UTA: 0-5578

Assessment and Validation of Managed Lanes Weaving and Access Guidelines

UNIVERSITY OF TEXAS ARLINGTON

Technical Report 0-5578-1

Cooperative Research Program

June 2010

Civil Engineering Department
University of Texas at Arlington
Arlington, Texas 76019-0308

in cooperation with
the Federal Highway Administration and
the Texas Department of Transportation

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-09/0-5578-1		

4. Title and Subtitle	5. Report Date
ASSESSMENT AND VALIDATION OF MANAGED LANES WEAVING AND ACCESS GUIDELINES	
	6. Performing Organization Code
7. Author(s) James C. Williams, Stephen P. Mattingly, Chulsu Yang	8. Performing Organization Report No. Report 0-5578-1
9. Performing Organization Name and Address Civil Engineering Department University of Texas at Arlington Arlington, Texas 76019-0308	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-5578
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Technical Report September 2006—August 2008 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

The goal of this project was to establish spacing requirements for access points to managed lanes with respect to the location of entrance and exit ramps on the general purpose lanes of the freeway. Traffic entering the freeway destined for the managed lane must weave across the general purpose lanes. Traffic exiting the freeway from the managed lane must also perform this maneuver.

The results are based on microscopic simulation using the VISSIM model. The simulation model was carefully calibrated using data collected on IH 635 (LBJ Freeway) in Dallas, Texas. A genetic algorithm was used in the calibration. The model was subsequently validated using data collected at a nearby site along IH 635.

The weaving was analyzed as a Type C two-sided weave. Capacity was estimated by gradually increasing flow in the general purpose lanes for each set of conditions until the simulation model throughput was less than the input flows, indicating the formation of queues. The specific conditions included ramp flows (500 to 1250 veh/hour), ramp to managed lanes flows (100 to 400 veh/hour), general purpose lanes to managed lane flows (200 to 800 veh/hour), and length of weave (1000 to 4000 feet).

The principal determinant for spacing was the weaving flow (ramp to managed lane flow), with a minimum weaving distance of 2000 to 3500 feet for flows from 200 to 400 veh/hour. A desirable minimum distance of 4000 feet was found. All results were for four general purpose lanes.

17. Key Word	18. Distribution Statement
Managed Lane Access, Freeway Weaving, Microscopic Simulation, Weaving Capacity	No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	128	

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

ASSESSMENT AND VALIDATION OF MANAGED LANES WEAVING AND ACCESS GUIDELINES

by

James C. Williams, Ph.D., P.E.
Professor of Civil Engineering
University of Texas at Arlington

Stephen P. Mattingly, Ph.D.
Associate Professor of Civil Engineering
University of Texas at Arlington

Chulsu Yang
Graduate Student
University of Texas at Arlington

Report 0-5578-1
Project 0-5578
Project Title: Assessment and Validation of Managed Lanes Weaving and Access Guidelines

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: June 2010

Civil Engineering Department
University of Texas at Arlington
Arlington, Texas 76019-0308

DISCLAIMER

The contents of this report reflect the views of the authors, who are solely responsible for the facts and accuracy of the data, opinions, and conclusions presented herein. The contents do not necessarily reflect the official views of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. The names of specific products or manufacturers listed herein do not imply endorsement of these products or manufacturers. The engineer in charge of this project was James C. Williams, Ph.D., P.E. (Texas #49220).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names may appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted under a cooperative research program between the University of Texas at Arlington, the Texas Department of Transportation (TxDOT), and the Federal Highway Administration (FHWA). The members of the Project Monitoring Committee (PMC) were:

- Tom Beeman, TxDOT Design Division
- Stuart Corder, TxDOT, Houston District
- John Gaynor, TxDOT, Houston District
- David Rodgers, TxDOT, Houston District (Retired)
- Flor Tamez, TxDOT, Design Division

Wade Odell, P.E., of TxDOT's Research and Technology Implementation Office was an active participant in project meetings.

In addition, Dan Loving of TxDOT's Dallas District was instrumental in selecting surveillance cameras for the field studies and providing access to the Dallas District's remote control center. Also, Diana Wallace of the TTI office in Arlington provided assistance in organizing the field data collection crews.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Traffic growth in urban areas continues to rise, due in part to rapid population growth. This traffic growth results in worsening congestion on urban freeways which often cannot be addressed in a timely manner by widening existing facilities or the construction of new facilities due to funding limitations, or the often-extensive time required for environmental clearances and actual construction. In some cases, the public may not support the expansion of a freeway or the construction of a new one. The need for new roads to address this congestion exceeds not only the funding capacity but also the ability to gain environmental and public approval for large-scale construction projects.

As alternative solutions to roadway widening to mitigate the adverse effects of congestion, one strategy for improving freeway performance is through the implementation of managed lanes. Managed lanes provide a good opportunity to reduce traffic congestion by increasing person-carrying capacity and to improve the operations of our urban freeways at a much lower cost than simply providing equivalent capacity with general purpose lanes only.

Managed lanes are typically found in the freeway median, and are accessed directly from frontage roads, local arterial streets, other managed lanes facilities, or park-and-ride lots with grade-separated ramps (direct access) or accessed by weaving across the general purpose lanes and entering them from the left lane (indirect access). The second option is often preferred from a cost standpoint, but requires the traffic which desires to use the managed lanes to weave across the general purpose lanes.

Existing managed lane manuals [Refs. 1, 2, 3] do not reflect the weaving volume between the ramp and the managed lane. Venglar, et al. [Ref. 4], provides guidance in this regard, but the results are based on uncalibrated simulation runs, where the default values of the parameters were used. While these guidelines are not drastically different from those in existing manuals, they have not been validated against field data.

Research Approach

Microscopic simulation will be used to develop guidelines for the spacing between right-side entrance ramps and left-side access points to managed lanes (as well as the reverse situation, i.e., between left-side access points to managed lanes and right-side exit ramps). A wide range of flow conditions will be considered, the flows of interest including the flows in the general purpose lanes, the ramps, as well as the flow weaving across the general purpose lanes. The simulation model will be calibrated and validated using data from an urban Texas freeway currently operating with managed lanes. The analysis is largely a freeway weaving analysis.

This report is organized as follows, which generally corresponds to the project tasks. A general overview of managed lanes is provided in chapter 2, with a literature review of freeway weaving in chapter 3. Freeway weaving is the predominant feature in determining adequate distances for these managed lane access points.

Chapter 4 describes the data collection effort and the type of data collected. The calibration and validation of the microscopic simulation model is detailed in chapter 5. Simulation results, indicating capacity for a wide range of flows and weaving distances are described in chapter 6. The conclusions and recommendations for weaving length are provided in the final chapter. Finally, there are extensive appendices detailing the calibration and validation process, the collected field data, as well as additional simulation results.

CHAPTER 2
OVERVIEW OF MANAGED LANE FACILITIES

The Federal Highway Administration defines managed lane(s) as "a lane or lanes designed and operated to achieve stated goals by managing access via user group, pricing, or other criteria. A managed lane facility typically provides improved travel conditions to eligible users." The Texas Department of Transportation (TxDOT) has developed the following definition: "A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals." Examples of managed lanes include [Ref. 6]:

- high occupancy vehicle (HOV) lanes,
- value-priced and high occupancy-toll (HOT) lanes,
- exclusive lanes,
- mixed-flow separation/bypass lanes,
- lane restrictions, and
- dual facilities.

Managed lanes enhance the efficiency of traffic corridors through various operational and design adjustments to implement regional objectives. The key objective of the implementation of managed lanes is to meet the following transportation systems goals:

- increase person-carrying capacity,
- reduce traffic congestion by increasing person-carrying capacity,
- provide travel time savings and more reliable trip times, and
- improve air quality by reducing congestion.

In general, the capacity of a managed lane ranges from 1500 to 1800 vehicles/hour, with a recommended maximum flow of 1500 vehicles/hour for efficient operation [Ref. 7].

Indirect Access to Managed Lanes

As indicated in the first chapter, managed lanes are often placed in the median of an existing freeway. While generally less expensive, this design requires vehicles destined for the managed lane to weave across the general purpose lanes on the freeway. Vehicles access the managed lane by essentially changing lanes from the left general purpose lane to the managed lane at designated locations. Between these locations, the managed lane is separated from the general purpose lanes by a buffer, which can be driven across, but should not be. Fuhs [Ref. 2] recommends providing access points for the managed lane every two or three entrance-exit ramp pairs. The length of the access should be between 1000 and 1500 feet. The access points can be designed with and without a weaving lane, with two common designs shown in figure 2.1 [Ref. 9].

