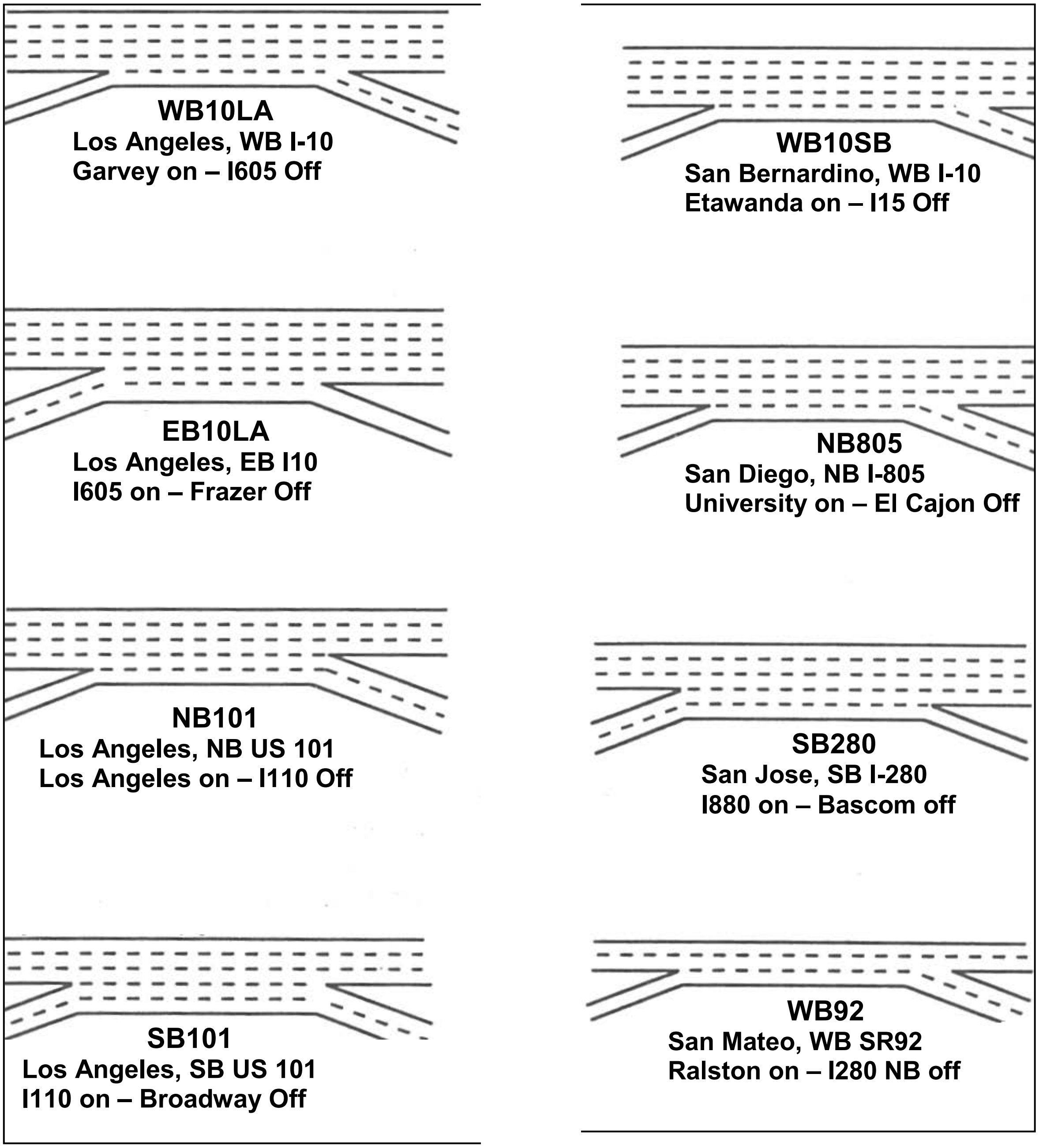


Table A.1 Major Weaving Sites—California: Field Data vs. HCM2010 Predictions

											FIELD DATA			HCM2010		
TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	V_{FF} (vph)	V_{RF} (vph)	V_{FR} (vph)	V_{RR} (vph)	Σ V (vph)	S (mph)	D (veh/m/l)	LOS	S (mph)	D (veh/m/l)	LOS
SR 92WB	3	1400	1078	3	65	1822	1236	136	27	3221	51.73	20.75	C	51.50	20.80	C
San Mateo						1601	941	190	28	2760	53.55	17.18	B	53.80	17.10	B
						1894	543	519	79	3035	59.67	16.95	B	56.00	18.10	B
						2641	697	622	73	4033	57.44	23.40	C	53.70	25.00	C
I-805NB	5	1371	1056	3	65	5589	890	691	27	7197	60.69	23.72	C	51.50	27.90	C
San Diego						5058	877	668	60	6663	60.66	21.97	C	52.10	25.60	C
						5127	993	700	83	6903	61.04	22.62	C	51.10	27.00	C
						5266	767	853	23	6909	56.75	24.35	C	52.60	26.30	C
I-10WB	5	1690	1301	3	65	5200	168	2242	141	7751	58.00	26.73	C	55.80	27.80	C
Los Angeles						4001	154	1714	117	5986	62.90	19.03	B	57.40	20.90	C
						3942	127	1759	113	5941	62.03	19.15	B	57.60	20.60	C
						3795	191	1755	91	5832	62.17	18.76	B	57.30	20.40	C
						4178	240	1907	102	6427	60.42	21.27	C	56.50	22.80	C
I-10WB	5	1989	1532	3	65	2898	362	623	137	4020	59.01	13.62	B	57.90	13.90	B
San Bernardino						2750	321	641	110	3822	60.16	12.71	B	58.30	13.10	B
						3257	462	695	198	4612	65.61	14.06	B	56.80	16.20	B
US 101NB	5	787	606	2	65	5346	195	3924	219	9684	48.70	39.77	E	v>c >1		
Los Angeles						5442	173	3344	243	9202	48.72	37.77	E	v>c >1		
I-280SB	5	1347	1037	2	65	3907	1505	198	55	5665	67.80	16.71	B	56.00	20.20	C
San Jose						3436	1407	217	70	5130	67.13	15.28	B	56.30	18.20	B
						3189	1135	308	88	4720	62.74	15.05	B	55.40	17.00	B
						3351	1208	346	92	4997	65.86	15.17	B	54.70	18.30	B
						5097	1464	430	101	7092	64.23	22.08	C	51.80	27.40	C
						5178	1599	477	137	7391	61.36	24.09	C	51.00	29.00	D
I-10EB	6	1437	1106	2	65	2766	184	1545	127	4622	52.70	14.62	B	41.50	18.60	B
Los Angeles						2538	141	1624	86	4389	51.73	14.14	B	40.90	17.90	B
						3679	193	1787	141	5800	57.25	16.88	B	37.50	25.80	C
						4129	222	1928	132	6411	56.93	18.77	B	35.30	30.30	D
						6056	409	3372	265	10102	45.65	36.88	E	v>c >1		
US 101SB	5	792	610	2	65	3685	1407	326	491	5909	53.4	22.1	C	46.4	25.4	C
Los Angeles						3351	1284	461	438	5534	54.7	20.2	C	46.3	23.7	C
						4223	1613	282	345	6463	60.3	21.4	C	44.8	28.7	D