Direct Access to Managed Lanes

If the flow into or out of the managed lane is greater than 500 vehicles/hour, Fuhs [Ref. 2] recommends the use of direct access. Fitzpatrick, et al. [Ref. 8], recommends direct access if the flow entering or leaving the managed lane exceeds 400 vehicles/hour, or as low as 250 vehicles/hour in some cases. Direct access is generally provided by a ramp that passes over the general purpose lanes, eliminating the weaving maneuver. These ramps can provide access from

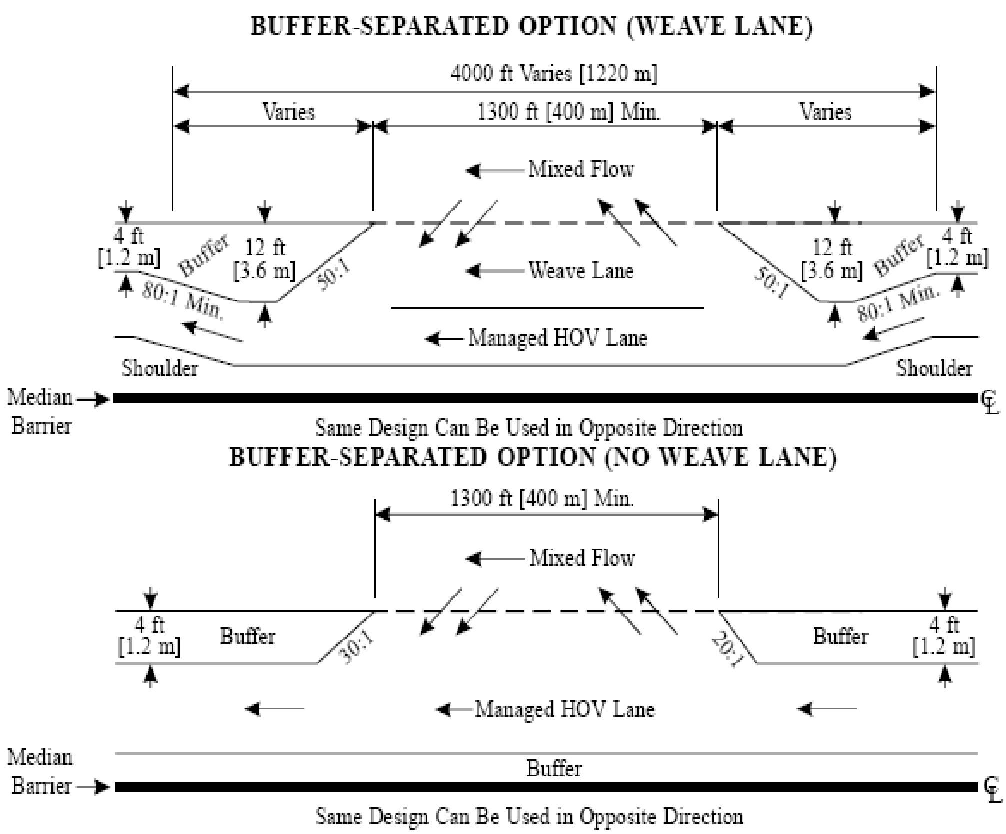


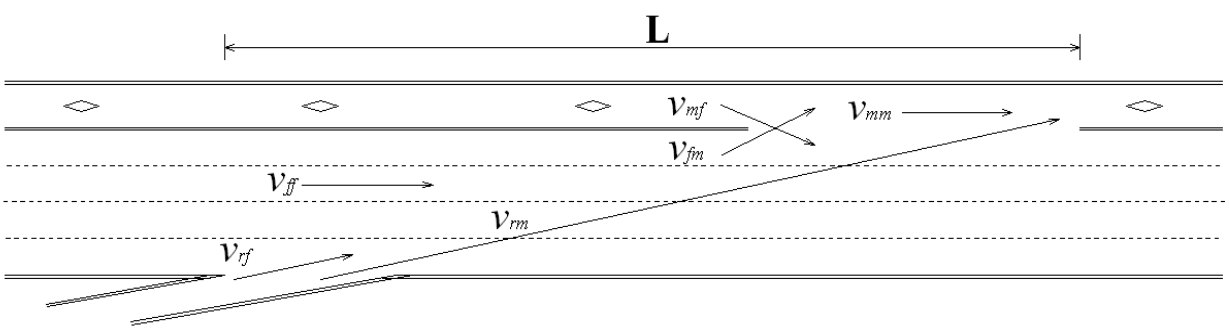
Figure 2.1. Buffer-separated intermediate access with and without weave lane [Ref. 9]

frontage roads, nearby arterials, park and ride lots, and transit stations (when busses are allowed to use the managed lane).

Design Issues for Access to Managed Lanes

A schematic showing a freeway with four general purpose lanes with a single managed lane in the median is shown in figure 2.2. Because entrance ramps on urban freeways are one mile apart or closer, the access points to managed lanes are only a limited distance downstream from the entrance ramp (L in figure 2.2). This length is a critical design issue, as it represents the length of a two-sided Type C weave, as defined by the Highway Capacity Manual [Ref. 5]. This process is reversed for traffic exiting the managed lane which must weave across the general purpose lanes to exit the freeway.

Existing design guidelines provide a range of answers, but are likely based on operational experience rather than a thorough analysis of the weaving area. Caltrans recommends a minimum L (as shown in figure 2.2) of 660 feet per lane change needed to enter the managed lane [Ref. 1]. Fuhs



where L = distance from the freeway ramp to the access point of the managed lane

- v_{ff} = through traffic remaining on the general purposes lanes
- v_{mm} = through traffic remaining on the managed lane
- v_{fm} = traffic entering the managed lane from the general purpose lanes
- v_{mf} = traffic leaving the managed lane to the general purpose lanes
- v_{rf} = ramp traffic destined for general purpose lanes
- v_{rm} = ramp traffic destined for the managed lane

Figure 2.2. Lane configuration and notation for traffic movements.

recommends a minimum L of 500 feet per lane change, with a desired distance of 1000 feet per lane change [Ref. 2]. Turnbull and Capelle recommended a distance of 2500 feet between the entrance ramp or exit ramp and managed lane access [Ref. 3].

Venglar, et al. [Ref. 4], developed a more detailed set of design guidelines using simulation, which are summarized in table 2.1. Their recommendations are based on the expected flows in the general purpose lanes (medium or heavy), the degree to which the average speed in the general purpose lanes would be affected (not at all or a reduction of 10 mph), and whether there is an intermediate ramp on the general purpose lanes between the entrance or exit ramp in question and the managed lane access point.

The distance between an entrance ramp to the general purpose lanes and the access point for the managed lanes forms a weaving area. An overview of the analysis of weaving areas and recent research is summarized in the next chapter.

Table 2.1. Weaving distances for cross-freeway maneuvers [Ref. 4].

Design Year Volume Level	Allow up to 10 mph speed reduction in general purpose lanes for weave to managed lane?	Intermediate ramp between entrance/exit ramp on general purpose lanes and managed lane entrance/exit?	Recommended Minimum Weaving Distance Per Lane (feet)
Medium (LOS C or D)	Yes	No Yes	500 600
	No	No Yes	700 750
High (LOS E or F)	Yes	No Yes	600 650
	No	No Yes	900 950

Note: The provided weaving distances are appropriate for freeway vehicle mixes with up to 10 percent heavy vehicles; higher percentages of heavy vehicles will require increasing the per lane weaving distance. The value used should be based on engineering judgment, though a maximum of an additional 250 feet per lane is suggested.

CHAPTER 3
REVIEW OF EXISTING METHODS FOR WEAVING ANALYSIS AND CURRENT WEAVING RESEARCH

The development of the procedure for analyzing weaving areas on freeways is summarized in this chapter, followed by a brief summary of research results. The weaving research is grouped into an extension of standard procedures and some gap-based work.

Weaving Area Analysis in Highway Capacity Manuals

Weaving has been recognized as an important element of freeway capacity and LOS since the first edition of the Highway Capacity Manual (HCM) in 1950 [Ref. 10]. The 1950 HCM prescribed a length of weaving section based on the number of weaving vehicles per hour and the desired operating speed (up to 40 mph). All weaving traffic was assumed to have to change lanes. The procedure was based on data from six sites; four on the roadways surrounding the Pentagon in Arlington, Virginia, and two on the San Francisco Bay Bridge distribution system.

The second edition of the Highway Capacity Manual was published in 1965 [Ref. 11]. The basic procedure was carried over from the 1950 HCM, but was considerably amplified with additional data. The concept of quality of flow was introduced, and a service volume was used instead of capacity in the estimation of the required number of lanes.

The 1985, or third, edition of the Highway Capacity Manual [Ref. 12] introduced the effect of lane configuration to the analysis of weaving sections. Lane configuration is the relative placement and number of entry and exit lanes, and was generalized to three types, two of which are of interest with respect to managed lanes. All weaving vehicles are required to change lanes in Type A weaves (figure 3.1). (Type A weaves were implicitly assumed in the 1950 HCM and, to a lesser extent, in the 1965 HCM.) Ramp weaves are the most common Type A weaves. The lane changing between the managed lane and the left general purpose lane at the access point for the managed lane can be analyzed as a ramp weave (figure 2.2).

In Type B weaves, one weaving flow is not required to change lanes, and the other weaving flow must change lanes only once (figure 3.2). The procedure assumes that the larger weaving flow is the one that does not change lanes. Note that Type B weaves include geometries with internal

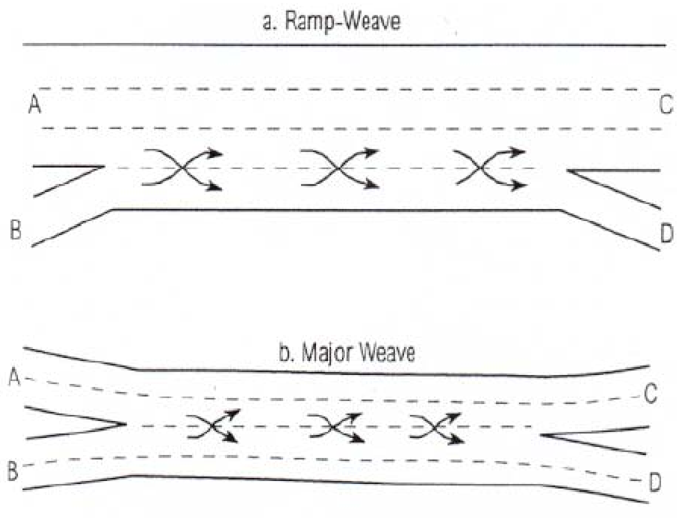


Figure 3.1. Type A weaves [Ref. 5].

merges (figures 3.2b and 3.2c). These are included in the HCM as an aid in the analysis of existing internal merges, and not as a design guide.

The third lane configuration, Type C, is generally used where one weaving flow is much smaller than the other. Vehicles in the smaller weaving flow must change lanes at least twice, while

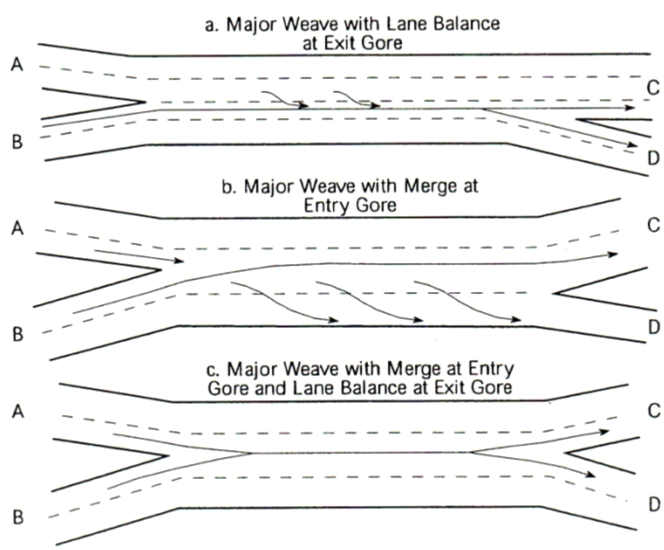


Figure 3.2. Type B weaves [Ref. 5].

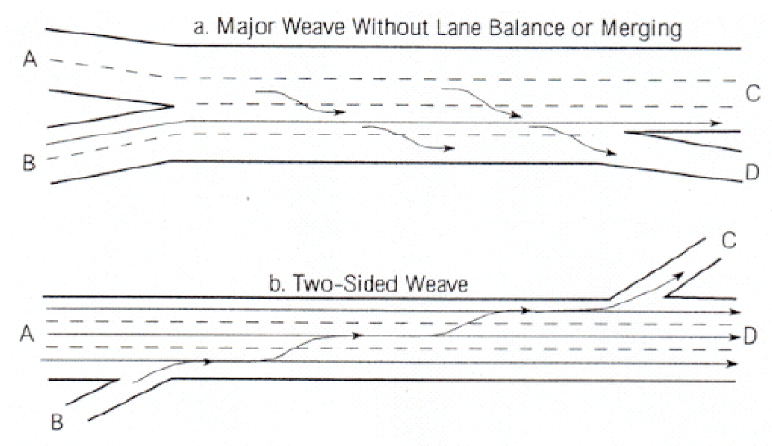


Figure 3.3. Type C weaves [Ref.5].

vehicles in the larger weaving flow do not have to change lanes. A typical example is shown in figure 3.3a. A special case of Type C weaves is the two-sided weave (figure 3.3b), where the flow from ramp to ramp is the smaller weaving flow, and the larger weaving flow is the through mainlane flow. Historically, two-sided weaves have been formed with a left-side ramp. Current design practice is to not used left-side ramps, and freeway reconstruction has reduced the number of two-sided weaves in recent years. However, the use of left-side managed lanes with access from the left general purpose lane have, in effect, created two-sided Type C weaves.

Of the three configurations, Type B weaves can handle higher capacities, as the minor weaving flow changes fewer lanes than in Type C weaves, and the major weaving flow does not have to change lanes, unlike Type A weaves, where all weaving traffic must change lanes. Balanced weaving flows suggest Type A weaves, while Type B and C weaves are more suited for unbalanced weaving flows.

An entirely new weaving model was developed for the 1985 HCM [Ref 12]. In addition to recognizing that lane configuration has a major impact on weaving operation, there were two major components in the procedure. First was a model to predict the speed of weaving and non-weaving vehicles, then a model to determine if the weaving traffic in a particular weaving area is constrained by its geometry. Both models were developed through regression techniques based on over 200 observations. While this procedure represented a major improvement over the earlier editions of the HCM, its use is awkward in design. An assumption of the weaving area's length, width (number of lanes), and configuration is required, thus requiring a trial-and-error approach in design.

The same basic models and procedure are found in the current (fourth) edition of the Highway Capacity Manual [Ref. 5], published in 2000. Some of the parameters were re-estimated to address problems in speed estimation, and tabulated values of weaving area capacity are provided.

Other Weaving Research

The analysis procedure for the 1985 HCM is largely a synthesis of three methods that were developed in the ten years before its publication. The Polytechnic Institute of New York (PINY) [Ref. 14] introduced a methodology to estimate the level of service for both weaving and non-weaving vehicles with a given set of geometry and traffic compositions. The lane configuration is a major determinant of operating quality. The number of lanes, weaving section length, traffic volumes, and speeds are the four basic variables. The Leisch method [Ref. 15] is based on the structure of the 1965 HCM. A nomograph approach was established to estimate an appropriate section length and number of lanes, given traffic volumes and a desired level of service. JHK and Associates [Ref. 16] developed speed estimation equations, but discarded the concepts of lane configuration central to PINY and Leisch methods. The concept of constrained and unconstrained operations introduced by the PINY method was eliminated.

Fazio and Rouphail [Ref. 17] offered a refinement to the estimation of weaving and non-weaving speeds in the 1985 HCM. They introduced the *lane-shift variable*, which represents the minimum number of lane shifts required by the driver of a weaving vehicle to complete the weaving maneuver. Rather than considering each configuration individually, they incorporated the number of lane shifts made by the weaving traffic directly into regression equations to estimate the speeds of weaving and non-weaving traffic. Field data consisted of Type A weaves only, but the general lane shift concept should apply to all configurations. They found that the inclusion of lane shift as an independent variable in average running weaving and non-weaving speed estimation models improved the model's prediction of speed.

Cassidy, Skabardonis, and May [Ref. 18] evaluated the weaving procedures in the 1985 HCM using observations from eight sites in California. They found that the 1985 HCM models predicted operating speeds slower than observed speeds, although they were quite variable. They recalibrated the 1985 HCM weaving models, but still found R^2 values less than 0.5 for Type B and Type C weaves. They found that the basic freeway segment analysis more reliably predicted average speeds in the weaving areas than the weaving analysis procedure.

Cassidy and May [Ref. 19] and Wang, et al. [Ref. 20], analyzed large amounts of empirical and simulated data collected from a number of sites throughout California and evaluated the capacity of freeway weaving sections. They criticized the regression-based speed estimation methodologies. They indicated that average travel speed would not be an appropriate measurement of effectiveness of the freeway performance because of its insensitivity to the change of traffic volumes, up to an average flow of 1600 pcphpl. They proposed a methodology to capture operational performance on a lane-by-lane basis, which represents the lane-changing activity. In other words, the proposed procedure predicts the spatial distribution of traffic streams within the weaving area.

They found that the highest concentration of lane-changing activity occured around the merge gore. The majority of lane changes occurred in the first 500 feet of the weaving area. The weaving flow rate (the sum of the two weaving flows) was the most significant factor affecting this longitudinal distribution along the weaving area. The authors recognized that the capacity of the weaving area varies with the total weaving flow rate. The capacity of a weaving section in this research was defined as the maximum flow of vehicles that can travel at any point in a single lane. Using the INTRAS simulation model, they showed that capacity flow values were 2,200 pcph at any point within a weaving section, and that the maximum rate of lane-changing ranged from 1,100 to 1,200 per hour (across a single lane-line) within any 250 ft segment. However, these values were not empirically verified.

Pietrzyk and Perez [Ref. 21] developed a calculation procedure to estimate the lengths of freeway weaving sections. Under this approach, a weaving section length was determined that would preserve a desired LOS established by the 1985 HCM. This approach could be useful for the design/planning analysis of weaving areas on freeways and collector-distributor roadways.

Kuwahara, et al. [Ref. 22], studied the capacity and speed of weaving sections on the Tokyo Metropolitan Expressway. They collected data from three weaving areas, and compared the results of the 1965 HCM, 1985 HCM, PINY, JHK, and Leisch. The 1985 HCM and JHK methods estimated capacity and speed well, while the 1965 HCM was inadequate for the particular weaving areas and the PINY and Leisch methods underestimated the speeds.