Table A.2 Ramp Weaving Sites—California: Field Data vs. HCM2010 Predictions

TEST SITE	N	L (ft)	L_s (ft)	N_{WL}	FFS (mph)	V_{FF} (vph)	V_{RF} (vph)	V_{FR} (vph)	V_{RR} (vph)	Σ V (vph)	FIELD DATA S (mph)	FIELD DATA D (veh/m/l)	LOS	HCM2010 S (mph)	HCM2010 D (veh/m/l)	HCM2010 LOS
I-580EB Oakland	5	1250	963	2	55	3972	1440	588	96	6096	45.0	27.1	C	36.5	33.4	D
						4320	1404	420	120	6264	46.0	27.2	C	37.3	33.6	D
						4536	1476	732	60	6804	42.0	32.4	D	34.8	39.1	E
						4488	1464	636	120	6708	44.0	30.5	D	35.4	37.9	E
						4236	1284	480	108	6108	47.0	26.0	C	37.4	32.7	D
						5208	1584	720	96	7608	42.0	36.2	E	33.3	45.7	E
						5340	1788	636	72	7836	41.0	38.2	E	v>c >1		
						6012	1572	648	96	8328	42.0	39.7	E	32.9	50.6	E
						6828	1752	720	144	9444	41.0	46.1	E	v>c >1		
						6372	1656	660	96	8784	42.0	41.8	E	31.9	55.1	E
						5940	1560	612	96	8208	43.0	38.2	E	33.3	49.3	E
						5508	1776	660	108	8052	41.0	39.3	E	v>c >1		
						5676	1728	660	48	8112	41.0	39.6	E	32.3	50.2	E
						6168	1596	636	132	8532	42.0	40.6	E	32.6	52.3	E
						5268	1920	792	120	8100	39.0	41.5	E	v>c >1		
						5832	1716	720	96	8364	41.0	40.8	E	v>c >1		
						5676	1728	828	108	8340	40.0	41.7	E	v>c >1		
						5688	1932	744	48	8412	39.0	43.1	E	v>c >1		
						6252	1608	768	108	8736	41.0	42.6	E	31.6	55.3	E
						6876	2208	744	156	9984	37.0	54.0	E	v>c >1		
						5796	1836	804	156	8592	39.0	44.1	E	v>c >1		
						6408	1992	936	192	9528	37.0	51.5	E	v>c >1		
						6540	1788	804	120	9252	40.0	46.3	E	v>c >1		
						5724	1992	852	132	8700	38.0	45.8	E	v>c >1		
						2520	756	552	144	3972	55.0	14.4	B	45.4	17.5	B
						2424	888	576	84	3972	55.0	14.4	B	45.0	17.7	B
						2292	960	492	168	3912	57.0	13.7	B	45.6	17.2	B
I-5SB San Diego	5	1255	966	2	55	3156	684	444	0	4284	55.0	15.6	B	43.2	19.9	B
						3432	552	372	36	4392	54.0	16.3	B	44.2	19.8	B
						3516	612	492	0	4620	55.0	16.8	B	42.9	21.5	C
						4620	588	636	24	5868	55.0	21.3	C	41.1	28.6	D
						4836	684	612	0	6132	53.0	23.1	C	40.4	30.4	D
						4980	564	672	24	6240	53.0	23.5	C	40.6	30.7	D
						4944	552	492	0	5988	53.0	22.6	C	42.0	28.5	D
						4752	588	528	12	5880	54.0	21.8	C	41.6	28.2	D
						4920	564	624	0	6108	54.0	22.6	C	41.0	29.8	D
SR 91WB Los Angeles	5	1895	1459	2	55	4728	564	156	0	5448	59.0	18.5	B	44.7	24.4	C
						4500	456	168	0	5124	60.0	17.1	B	45.7	22.4	C
						4968	492	120	12	5592	58.0	19.3	B	45.3	24.7	C

Table A.2 Ramp Weaving Sites—California: Field Data vs. HCM2010 Predictions (cont)