Alexiadias, et al. [Ref. 23], observed existing weaving section speeds in Boston and on Logan Airport roadways. The results showed that the 1985 HCM weaving method underestimated weaving and non-weaving speeds from 11 sites in the Boston area and 2 sites on the Logan Airport roadways. They then re-estimated the coefficients for the speed equation using data collected from the 11 sites in the Boston area, which improved speed prediction.

In addition, Alexiadias, et al. [Ref. 23] modified the weaving and non-weaving equation of 1985 HCM for two-sided Type C using data from two sites on the Logan Airport access roadways. The term for the fraction of weaving traffic (VR) for speed estimation was replaced by the ratio of the ramp-to-ramp volume to the total volume in the waving section. In the speed equation, the cross-weaving ratio variable has an inverse relationship to weaving speed. As the cross-weaving speed increases, the weaving conflict increases and weaving speed decreases. There is a direct relationship between cross-weaving ratio and nonweaving speeds.

Vermijs [Ref. 24] used the FOSIM simulation model, which had been developed at the Delft University of Technology in the early 1990s, to evaluate capacity for several Type A major weaves and ramp weaves. The capacity value for zero weaving flow rates was 2200 vphpl for 10% trucks. The simulation results showed that most lane changes took place within the first 1312 feet of a weaving section and that a longer weaving section had no significant impact on weaving capacity. The capacity of a weaving section was expected to increase with increasing length, up to a certain minimum value of weaving section length (1312 ft).

Denney and Williams [Ref. 25] developed capacity and density models for Type A weaves (ramp weaves and major weaves) using data from several sites in California and one in Houston, Texas, (all ramp weaves) and one site near Baltimore, Maryland (major weave). The capacity model reflects that, under capacity conditions, drivers are willing to accept very short headways as they change lanes, resulting in an effective lane capacity of over 3000 vehicles/hour. The capacity model is expressed in terms of the traffic in the two weaving lanes (both sides of the crown line for a Type A weave), and the model is

$$C_w = \begin{cases} 2300 + V_w & \text{for } V_w < 700 \text{ veh / hour} \\ 3000 & \text{for } V_w \geq 700 \text{ veh / hour} \\ & \quad \text{and } V_t < 3000 \text{ veh / hour} \\ \left(2 - VR_w\right)\left(1 + \dfrac{V_w - 2142}{2370}\right)(2300) & \text{for } V_t \geq 3000 \text{ veh / hour} \end{cases}$$

where V_{rw} = the ratio of weaving volume overall vehicles in the weaving lanes,

C_w = capacity (weaving and nonweaving traffic) in the weaving lanes,

V_w = total weaving volume, and

V_t = total volume in the weaving lanes.

Preliminary work was performed for Types B and C weaves, using one site in Grapevine, Texas (Type B), and five sites in Fort Worth, Arlington, and San Antonio, Texas (Type C). The Type C site in San Antonio was a two-sided weave. Observed data from the Texas and Maryland sites showed that the majority of the lane changes for Types A and B weaves occurred in the first 500 feet of the weave, confirming earlier observations in California. Lane changes in Type C weaves were distributed further downstream as two (or more) lane changes were required.

Vo [Ref. 26] extended Denney and Williams' work with a close examination of Type C two-sided weaves. He collected detailed data at the above-mentioned site in San Antonio (SB IH 35/410 between the Rittiman on-ramp and the SB IH 410 left exit), and calibrated a simulation model (VISSIM).

Gap Acceptance Theory-Based Weaving Analysis

Lertworawanich and Elefteriadou [Ref. 27] developed a capacity model for Type B weaves by using linear optimization and gap acceptance theory. The optimization tool enabled the estimation of the capacity of ramp weaves along with the overall capacity in the three lanes adjacent to the crown line by systematically choosing the values of various traffic demands with some constraints. In this model, weaving flow rates from the freeway and the ramp have different impacts on the capacities of weaving areas. In addition, the traffic flow rate from the lane adjacent to the crown line has more influence on capacity of the weaving area than traffic flow rate from other two lanes up to a certain value. They compared the results of the proposed capacity model with field data for a Type B weave observed in Toronto, Ontario, and capacity estimates from the 2000 HCM.

In order to model lane-changing activity, the gap acceptance theory of Drew, et al. [Ref. 28], was selected. The gap acceptance theory, also found in the Traffic Flow Theory Monograph [Ref. 29], is expressed as

$$Q_m = Q_p \int_0^{\infty} f(t) \cdot g(t)\, dt$$

where Q_m = maximum volume merging into target lane,

Q_p = volume in the target lane,

$f(t)$ = probability density function for gaps in the target lane, and

$g(t)$ = volume that can change lanes into a gap of duration t.

Lertworawanich and Elefteriadou [Ref. 29] extended the Type B weave capacity estimation methodology to a capacity model for Type A weaves. In the model, the capacity of a weaving area is determined by maximizing the traffic flow rates on two lanes adjacent to the crown line. The authors concluded that with a constant weaving flow ratio in the shoulder lane, the capacity of the weaving area increases with the increase of weaving flow ratio of the ramp lane. When it reaches a certain value, approximately around 0.3, the capacity starts to decrease. The reason is that at low weaving flow, weaving vehicles from the ramp will create additional gaps for merging from the shoulder lane after they have completed the lane-changing processes. As the number of weaving vehicles increase beyond a resulting weaving flow ratio of 0.3, they conflict with one another which reduces the capacity. For the same reason, similar trends are observed when the flow ratio of the ramp lane is constant.

The next chapter covers the data collection effort. Data was collected to calibrate the simulation model used in this work.

CHAPTER 4
DATA COLLECTION

The data collection for this project was conducted for the calibration of the simulation model. The goal was to create simulation models for the capacity and level of service of the weave across the general purpose lanes of the freeway from the entrance ramp to the entry point of the managed lane and vice versa. Collecting enough data to directly create these models was not feasible in this project.

Once the data needs were established, potential sites with operating managed lanes were selected. Sites in Houston and Dallas were investigated. Two sites in Dallas were selected because they offered a variety of weaving distances between the ramps and the managed lane entrance, surveillance cameras operated by TxDOT were available, and the sites were closer to the study team.

Site Description

Both sites in Dallas are along IH 635 (LBJ Freeway), where there are four general purpose lanes and one buffer-separated managed lane in each direction. This section of IH 635 is shown in figure 4.1, where IH 635 is east-west, IH 35E (Stemmons Freeway) is on the west side of the figure, and the Dallas North Tollway is on the east side. There are four access points to the managed lanes, two in each direction, shown on the photo as W1 and W2 for the westbound managed lane and E1 and E2 for the eastbound managed lane.

The distances from entrance and exit ramps to the managed lane access areas are shown in table 4.1. In this table the distance from the nearest entrance ramp to the access area and the distance from the access area to the nearest exit ramp are shown (L in figure 2.2). The length of the managed lane access area is also shown.

Site 1 is centered on the entry/exit point for the managed lane just west of Midway in the west bound lanes (access point W1 in figure 4.1). Site 2 is centered on the entry/exit point for the managed lane between the IH 35E interchange and Josey Lane in the east bound lanes (access point E1 in figure 4.1).

Figure 4.1. IH 635 and location of access points for the managed lanes.

Table 4.1. Spacing between managed lane access and entrance/exit ramps.

	Managed Lanes		
	Access Point	Spacing to Nearest Ramp, L, feet	Length of Access Area, feet
IH 635 Westbound	W1	1290 (entrance ramp) 3710 (exit ramp)	1160
	W2	2610 (entrance ramp) 1910 (exit ramp)	1350
IH 635 Eastbound	E1	1610 (entrance ramp) 2060 (exit ramp)	2910
	E2	6060 (entrance ramp) 2520 (exit ramp)	1410

Site 1 offers four entrance ramps upstream of the access point for the managed lane, and two downstream exit ramps. A schematic of site 1 is shown in figure 4.2. Distances from the entrance ramps to the beginning of the access to the managed lane are:

- Northbound Dallas North Tollway, 5850 feet,
- Southbound Dallas North Tollway, 4500 feet,
- Dallas Parkway, 3650 feet, and
- Midway, 0 feet.

Distances from the end of the access to the managed lane to the exit ramps downstream are:

- Marsh, 2400 feet, and
- Webb-Chapel, 4450 feet.

The entry/exit access for the managed lane is 1160 feet long. Note, too, that there is an auxiliary lane from the entrance from the southbound Dallas North Tollway and the exit to Midway.

Site 2 offers three upstream entrance ramps and two downstream exit ramps. The entry/exit access for the managed lane is about 3000 feet long. A schematic of site 2 is shown in figure 4.3. The upstream entrance ramps are:

- The ramp from southbound IH 35E joins IH 635 on the left and empties directly into the managed lane. The access to the managed lane begins just beyond this entrance ramp. Since the entrance ramp consists of mixed traffic, much of it must change lanes almost immediately to leave the managed lane.