SR 60EB	5	1100	847	2	55	8484	288	444	24	9240	60.0	30.8	D	40.9	45.2	E
Los Angeles						7956	384	444	0	8784	58.0	30.3	D	40.7	43.2	E
						7812	300	444	12	8568	59.0	29.0	D	41.4	41.3	E
						4968	120	312	0	5400	60.0	18.0	B	46.6	23.2	C
						4860	288	240	0	5388	63.0	17.1	B	45.9	23.5	C
						4464	204	360	24	5052	60.0	16.8	B	46.0	22.0	C
						4920	72	348	0	5340	60.0	17.8	B	46.7	22.9	C
						5268	144	348	0	5760	61.0	18.9	B	45.8	25.1	C
						5568	180	420	0	6168	61.0	20.2	C	44.7	27.6	C
						5724	108	408	0	6240	60.0	20.8	C	45.2	27.6	C
						4968	252	300	0	5520	61.0	18.1	B	45.6	24.2	C
						5448	180	240	12	5880	61.0	19.3	B	46.2	25.4	C
						6252	192	276	0	6720	59.0	22.8	C	45.1	29.8	D
						6504	240	324	0	7068	59.0	24.0	C	44.1	32.1	D
						6156	204	336	12	6708	59.0	22.7	C	44.6	30.1	D
I-10WB	5	1010	778	2	55	3684	336	408	0	4428	55.0	16.1	B	45.3	19.6	B
Los Angeles						3840	336	348	0	4524	56.0	16.2	B	45.6	19.8	B
						4032	468	300	0	4800	55.0	17.5	B	44.8	21.4	C
						3588	456	348	12	4404	55.0	16.0	B	44.9	19.6	B
						4500	312	432	0	5244	54.0	19.4	B	44.5	23.6	C
						3672	396	456	0	4524	56.0	16.2	B	44.5	20.3	C
						3972	264	372	0	4608	55.0	16.8	B	45.8	20.1	C
						4056	456	480	0	4992	54.0	18.5	B	43.5	23.0	C
						4200	240	300	12	4752	55.0	17.3	B	46.4	20.5	C
						3984	300	288	12	4584	56.0	16.4	B	46.2	19.8	B
						4200	300	456	24	4980	55.0	18.1	B	44.7	22.3	C
						4464	396	384	0	5244	55.0	19.1	B	44.2	23.7	C
I-110SB	5	610	470	2	55	7128	312	264	12	7716	52.0	29.7	D	44.0	35.1	E
Los Angeles						6936	288	228	36	7488	50.0	30.0	D	44.5	33.7	D
						6768	480	192	0	7440	53.0	28.1	D	43.8	34.0	D
SR 91EB	5	845	651	2	65	5784	780	48	0	6612	58.9	22.5	C	53.1	24.9	C
Los Angeles						5232	804	48	0	6084	58.4	20.8	C	54.1	22.5	C
						5748	600	24	24	6396	58.6	21.8	C	57.6	22.2	C
I-10EB	5	950	732	2	55	4812	324	96	12	5244	57.0	18.4	B	47.6	22.0	C
Los Angeles						4848	240	72	12	5172	55.0	18.8	B	48.3	21.4	C
						5148	360	120	36	5664	55.0	20.6	C	46.9	24.2	C
						4644	216	108	12	4980	59.0	16.9	B	48.4	20.6	C
						5832	312	108	12	6264	53.0	23.6	C	46.6	26.9	C
						5604	384	120	48	6156	54.0	22.8	C	46.2	26.6	C
						5112	264	108	24	5508	55.0	20.0	B	47.6	23.1	C
						5520	372	96	12	6000	55.0	21.8	C	46.6	25.8	C
						4644	576	84	36	5340	54.0	19.8	B	46.3	23.1	C
						4740	492	48	60	5340	55.0	19.4	B	46.9	22.8	C
						4668	324	72	48	5112	56.0	18.3	B	47.9	21.3	C
						4812	444	156	24	5436	54.0	20.1	C	46.5	23.4	C

APPENDIX B.
THE (CHAPTER 5, SAN DIEGO) STUDY DATABASE

(15-MINUTE PERIODS WITH HOURLY FLOW RATES >= 7,000 VPH)

Site #1: Interstate 5 SB in San Diego
between Gilman Drive (on) & SR 52 (off)

HCM 2010 Parameter		
Length of Weave Segment	L_s (feet)	1,567
Interchange Density	ID (IC/mile)	1.00
Number of Lanes in Weave	N (lanes)	5
Number of Weaving Lanes	N_{WL} (lanes)	2
Freeflow Speed	FFS (mph)	70
Capacity (Ideal Basic Fwy Seg)	C_{IFL} (pc/h/ln)	2,400
Minimum Lane Chages (Rmp to Fwy)	LC_{RF} (lanes)	1.00
Minimum Lane Chages (Fwy to Rmp)	LC_{FR} (lanes)	1.00
Peak Hour Factor	PHF	1.00
Factor for Heavy Vehicles	f_{HV}	1.00
Factor Driver Population	f_P	1.00

San Diego Site #1

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
16-Dec-13	2:45 PM	5,051	355	1,436	258	7,099	76	74	19.17	B	51	27.75	C	0.75
16-Dec-13	3:00 PM	5,167	566	1,429	397	7,560	76	66	22.81	C	50	30.50	D	0.83
16-Dec-13	3:15 PM	5,956	610	1,529	397	8,493	73	49	34.58	D	48	35.51	E	0.89
16-Dec-13	3:30 PM	5,690	713	1,458	463	8,324	72	40	41.95	E	48	34.80	D	0.90
16-Dec-13	3:45 PM	6,021	646	1,482	403	8,553	70	43	39.84	E	48	35.76	E	0.89
16-Dec-13	4:00 PM	6,436	765	1,376	478	9,054	69	47	38.78	E	47	38.33	E	0.89
16-Dec-13	4:15 PM	6,729	915	1,373	545	9,563	65	40	48.29	F	46	41.67	E	0.95
16-Dec-13	4:30 PM	6,068	896	1,363	587	8,914	68	53	33.35	D	47	38.14	E	0.94
16-Dec-13	4:45 PM	6,426	866	1,314	517	9,123	69	50	36.81	E	47	38.86	E	0.91
16-Dec-13	5:00 PM	6,370	649	1,216	466	8,701	66	52	33.73	D	49	35.41	E	0.81
16-Dec-13	5:15 PM	6,217	759	1,182	543	8,701	64	50	34.93	D	49	35.72	E	0.81
16-Dec-13	5:30 PM	6,060	672	1,167	488	8,387	58	55	30.76	D	50	33.81	D	0.78
16-Dec-13	5:45 PM	6,221	511	1,191	368	8,291	63	57	29.12	D	50	32.84	D	0.76
16-Dec-13	6:00 PM	5,269	516	1,103	297	7,186	70	63	22.83	C	52	27.61	C	0.67
17-Dec-13	2:45 PM	5,302	345	1,292	215	7,155	78	67	21.22	C	52	27.53	C	0.68
17-Dec-13	3:00 PM	5,530	419	1,479	284	7,712	78	60	25.56	C	50	30.88	D	0.79
17-Dec-13	3:15 PM	6,528	500	1,596	310	8,934	77	54	33.00	D	48	37.52	E	0.87
17-Dec-13	3:30 PM	6,505	630	1,516	372	9,023	75	49	36.85	E	47	38.20	E	0.89
17-Dec-13	3:45 PM	6,458	554	1,543	336	8,890	71	43	41.03	E	48	37.31	E	0.87
17-Dec-13	4:00 PM	6,357	670	1,404	432	8,863	72	56	31.84	D	48	37.07	E	0.86
17-Dec-13	4:15 PM	6,681	841	1,368	503	9,394	71	49	38.35	E	47	40.39	E	0.92
17-Dec-13	4:30 PM	6,390	862	1,310	516	9,077	70	46	39.30	E	47	38.58	E	0.90
17-Dec-13	4:45 PM	6,531	861	1,319	507	9,218	62	42	43.61	F	47	39.34	E	0.91
17-Dec-13	5:00 PM	6,169	812	1,156	573	8,711	56	42	41.92	E	49	35.88	E	0.82
17-Dec-13	5:15 PM	6,205	772	1,221	572	8,769	50	38	45.90	F	48	36.27	E	0.83
17-Dec-13	5:30 PM	5,594	699	1,112	523	7,929	32	26	60.95	F	50	31.58	D	0.75
17-Dec-13	5:45 PM	5,363	618	1,117	484	7,582	33	26	57.76	F	51	29.74	D	0.72
17-Dec-13	6:00 PM	5,621	626	1,226	375	7,848	31	29	54.25	F	50	31.35	D	0.77
17-Dec-13	6:15 PM	5,675	474	1,189	273	7,610	31	33	45.97	F	51	29.62	D	0.71
18-Dec-13	2:45 PM	5,285	440	1,300	277	7,302	75	65	22.30	C	51	28.50	D	0.73
18-Dec-13	3:00 PM	5,900	461	1,529	303	8,193	75	64	25.65	C	49	33.47	D	0.83
18-Dec-13	3:15 PM	6,303	523	1,633	343	8,802	74	49	36.23	E	47	37.13	E	0.90
18-Dec-13	3:30 PM	6,113	595	1,507	372	8,586	71	48	36.01	E	48	35.82	E	0.88
18-Dec-13	3:45 PM	6,422	649	1,568	402	9,042	70	49	36.80	E	47	38.61	E	0.92
18-Dec-13	4:00 PM	6,639	707	1,395	434	9,174	70	50	36.51	E	47	38.76	E	0.88
18-Dec-13	4:15 PM	6,505	845	1,352	513	9,215	66	48	38.03	E	47	39.41	E	0.92
18-Dec-13	4:30 PM	6,457	772	1,413	493	9,135	64	55	33.44	D	47	38.94	E	0.91
18-Dec-13	4:45 PM	6,041	806	1,351	526	8,724	52	36	48.68	F	47	36.74	E	0.90
18-Dec-13	5:00 PM	6,065	826	1,119	574	8,584	43	30	56.71	F	49	35.17	E	0.81
18-Dec-13	5:15 PM	6,009	742	1,143	531	8,426	36	29	58.61	F	49	34.18	D	0.79
18-Dec-13	5:30 PM	5,715	742	1,119	547	8,123	34	26	62.17	F	50	32.66	D	0.78
18-Dec-13	5:45 PM	5,787	659	1,099	471	8,016	34	27	60.39	F	50	31.79	D	0.74
18-Dec-13	6:00 PM	5,871	609	1,191	340	8,010	35	29	55.21	F	50	31.91	D	0.75
18-Dec-13	6:15 PM	6,025	484	1,119	247	7,876	35	31	50.72	F	51	30.60	D	0.73