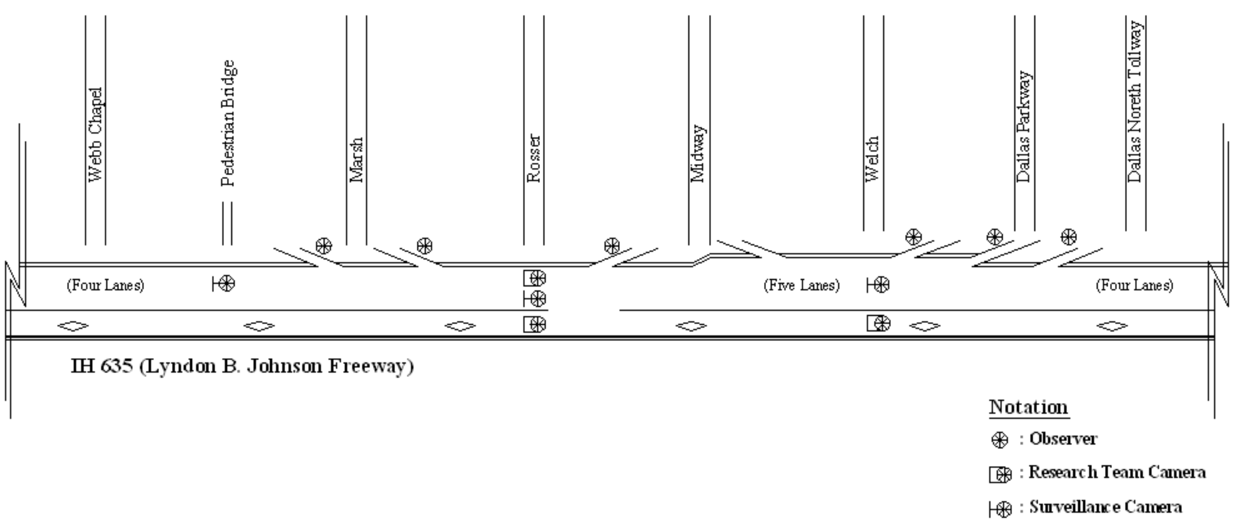


Figure 4.2. Layout of site 1 (managed lane access W1).

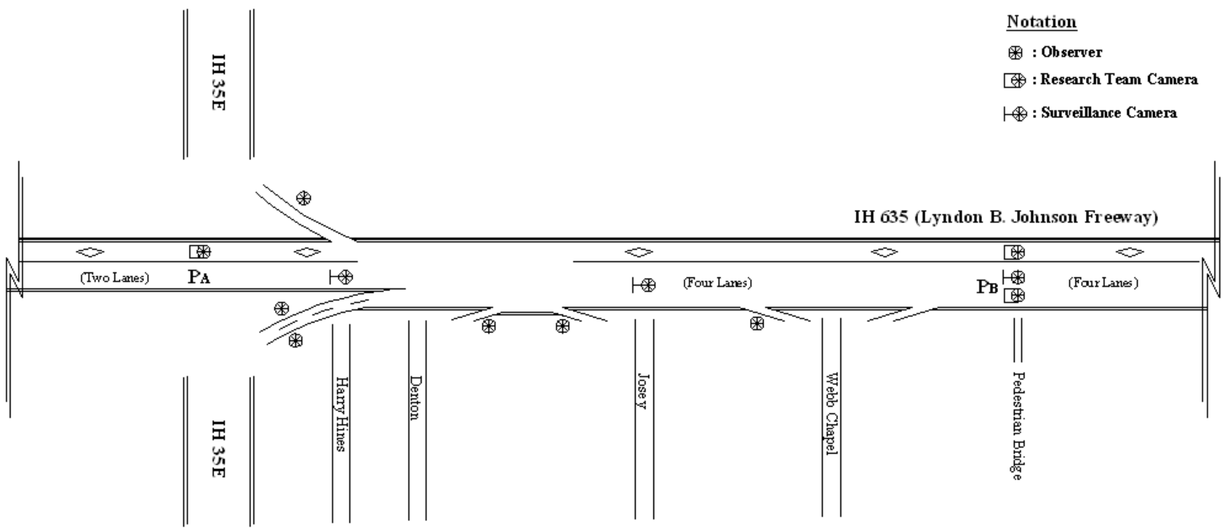


Figure 4.3. Layout of site 2 (managed lane access E1).

- The ramp from northbound IH 35E is a two-lane entrance ramp and joins the eastbound IH 635 general purpose lanes on the right shortly after the beginning of the access to the managed lane. Traffic entering from this ramp has about 2800 feet to weave across to the managed lane.
- The ramp from Denton Drive joins the eastbound IH 635 general purpose lanes about 1300 feet beyond the beginning of the access to the managed lane. Traffic entering from this ramp has about 1700 feet to weave across to the managed lane. Note, too, that an auxiliary lane is added between this ramp and the next exit ramp, that for Josey Lane.

The downstream exit ramps are:

- The ramp to Josey Lane is about 2100 feet downstream of the beginning of the access to the managed lane.
- The ramp to Webb-Chapel is about 1400 feet downstream of the end of the access to the managed lane.

Study Times

Four one-hour studies were performed, two at each site. One study was conducted in the late morning to collect data for moderate flow conditions, the other conducted in the mid-afternoon, prior to the evening peak, to collect heavy flow conditions. The data was reduced into ten-minute intervals, with each interval potentially providing an "observation" for use in the calibration and validation of the simulation model. The data was collected at the following times:

- Site 1
  - Friday, March 14, 2008, 10:20 to 11:20 am.
  - Friday, March 14, 2008, 3:25 to 4:25 pm.
- Site 2
  - Friday, March 21, 2008, 10:40 to 11:40 am.
  - Friday, March 21, 2008, 3:45 to 4:45 pm.

Field Data Summary

Data was collected for three general purposes. First, to provide input information to run the simulation model, the distribution of desired speeds and origin-destination flows were collected at both sites. Data used for calibration was collected at Site 1, and consisted of actual speeds and the distribution of lane changes. Travel times were collected at Site 2 for model validation. Once a simulation model is calibrated, it should be checked with independent data to make sure the calibration is effective.

Simulation Model Input Data

Distribution of Desired Speeds

Free flow speeds are found in light traffic, when drivers are not obstructed by vehicles in front of them. As such, they were used as desired speeds in the simulation model. Free flow speeds were collected on Sunday mornings, as that is generally the lightest traffic throughout the week during daylight hours. Free flow speeds on eastbound IH 635 were collected from the Webb Chapel overpass (in Site 2) on April 6, 2008. Free flow speeds on westbound IH 635 were collected from the Midway overpass (in Site 1) on May 11, 2008.

Radar was used to collect the speeds; the operator randomly targeted vehicles that were not directly following other vehicles. Speeds were collected separately for cars and trucks. Speeds from 227 cars and 75 trucks were recorded for eastbound IH 635, and from 257 cars and 78 trucks for westbound IH 635. The speed data is shown in Appendix A. The cumulative distribution of free flow speeds is shown in figure 4.4. Note that the speed limit in both directions is 60 mph.

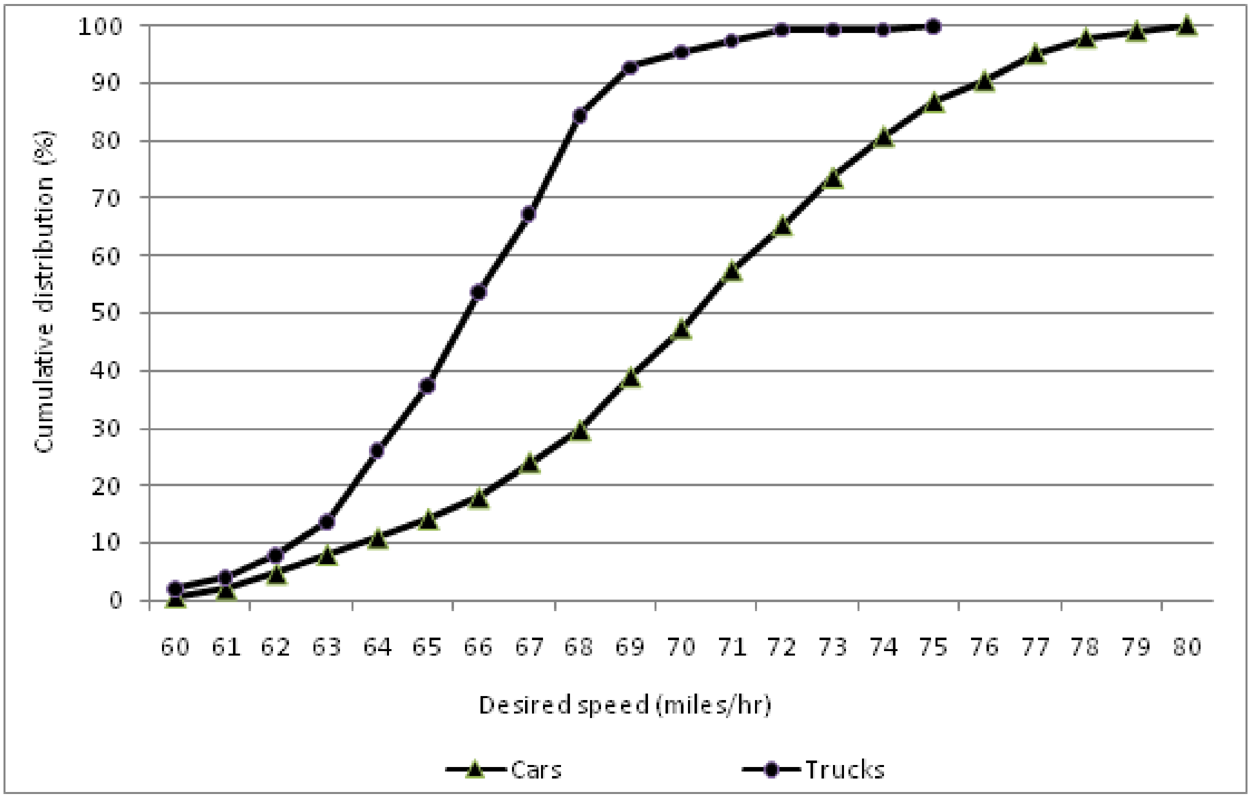


Figure 4.4. Cumulative distribution of speeds.