San Diego Site #1

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
18-Dec-13	6:30 PM	6,283	450	1,238	244	8,216	39	46	35.72	E	51	32.44	D	0.76
19-Dec-13	2:45 PM	5,199	386	1,335	254	7,174	73	65	22.15	C	51	27.88	C	0.72
19-Dec-13	3:00 PM	5,661	495	1,546	343	8,045	73	63	25.48	C	49	32.96	D	0.85
19-Dec-13	3:15 PM	6,178	474	1,538	299	8,488	70	48	35.14	E	49	34.97	D	0.84
19-Dec-13	3:30 PM	6,224	529	1,505	324	8,582	65	47	36.19	E	48	35.53	E	0.85
19-Dec-13	3:45 PM	6,250	543	1,493	329	8,616	58	52	32.96	D	48	35.70	E	0.85
19-Dec-13	4:00 PM	6,667	718	1,485	467	9,337	67	45	41.49	E	47	40.07	E	0.92
19-Dec-13	4:15 PM	6,219	829	1,186	462	8,695	57	36	48.16	F	48	36.00	E	0.84
19-Dec-13	4:30 PM	6,272	816	1,238	470	8,796	45	31	56.95	F	48	36.66	E	0.86
19-Dec-13	4:45 PM	6,013	825	1,258	504	8,600	36	25	68.87	F	48	35.82	E	0.87
19-Dec-13	5:00 PM	5,678	770	1,109	566	8,122	29	25	64.29	F	50	32.72	D	0.78
19-Dec-13	5:15 PM	5,709	854	1,007	567	8,138	30	23	69.84	F	50	32.73	D	0.78
19-Dec-13	5:30 PM	5,687	738	1,036	506	7,968	31	24	67.06	F	50	31.63	D	0.74
19-Dec-13	5:45 PM	5,558	594	1,024	412	7,589	28	23	65.62	F	52	29.38	D	0.70
19-Dec-13	6:00 PM	5,643	644	962	302	7,551	29	25	61.38	F	52	29.17	D	0.70
19-Dec-13	6:15 PM	5,395	539	1,035	285	7,254	32	28	52.63	F	52	27.77	C	0.67
20-Dec-13	2:15 PM	5,075	439	1,228	272	7,014	78	65	21.54	C	52	27.01	C	0.69
20-Dec-13	2:30 PM	5,771	514	1,333	303	7,921	77	66	24.05	C	50	31.67	D	0.77
20-Dec-13	2:45 PM	5,945	428	1,584	292	8,248	77	66	24.88	C	49	33.82	D	0.84
20-Dec-13	3:00 PM	6,292	487	1,616	317	8,712	75	56	31.26	D	48	36.45	E	0.88
20-Dec-13	3:15 PM	6,102	540	1,506	338	8,486	73	47	35.83	E	48	35.11	E	0.85
20-Dec-13	3:30 PM	6,154	588	1,465	355	8,562	72	54	31.89	D	48	35.50	E	0.86
20-Dec-13	3:45 PM	6,302	672	1,475	399	8,848	74	55	32.12	D	47	37.32	E	0.89
20-Dec-13	4:00 PM	6,579	685	1,453	442	9,160	68	54	33.73	D	47	38.86	E	0.89
20-Dec-13	4:15 PM	6,565	788	1,374	482	9,210	61	50	36.52	E	47	39.22	E	0.90
20-Dec-13	4:30 PM	6,343	697	1,353	434	8,828	60	54	32.44	D	48	36.80	E	0.85
20-Dec-13	4:45 PM	6,161	691	1,292	423	8,568	49	49	35.18	E	49	35.25	E	0.83
20-Dec-13	5:00 PM	6,237	613	1,107	410	8,367	49	51	32.87	D	50	33.26	D	0.77
20-Dec-13	5:15 PM	6,011	627	1,230	483	8,351	37	37	45.44	F	50	33.71	D	0.77
20-Dec-13	5:30 PM	5,771	568	1,129	418	7,887	33	39	40.03	E	51	30.98	D	0.73
20-Dec-13	5:45 PM	5,835	492	1,007	320	7,654	36	31	48.92	F	52	29.27	D	0.70
20-Dec-13	6:00 PM	5,612	471	1,095	253	7,431	50	51	29.06	D	52	28.52	D	0.69

Site #2: Interstate 5 NB in San Diego
between I-8 (on) & Sea World Drive (off)

HCM 2010 Parameter		
Length of Weave Segment	L_s (feet)	1,545
Interchange Density	ID (IC/mile)	1.33
Number of Lanes in Weave	N (lanes)	5
Number of Weaving Lanes	N_{WL} (lanes)	2
Freeflow Speed	FFS (mph)	65
Capacity (Ideal Basic Fwy Seg)	C_{IFL} (pc/h/ln)	2,350
Minimum Lane Chages (Rmp to Fwy)	LC_{RF} (lanes)	1.00
Minimum Lane Chages (Fwy to Rmp)	LC_{FR} (lanes)	1.00
Peak Hour Factor	PHF	1.00
Factor for Heavy Vehicles	f_{HV}	1.00
Factor Driver Population	f_P	1.00

San Diego Site #2

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
21-Jan-14	6:30 AM	5,819	1,682	153	61	7,715	63	62	25.08	C	46	33.88	D	0.76
21-Jan-14	6:45 AM	6,183	2,016	179	81	8,459	58	63	26.93	C	43	39.51	E	0.91
21-Jan-14	7:00 AM	6,846	1,778	169	62	8,856	56	45	39.63	E	43	41.12	E	0.84
21-Jan-14	7:15 AM	6,221	1,496	151	51	7,920	39	24	64.87	F	46	34.14	D	0.75
21-Jan-14	7:30 AM	5,882	1,444	161	56	7,543	32	22	67.36	F	47	32.10	D	0.71
21-Jan-14	7:45 AM	6,250	1,454	224	73	8,002	32	27	60.01	F	45	35.25	E	0.76
21-Jan-14	9:00 AM	5,511	1,441	393	142	7,486	33	28	54.00	F	46	32.70	D	0.76
21-Jan-14	2:45 PM	5,317	1,134	489	99	7,039	66	65	21.59	C	47	29.70	D	0.68
21-Jan-14	3:00 PM	5,255	1,236	408	146	7,044	66	63	22.29	C	47	29.80	D	0.68
21-Jan-14	3:15 PM	5,316	1,167	423	141	7,047	65	65	21.80	C	48	29.62	D	0.67
21-Jan-14	3:30 PM	5,541	1,176	429	139	7,285	65	65	22.31	C	47	30.83	D	0.69
21-Jan-14	3:45 PM	5,234	1,200	498	174	7,106	65	66	21.63	C	47	30.29	D	0.71
21-Jan-14	4:15 PM	5,996	1,337	490	134	7,956	62	61	25.93	C	45	35.09	E	0.76
21-Jan-14	4:30 PM	5,941	1,290	439	117	7,787	61	64	24.30	C	46	33.81	D	0.74
21-Jan-14	4:45 PM	5,850	1,357	539	153	7,898	64	62	25.32	C	45	35.08	E	0.79
21-Jan-14	5:00 PM	5,930	1,394	478	138	7,940	64	62	25.52	C	45	35.20	E	0.78
21-Jan-14	5:15 PM	6,521	1,426	576	154	8,677	57	53	32.74	D	43	40.42	E	0.83
21-Jan-14	5:30 PM	5,799	1,256	517	137	7,708	55	50	30.53	D	46	33.59	D	0.74
22-Jan-14	6:30 AM	5,750	1,733	140	58	7,682	63	61	25.12	C	45	33.87	D	0.78
22-Jan-14	6:45 AM	6,311	1,984	170	74	8,539	60	60	28.25	D	42	40.45	E	0.90
22-Jan-14	7:00 AM	6,482	1,642	176	63	8,363	46	30	55.10	F	44	37.79	E	0.79
22-Jan-14	7:15 AM	6,142	1,523	158	55	7,878	42	25	62.84	F	46	34.07	D	0.75
22-Jan-14	7:30 AM	5,708	1,422	177	62	7,370	35	22	68.47	F	47	31.22	D	0.70
22-Jan-14	7:45 AM	5,600	1,325	164	55	7,144	33	23	62.53	F	48	29.73	D	0.68
22-Jan-14	3:00 PM	5,434	1,185	412	137	7,167	65	64	22.47	C	47	30.23	D	0.68
22-Jan-14	3:15 PM	5,433	1,192	398	133	7,155	66	65	22.08	C	47	30.14	D	0.68
22-Jan-14	3:45 PM	5,413	1,096	491	151	7,151	65	59	24.15	C	47	30.11	D	0.68
22-Jan-14	4:00 PM	5,451	1,229	431	119	7,231	66	65	22.29	C	47	30.77	D	0.69
22-Jan-14	4:15 PM	5,507	1,350	538	161	7,556	64	60	25.14	C	45	33.27	D	0.79
22-Jan-14	4:30 PM	5,782	1,371	463	134	7,751	66	63	24.50	C	46	34.06	D	0.76
22-Jan-14	4:45 PM	5,917	1,312	441	120	7,790	62	63	24.72	C	46	33.93	D	0.74
22-Jan-14	5:00 PM	5,835	1,393	413	121	7,762	64	63	24.47	C	46	34.00	D	0.75
22-Jan-14	5:15 PM	6,761	1,388	511	128	8,789	59	57	30.69	D	43	40.49	E	0.83
22-Jan-14	5:30 PM	5,566	1,245	553	151	7,515	39	39	38.47	E	46	32.71	D	0.75
23-Jan-14	6:30 AM	5,845	1,569	120	45	7,579	64	62	24.40	C	46	32.60	D	0.72
23-Jan-14	6:45 AM	6,339	1,926	164	69	8,498	58	59	28.74	D	43	39.89	E	0.87
23-Jan-14	7:00 AM	6,877	1,755	159	57	8,848	54	43	41.60	E	43	40.89	E	0.84
23-Jan-14	7:15 AM	6,351	1,402	141	44	7,938	38	26	61.71	F	46	34.32	D	0.75
23-Jan-14	7:30 AM	5,907	1,326	158	50	7,441	39	23	64.57	F	48	31.13	D	0.70
23-Jan-14	8:30 AM	5,490	1,215	274	80	7,058	23	22	64.71	F	48	29.32	D	0.67
23-Jan-14	9:15 AM	5,361	1,215	449	140	7,166	25	23	61.16	F	47	30.46	D	0.69
23-Jan-14	3:15 PM	5,444	1,278	417	149	7,287	63	65	22.47	C	47	31.17	D	0.71
23-Jan-14	3:30 PM	5,438	1,275	489	174	7,377	63	63	23.29	C	46	31.88	D	0.74
23-Jan-14	3:45 PM	5,359	1,301	463	171	7,295	65	65	22.62	C	46	31.47	D	0.74
23-Jan-14	4:00 PM	5,338	1,250	490	141	7,219	64	64	22.50	C	47	31.00	D	0.73