Origin-Destination Flows

The simulation model requires that flows be identified between each origin and destination. Synthetic origin-destination flows can be generated from counts at the entry and exit points. However, since we were specifically modelling the lane changing behavior of traffic as vehicles weaved between ramps and the managed lane, we collected origin-destination flows between each pair of entries and exits to both sites.

The origin-destination flows were collected for each site as follows.

- Observers were placed at each of the entrance and exit ramps and were equipped with a voice recorder and a stopwatch. During the designated study times, the observer read partial license plates (the portion after the space, generally three digits) into the voice recorder, noting times from the stopwatch at periodic intervals.
- Because there was no safe place to stand near the managed lane, two digital video cameras were used to record license plate numbers. One camera was placed upstream of the managed lane access point, the other placed downstream of the access point. In both

cases, the camera was facing downstream to capture the backs of vehicles as they passed the cameras. For Site 1, the cameras were placed on the Welch overpass (upstream of the access point) and the Rosser overpass (downstream). For Site 2, the upstream camera was in the median west of IH 35E, and the downstream camera was placed on the pedestrian overpass. Examples of the clarity of the video images are shown in figures 4.5 and 4.6.

Figure 4.5a. Westbound from Welch overpass.

Figure 4.5b. Westbound from Rosser overpass.

Figure 4.6a. Eastbound from west of IH 35E.

Figure 4.6b. Eastbound from pedestrian overpass.

- Flows on the general purpose lanes were recorded using DalTrans surveillance cameras placed along IH 635. The cameras at Welch, Rosser, and the pedestrian overpass were used for Site 1, and the cameras at Harry Hines, Josey, and the pedestrian overpass were used for Site 2. In each case, the field of view of each of the cameras was selected to capture the flow on the general purpose lanes and as many ramps as possible. The video feeds were recorded at the satellite center at US 75 and Churchill Way.

- The license plate data was then matched. Plates with no origin were assumed to have entered the site in the general purpose lanes, and those with no destination were assumed to have left the site in the general purpose lanes. One hour summaries of the origin-destination flows are shown in tables 4.2 through 4.5 for the morning and afternoon counts at Sites 1 and 2. Ten minute origin-destination flows are shown in Appendix B.

Table 4.2. Origin-destination volume matrix during late morning at site 1 (7.5% trucks).

		Destination / volume at destination				
Origin	volume at origin	Midway 776	Marsh 465	Webb Chapel 566	GPL down 6251	ML down 439
GPL up	5404	707	356	452	3805	84
ML up	371	–	4	4	57	306
DNT NB	236	41	25	5	159	6
DNT SB	811	28	16	41	707	19
Dallas Parkway	834	0	35	41	742	16
Midway	841	–	29	23	781	8

Note to table 4.2: GPL: general purpose lanes; ML: managed lane; up/down: upstream/downstream end within study section; all volumes in vehs/60 minutes.

Table 4.3. Origin-destination volume matrix during early afternoon at site 1 (5.0% trucks).

		Destination / volume at destination				
Origin	volume at origin	Midway 1169	Marsh 517	Webb Chapel 979	GPL down 6056*	ML down 1336
GPL up	5500	1014	353	718	3345	70
ML up	1242	–	32	64	92	1054
DNT NB	355	55	19	20	246	15
DNT SB	856	100	36	49	596	75
Dallas Parkway	1106	0	39	66	931	70
Midway	998	–	38	62	846	52

* Derived volume, count was 5556 vehicles, also see note to table 4.2.

Table 4.4. Origin-destination volume matrix during late morning at site 2 (6.5% trucks).

Origin	volume at origin	Josey	Webb Chappel	GPL down	ML (down)
		473	338	6881	718
GPL up	2936	319	218	2185	214
ML up	321	2	1	40	278
NB IH 35E	2351	100	77	2106	68
SB IH 35E	1360	38	25	1150	147
Denton	547	14	17	505	11
Webb Chapel	895	–	–	895	–

Destination / volume at destination

See note to table 4.2.

Table 4.5. Origin-destination volume matrix during early afternoon at site 2 (3.0% trucks).

Origin	volume at origin	Josey	Webb Chappel	GPL down	ML (down)
		954	598	5686	1324
GPL up	2759	440	333	1735	251
ML up	857	50	32	168	607
NB IH 35E	2738	327	166	2023	222
SB IH 35E	802	64	37	522	179
Denton	612	73	30	444	65
Webb Chapel	794	–	–	794	–

Destination / volume at destination

See note to table 4.2.

Distribution of Lane Changes

This data, collected at Site 1, was used in the calibration of the simulation model. This data consisted of the longitudinal location of lane changes for westbound vehicles entering the general purpose lanes from the Midway entrance ramp and weaving across to the managed lane. A sketch of this area is shown in figure 4.7. This section of freeway is in the middle of Site 1.

The opening into the managed lane is divided into 100-foot zones. Since the access to the managed lane is 1160 feet long, part of the 12th zone and the 13th zone are beyond the end of the managed lane access. However, these zones were used because a considerable number of vehicles made lane changes into and out of the managed lane at this point.

A digital video camera was placed on the Rosser overpass, and could capture this entire segment of freeway in a single field of view. The data was reduced from the video. A sample video image is shown in figure 4.8.

The number of vehicles entering the managed lane in each zone for the morning period in figure 4.9, and for the afternoon in figure 4.10. Separate curves are shown for vehicles entering from the general purpose lanes upstream of the Midway entrance ramp and those entering from the Midway entrance (and weaving across all four general purpose lanes). At four locations (between zones 3 and 4, zones 7 and 8, zones 10 and 11, and at the end of zone 13), the cumulative number of vehicles entering the managed lane are shown. First, the number entering from the general purpose lanes, then the number entering from the Midway entrance ramp, and finally the total number.

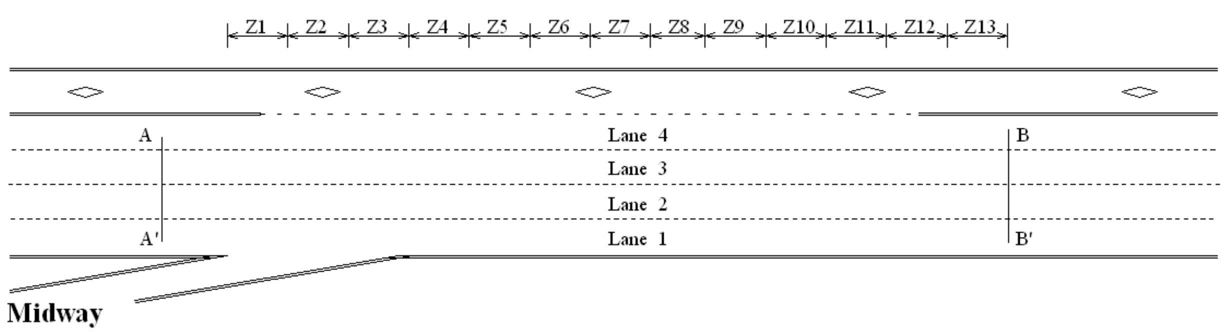


Figure 4.7. Weaving area in Site 1 at the access to the managed lane.

Figure 4.8. Video image of weaving area.

The number of vehicles which entered the managed lane from the general purpose lanes in the morning and afternoon counts are shown in table 4.6 by which lane they entered the study section (i.e., crossed line AA' in figure 4.7). This table also shows in which general purpose lane vehicles which left the managed lane then left the study section (i.e., crossed line BB' in figure 4.7). In this table, lane 1 is the right lane, and lane 4 is the left lane, adjacent to the managed lane.

Table 4.6. Number of vehicles entering or leaving the managed lane by general purpose lane.