San Diego Site #2

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
23-Jan-14	4:15 PM	5,926	1,416	507	148	7,997	62	64	25.14	C	45	35.72	E	0.80
23-Jan-14	4:30 PM	5,733	1,343	462	132	7,671	62	64	23.93	C	46	33.53	D	0.75
23-Jan-14	4:45 PM	5,909	1,267	519	136	7,832	62	64	24.62	C	46	34.28	D	0.75
23-Jan-14	5:00 PM	5,728	1,325	388	110	7,552	63	63	24.07	C	46	32.56	D	0.72
23-Jan-14	5:15 PM	6,418	1,452	541	150	8,561	60	61	27.99	C	43	39.73	E	0.83
23-Jan-14	5:30 PM	5,775	1,372	378	110	7,634	63	61	25.14	C	46	33.12	D	0.73
23-Jan-14	5:45 PM	5,308	1,242	404	116	7,069	64	62	22.98	C	47	29.93	D	0.69
24-Jan-14	6:45 AM	6,044	2,133	160	78	8,414	59	62	27.34	C	42	39.73	E	0.96
24-Jan-14	7:00 AM	6,447	1,971	156	67	8,640	57	47	37.14	E	42	40.88	E	0.89
24-Jan-14	7:15 AM	6,100	1,554	113	41	7,807	38	25	61.66	F	46	33.66	D	0.74
24-Jan-14	7:30 AM	6,146	1,433	155	51	7,786	35	24	63.57	F	47	33.23	D	0.74
24-Jan-14	7:45 AM	5,884	1,429	212	72	7,597	39	26	57.80	F	47	32.50	D	0.72
24-Jan-14	8:00 AM	5,306	1,407	267	94	7,074	29	25	57.14	F	47	30.05	D	0.70
24-Jan-14	8:15 AM	5,317	1,428	249	88	7,082	32	24	59.14	F	47	30.10	D	0.70
24-Jan-14	8:30 AM	5,689	1,620	274	103	7,686	46	44	35.03	E	45	33.97	D	0.79
24-Jan-14	8:45 AM	5,366	1,471	271	99	7,207	64	63	22.91	C	47	30.95	D	0.73
24-Jan-14	1:45 PM	5,197	1,372	408	113	7,089	63	65	21.89	C	46	30.50	D	0.74
24-Jan-14	2:15 PM	5,195	1,427	371	97	7,089	65	63	22.52	C	46	30.56	D	0.75
24-Jan-14	2:45 PM	5,141	1,296	524	125	7,087	65	65	21.74	C	46	30.64	D	0.76
24-Jan-14	3:00 PM	5,774	1,246	464	152	7,636	65	66	22.98	C	46	32.97	D	0.73
24-Jan-14	3:15 PM	5,971	1,277	387	126	7,761	64	63	24.74	C	46	33.41	D	0.74
24-Jan-14	3:30 PM	5,620	1,199	509	165	7,494	64	64	23.58	C	46	32.25	D	0.71
24-Jan-14	3:45 PM	5,480	1,260	481	168	7,390	65	64	23.17	C	46	31.86	D	0.73
24-Jan-14	4:00 PM	5,427	1,321	366	109	7,222	67	67	21.68	C	47	30.82	D	0.70
24-Jan-14	4:15 PM	5,569	1,345	421	124	7,458	65	65	22.79	C	46	32.29	D	0.74
24-Jan-14	4:30 PM	5,381	1,280	371	108	7,139	67	63	22.68	C	47	30.28	D	0.69
24-Jan-14	4:45 PM	5,453	1,409	462	146	7,470	64	64	23.24	C	46	32.77	D	0.78
24-Jan-14	5:00 PM	5,768	1,430	399	121	7,719	66	63	24.60	C	46	33.88	D	0.76
24-Jan-14	5:15 PM	5,956	1,354	415	115	7,841	64	64	24.66	C	46	34.25	D	0.75
24-Jan-14	5:30 PM	5,279	1,327	341	105	7,052	66	63	22.55	C	47	29.92	D	0.69

Site #3: Interstate 805 NB in San Diego
between SR 52 (on) & Governor Drive (off)

HCM 2010 Parameter		
Length of Weave Segment	L_s (feet)	1,670
Interchange Density	ID (IC/mile)	1.00
Number of Lanes in Weave	N (lanes)	5
Number of Weaving Lanes	N_{WL} (lanes)	2
Freeflow Speed	FFS (mph)	65
Capacity (Ideal Basic Fwy Seg)	C_{IFL} (pc/h/ln)	2,350
Minimum Lane Chages (Rmp to Fwy)	LC_{RF} (lanes)	1.00
Minimum Lane Chages (Fwy to Rmp)	LC_{FR} (lanes)	1.00
Peak Hour Factor	PHF	1.00
Factor for Heavy Vehicles	f_{HV}	1.00
Factor Driver Population	f_P	1.00