		Lane 1	Lane 2	Lane 3	Lane 4
Late morning data	Number of incoming HOVs	1	2	17	104
	Number of outgoing HOVs	1	2	15	47
Early afternoon data	Number of incoming HOVs	2	5	24	199
	Number of outgoing HOVs	13	18	56	101

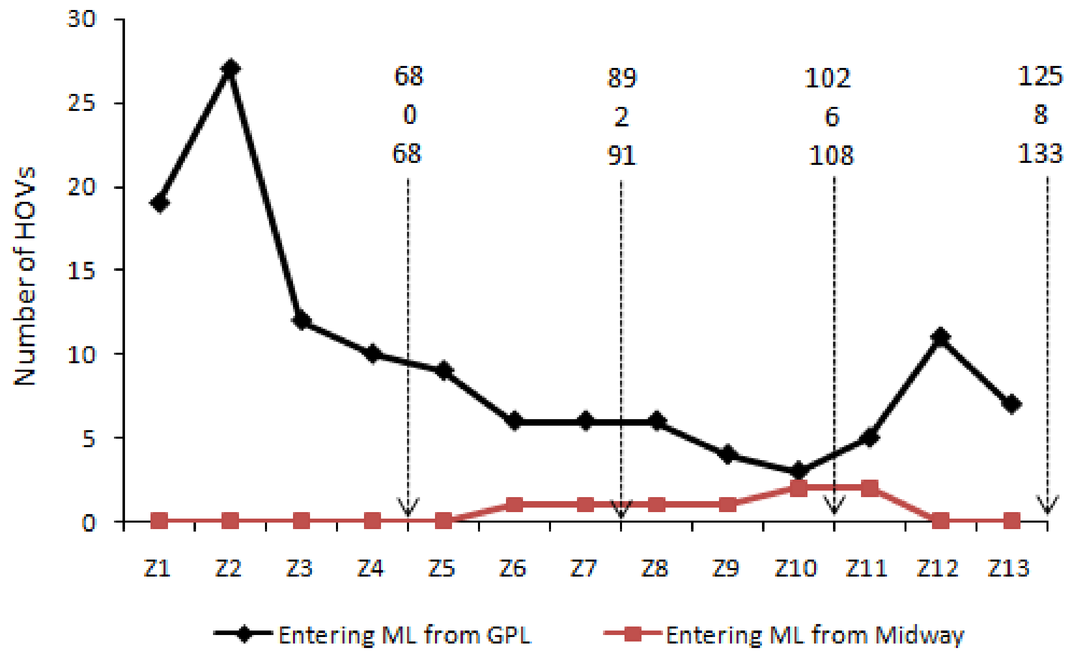


Figure 4.9. Location of lane changes during late morning period.

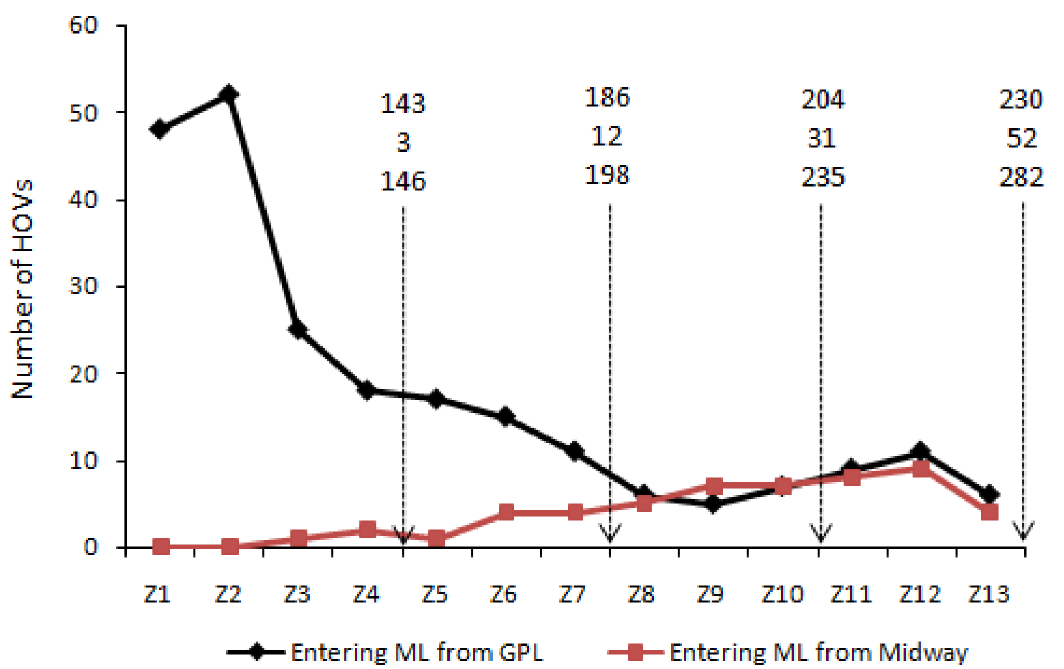


Figure 4.10. Location of lane changes during early afternoon period.

Distribution of Lane-Based Speeds

Speed data (also to be used in the calibration of the simulation model) was collected from the same video recording as the distribution of lane changes. In this case, randomly selected vehicles in each lane were timed as they travelled the length of the managed lane opening, which, as stated above, was 1160 feet. Each selected vehicle's speed was then calculated by dividing the section length by the travel time. Average speeds from the morning and afternoon studies are shown in tables 4.7 and 4.8, respectively.

Table 4.7. Lane-based speeds on the general purpose lanes during the late morning counts.

	Speed, miles/hour			
Time	Lane 1	Lane 2	Lane 3	Lane 4
10:20 - 10:30 am	55.7	63.3	61.3	65.4
10:30 - 10:40 am	58.6	61.8	63.8	66.5
10:40 - 10:50 am	58.6	61.3	63.8	66.5
10:50 - 11:00 am	58.6	62.3	64.8	67.6
11:00 - 11:10 am	56.9	65.4	64.3	65.9
11:10 - 11.20 am	54.2	62.3	62.8	63.8
10:20 - 11:20 am	57.0	62.7	63.4	65.9

Table 4.8. Lane-based speeds on the general purpose lanes during the early afternoon counts.

	Speed, miles/hour			
Time	Lane 1	Lane 2	Lane 3	Lane 4
3:25 - 3:35 pm	25.4	29.1	32.0	36.0
3:35 - 3:45 pm	27.6	31.5	35.3	40.4
3:45 - 3:55 pm	22.5	27.8	30.3	30.7
3:55 - 4:05 pm	20.8	24.3	26.7	30.1
4:05 - 4:15 pm	17.3	22.0	26.3	27.1
4:15 - 4:25 pm	21.7	26.5	24.9	29.1
3:25 - 4:25 pm	22.1	26.5	28.8	31.6

Travel Times

Travel time data was collected from Site 2 for validation of the calibrated simulation model. The data collected with the digital video cameras for the origin-destination flows was used for estimating travel times. The upstream camera was located in the median immediately west of IH 35E (P_A in figure 4.3) and the downstream camera was located on the pedestrian overpass (P_B in figure 4.3), yielding a distance of 11,800 feet between the camera locations. Vehicles were matched in the two video images, and the relative times between cameras was noted. The average travel times are shown in table 4.9 for the morning study, and in table 4.10 for the afternoon study. Example images indicating matched vehicles from the two cameras are shown in figure 4.11.

Table 4.9. Travel times during late morning counts.

Time	Travel time, secs
10:20 - 10:30 am	118.5
10:30 - 10:40 am	125.0
10:40 - 10:50 am	128.1
10:50 - 11:00 am	125.6
11:00 - 11:10 am	124.1
11:10 - 11.20 am	118.9
10:20 - 11:20 am	123.4

Table 4.10. Travel times during early afternoon counts.

Time	Travel time, secs
3:25 - 3:35 pm	417.8
3:35 - 3:45 pm	439.4
3:45 - 3:55 pm	443.0
3:55 - 4:05 pm	441.1
4:05 - 4:15 pm	342.7
4:15 - 4:25 pm	270.0
3:25 - 4:25 pm	392.3

Figure 4.11a. Upstream image on the general purpose lanes (at P_A).

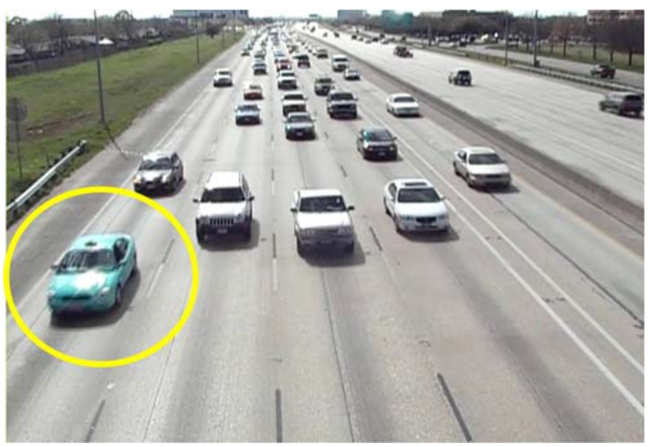


Figure 4.11b. Downstream image on the general purpose lanes (at P_B).

CHAPTER 5
SIMULATION MODEL AND ITS CALIBRATION

Traffic simulation models describe the interaction between driver behavior, vehicle capability, and the performance of the transportation system. The principal advantage of using simulation models is in the analysis of complex transportation systems which are difficult to impossible to examine analytically.

VISSIM 4.3 was used in this project to simulate freeway operation as entering vehicles weaved across the general purpose lanes to enter the managed lane and as vehicles left the managed lane and weaved across to leave the freeway. VISSIM is a microscopic, stochastic, and time step-based traffic simulation model which uses car following and lane change routines. It is capable of assessing traffic and transit operations for a wide variety of traffic conditions. Much of the material in this chapter is from the VISSIM User Manual [Ref. 31].