San Diego Site #3

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
19-May-14	5:45 AM	6,711	1,607	276	111	8,704	68	28	61.67	F	44	39.23	E	0.82
19-May-14	6:00 AM	6,274	1,503	273	134	8,184	64	29	57.03	F	46	35.97	E	0.77
19-May-14	6:15 AM	7,394	1,750	318	154	9,616	57	26	72.79	F	42	45.36	F	0.91
19-May-14	6:30 AM	6,537	1,810	353	200	8,900	53	27	66.96	F	43	41.75	E	0.90
19-May-14	6:45 AM	5,414	2,123	329	265	8,130	52	25	65.50	F	42	38.71	E	1.02
19-May-14	7:00 AM	5,399	2,278	324	224	8,224	51	23	72.61	F	41	39.97	E	1.08
19-May-14	7:15 AM	5,347	2,177	359	239	8,122	52	24	67.02	F	42	39.05	E	1.06
19-May-14	7:30 AM	4,689	2,507	259	227	7,682	51	27	57.95	F	41	37.42	E	1.15
19-May-14	7:45 AM	4,174	2,357	284	263	7,078	50	24	58.48	F	42	33.38	D	1.10
19-May-14	8:00 AM	4,232	2,388	217	181	7,018	51	27	51.85	F	43	32.91	D	1.09
19-May-14	9:00 AM	4,584	1,903	324	219	7,030	48	66	21.25	C	44	31.67	D	0.93
19-May-14	9:30 AM	5,067	1,550	376	187	7,180	59	65	21.94	C	46	31.40	D	0.80
19-May-14	9:45 AM	5,461	1,348	304	122	7,236	60	64	22.57	C	47	30.69	D	0.69
20-May-14	5:45 AM	6,975	1,680	251	101	9,008	68	29	63.13	F	44	41.14	E	0.85
20-May-14	6:00 AM	6,273	1,534	322	161	8,290	62	33	50.61	F	45	36.88	E	0.79
20-May-14	6:15 AM	7,340	1,672	358	167	9,538	57	28	69.35	F	43	44.68	F	0.90
20-May-14	6:30 AM	7,098	1,819	367	193	9,476	53	25	74.64	F	42	45.23	F	0.91
20-May-14	6:45 AM	5,039	1,941	313	247	7,540	52	25	60.45	F	44	34.53	D	0.94
20-May-14	7:00 AM	5,988	1,757	387	186	8,318	53	24	69.57	F	43	38.36	E	0.89
20-May-14	7:15 AM	5,366	2,293	339	237	8,236	52	24	69.35	F	41	40.18	E	1.10
20-May-14	7:30 AM	4,596	2,499	265	236	7,596	53	25	60.19	F	41	36.89	E	1.15
20-May-14	7:45 AM	4,390	2,445	262	239	7,336	53	25	58.07	F	42	35.12	E	1.13
20-May-14	8:00 AM	4,083	2,593	254	238	7,168	53	24	60.92	F	41	34.63	D	1.19
20-May-14	8:15 AM	4,258	2,428	260	219	7,164	52	22	64.50	F	42	34.04	D	1.12
20-May-14	9:45 AM	5,367	1,515	313	144	7,338	55	66	22.27	C	46	31.84	D	0.76
21-May-14	5:45 AM	6,601	1,618	277	114	8,610	68	25	68.87	F	44	38.78	E	0.81
21-May-14	6:00 AM	6,392	1,612	259	134	8,398	64	25	67.40	F	45	37.53	E	0.79
21-May-14	6:15 AM	6,707	1,679	320	164	8,870	55	25	69.73	F	44	40.72	E	0.84
21-May-14	6:30 AM	6,102	1,964	306	202	8,574	52	25	69.27	F	42	40.42	E	0.95
21-May-14	6:45 AM	5,007	2,174	258	229	7,668	52	26	59.66	F	43	35.96	E	1.01
21-May-14	7:00 AM	4,712	2,208	317	243	7,480	52	24	61.48	F	42	35.26	E	1.05
21-May-14	7:15 AM	4,823	2,255	261	200	7,540	52	24	63.81	F	42	35.57	E	1.05
21-May-14	7:30 AM	4,410	2,340	250	217	7,216	52	24	59.32	F	42	33.99	D	1.08
21-May-14	7:45 AM	4,514	2,453	288	256	7,512	53	25	61.20	F	41	36.29	E	1.14
21-May-14	8:00 AM	4,534	2,521	246	202	7,504	52	23	64.54	F	41	36.35	E	1.15
21-May-14	8:30 AM	4,165	2,400	292	249	7,106	50	26	54.61	F	42	33.72	D	1.12
21-May-14	9:45 AM	5,435	1,395	279	117	7,226	51	61	23.65	C	47	30.72	D	0.70
22-May-14	5:45 AM	6,701	1,574	255	100	8,630	67	26	66.62	F	45	38.57	E	0.81
22-May-14	6:00 AM	5,942	1,483	319	163	7,908	64	26	61.91	F	46	34.65	D	0.75
22-May-14	6:15 AM	7,075	1,796	316	165	9,352	58	23	79.96	F	42	44.08	F	0.89
22-May-14	6:30 AM	6,205	1,883	329	205	8,622	52	25	68.38	F	43	40.41	E	0.92
22-May-14	6:45 AM	5,154	2,210	289	254	7,906	53	26	60.25	F	42	37.61	E	1.04
22-May-14	7:00 AM	5,111	2,224	320	228	7,882	51	23	68.15	F	42	37.67	E	1.06
22-May-14	7:15 AM	4,995	2,306	303	229	7,832	52	23	67.50	F	42	37.65	E	1.09

San Diego Site #3

Date	Time	V_{FF} (pc/h)	V_{RF} (pc/h)	V_{FR} (pc/h)	V_{RR} (pc/h)	V (pc/h)	Measured Downstream Speed (mph)	Measured Speed (mph)	Measured Density (pc/mi/ln)	Measured LOS	HCM2010 Speed (mph)	HCM2010 Density (pc/mi/ln)	HCM2010 LOS	HCM2010 V/C Ratio
22-May-14	7:30 AM	4,722	2,423	293	246	7,684	53	23	67.71	F	41	37.22	E	1.13
22-May-14	7:45 AM	4,687	2,458	271	232	7,648	52	24	64.09	F	41	37.06	E	1.14
22-May-14	8:00 AM	4,355	2,509	227	193	7,284	50	24	61.32	F	42	34.92	D	1.14
22-May-14	9:45 AM	5,540	1,521	342	153	7,556	56	63	23.86	C	46	33.09	D	0.78
23-May-14	5:45 AM	6,445	1,464	226	86	8,222	67	31	53.89	F	46	35.79	E	0.77
23-May-14	6:00 AM	5,605	1,267	264	122	7,258	64	27	53.77	F	48	30.36	D	0.68
23-May-14	6:15 AM	6,893	1,578	345	162	8,978	55	27	67.33	F	44	40.93	E	0.85
23-May-14	6:30 AM	6,049	1,876	307	195	8,428	50	25	67.89	F	43	39.16	E	0.91
23-May-14	6:45 AM	5,580	2,164	301	239	8,284	51	24	69.57	F	42	39.68	E	1.03
23-May-14	7:00 AM	5,190	2,228	338	238	7,994	51	22	72.17	F	42	38.43	E	1.07
23-May-14	7:15 AM	5,106	2,353	338	255	8,052	53	27	59.40	F	41	39.34	E	1.12
23-May-14	7:30 AM	5,242	2,364	303	224	8,132	53	30	53.68	F	41	39.71	E	1.11
23-May-14	7:45 AM	4,727	2,423	272	229	7,652	52	55	28.00	D	41	36.95	E	1.12
23-May-14	8:15 AM	4,612	2,217	294	209	7,332	50	62	23.61	C	43	34.36	D	1.05
23-May-14	8:30 AM	4,719	2,138	353	236	7,446	49	63	23.80	C	43	34.93	D	1.04
23-May-14	8:45 AM	5,674	1,841	399	191	8,104	57	65	25.12	C	43	37.60	E	0.93
23-May-14	9:00 AM	5,539	1,617	358	170	7,684	61	63	24.45	C	45	34.19	D	0.82
23-May-14	9:15 AM	5,316	1,483	316	143	7,258	62	66	22.15	C	46	31.33	D	0.75
23-May-14	9:30 AM	5,818	1,630	301	137	7,886	58	66	23.96	C	45	35.08	E	0.80
23-May-14	9:45 AM	5,767	1,521	328	141	7,756	59	70	22.29	C	46	34.06	D	0.77