The car-following rules are broken into four driving modes:

- Free – no influence from other vehicles, the simulated drivers travel at their desired speeds, or are accelerating or decelerating to their desired speeds.
- Approaching – simulated driver is approaching a slower moving vehicle in the same lane, the vehicle decelerates until the speed difference between the subject vehicle and the lead vehicle is zero when the following vehicle reaches its desired safety distance.
- Following – the following vehicle tries to maintain its desired safety distance behind the lead vehicle, keeping the speed differences between the two vehicles near zero; the following vehicle must respond to changes in speed of the lead vehicle.
- Braking – the application of medium to heavy braking which will occur if the following distance drops below the desired safety distance (if the lead vehicle decelerates abruptly or if a car changes into the subject lane in front of the following vehicle).

There are two types of lane change in VISSIM. One is the required lane change, where a lane change must be performed to be in a proper lane for a downstream maneuver. The second type is the free lane change, where the simulated driver changes into a more opportune lane, i.e., one that is less crowded and/or faster.

VISSIM Inputs

Coding of Network Geometry

Aerial photographs, accessed through Google Earth, were used to establish network geometry, which included locations of entrance and exit ramps and horizontal alignment. Lane configurations and access to the managed lane were confirmed in the field.

Vehicle Types and Traffic Mix

The two vehicle types used in this work were car and truck. Each vehicle type is characterized by minimum and maximum acceleration, minimum and maximum deceleration, weight, power, width, occupancy, and width. User-defined ranges of each of these parameters can be specified. Other "vehicle" types available in VISSIM include bus, tram, pedestrian, and bicycle. The traffic mix is defined as the fraction of each vehicle type in the traffic stream.

Vehicle Inputs and Routing

Traffic volumes and mixes are specified in terms of specific routes, which connect each origin-destination pair. Thus, turning movements are not explicitly defined, but derived from the specified routes.

Model Calibration

Calibration is the process by which user-defined parameters are specified in such a way that the model reflects the traffic conditions observed in the field. Each parameter has a default value that represents broadly "typical" conditions. The specific parameters selected for calibration are described in detail below, followed by a description of the calibration process itself.

Parameters Used in Calibration

Lane-Changing Parameters

- Lane Change – the point where the vehicle starts to attempt to change lanes. This is the earliest that a vehicle will start to search for an opportunity to change lanes for a required lane change, measured in feet from the point at which the lane change must be completed.

- Maximum Deceleration for Own Vehicle – the maximum acceptable deceleration for the vehicle changing lanes. The higher this number (in absolute terms), the greater the aggressiveness of the lane change.
- Maximum Deceleration for Trailing Vehicle – the maximum acceptable deceleration for the vehicle that will be behind the vehicle that is changing lanes, once the lane change is complete. A higher number (in absolute terms) indicates greater aggressiveness.
- Waiting time before diffusion – If a vehicle is unable to make a lane change, it will stop at the last possible position to make the lane change. Once it has stopped there for the waiting time before diffusion, the vehicle is removed from the simulation. In reality, vehicles unable to make their lane change either continue downstream or force their way into the target lane, and, at any rate, are seldom stopped for long. Thus, the specified waiting time should be fairly short, and the number of diffused vehicles should be small. If vehicles are being diffused, that is an indication that either the system is operating at some sort of capacity or that the maximum decelerations need to be made larger for more aggressive lane changes.
- Safety Distance Reduction Factor – allows shorter distances in front of and behind the vehicle that has just changed lanes, i.e., the smaller this number, the smaller the gap needs to be between vehicles in the target lane. This reduction factor is multiplied by the original safety distance to find the resulting acceptable safety distances in the target lane, thus a reduction factor of 0.6 reduces the safety distance by 40%. Once the vehicle has completed its lane change, the original safety distance is again used in maintaining headways.

Car-Following Parameters

- Standstill Distance (CC0) – the desired distance between stopped vehicles; no distribution is applied to this number.
- Headway Time (CC1) – the desired time (in seconds) per unit speed that a following driver wishes to maintain behind the lead vehicle. The desired safety distance in feet is

$$\textit{desired safety distance} = CC0 + CC1 \bullet v$$

where *v* is the speed in feet/second. This results in the desired safety distance maintained during the "following" mode. The higher the value of CC1, the more cautious the following driver.

- Following Variation (CC2) – the distance beyond the desired safety distance which will cause the following vehicle to intentionally move closer to the lead vehicle. The actual following distance will vary if the two vehicles do not have exactly the same speed; VISSIM introduces a slight oscillation in the speed of the following vehicle to replicate driver behavior. This will result in a varying distance between vehicles. If the distance between the lead vehicle and the following vehicle is *desired safety distance + CC2*, the following vehicle will accelerate to re-establish the desired safety distance.
- Threshold for Entering "Following" Mode (CC3) – the distance behind the lead vehicle at which the following vehicle begins to decelerate in order to go into the "following" mode. This parameter is used when a vehicle is approaching a slower-moving vehicle; the faster vehicle will begin to decelerate CC3 feet behind the soon-to-be lead vehicle.
- "Following" Thresholds (CC4 and CC5) – these parameters control the speed differences between the lead and following vehicles. Smaller (absolute) values represent a quicker response by the following vehicle to speed changes of the lead vehicle. CC4 is used for negative speed differences, while CC5 is used for positive speed differences. The absolute values of these parameters are typically equal, implying the same response for negative and positive speed differences.

The parameters selected for use in calibration are listed in table 5.1, along with their acceptable ranges and default values. In two cases, the default value lies outside the range of acceptable values. Research has shown that the default values are unrealistic, and the ranges shown are those recommended [Ref. 37].

Use of Genetic Algorithm in Calibration

Because there are many different levels of the eleven parameters selected for calibration, examination of all possible combinations of parameter values was unrealistic. A genetic algorithm is a global search technique which was inspired by evolutionary biology, and was selected for the

Table 5.1. Selected calibration parameters and ranges.

Parameter	Description	Default	Range Minimum	Range Maximum
p_1	Lane change	656 feet	1500	5000
p_2	Max. deceleration for own vehicle	-13.1 ft/sec^2	-20	-11
p_3	Max. deceleration for trailing vehicle	-9.8 ft/sec^2	-17	-8
p_4	Waiting time before diffusion	60 secs	2	30
p_5	Safety distance reduction factor	0.6	0.0	0.8
p_6	CC0 (Standstill distance)	4.9 feet	4	10
p_7	CC1 (Headway time)	0.90 sec	0.7	1.2
p_8	CC2 (Following variation)	13.1 feet	10	35
p_9	CC3 (Threshold for entering "following" mode)	-8.00	-15	-5
p_{10}	CC4 (Negative "following" threshold)	-0.35	-2.4	-0.2
p_{11}	CC5 (Positive 'following" threshold)	0.35	0.2	2.4

calibration of the simulation model. Genetic algorithms have been used for the calibration of microscopic simulation by a number of authors [Refs. 32-36].

Initial candidate solutions were created where the values of each of the calibration parameters were selected randomly. Simulation runs were made using the parameter settings of each of the candidate solutions, and the resulting solutions were compared with the field data, and the candidate solutions were ranked by how close each came to the field data. (The fitness test is described in the next section.)

Better ranked candidate solutions (combinations of parameter values) are used to "breed" the next "generation" of candidate solutions. These are then evaluated with the fitness function, and the higher-ranked candidate solutions in the new generation replace the lower-ranked candidate solutions from the earlier generation(s). This new population then is "bred" for the next "generation" of candidate solutions. This process is continued for a pre-specified number of generations or until at least one of the candidate solutions produces simulation results "close enough" to the field data.

Each of the eleven selected parameters (in table 5.1) are continuous, but were broken into discrete values for the application of the genetic algorithm. For example, the lane change parameter (p_1) has a range of 1500 to 5000 feet. Discrete values every 250 feet were selected (1500, 1750, 2000, and so forth to 5000) resulting in 15 values of this parameter. Discrete values were similarly selected for the other ten parameters. Candidate solutions (i.e., specific values for each parameter) were randomly selected and simulated. The fitness test then compared the simulation results with the field data, and the results of the fitness test were used to score each candidate solution.

The better candidate solutions were then used to generate new candidate solutions. Each offspring candidate solution shared a parameter value from one of its parents. Which parent provided each parameter value was determined randomly, thus some of the offspring's parameter values came from one parent, the remaining parameter values came from the other.

Fitness Test

Fitness tests used by genetic algorithms generally take a set of simulation results and compare them to corresponding field data. Once more than one result is used, some means to combine the comparisons of all the results must be used. The three most widely used functions are

- RMSE – root mean square error,
- MAER – mean absolute error ration, and
- MAPE – mean absolute percentage error.

Outliers have a large impact on RMSE and MAER calculates the average ratio of absolute errors to observations. MAPE is the average of the percentage errors for the selected results. The use of a single result would likely identify a number of candidate solutions. As such, several results were selected to rate each candidate solution. The results selected for the calibration were

1. The cumulative number of vehicles entering the managed lane from the general purpose lanes from the Midway ramp at Z4, Z7, Z10, and Z13 (see figure 4.7 for the zone locations within the entry area for the managed lane).
2. The number of vehicles entering the study section in lanes 1, 2, 3, and 4 of the general purpose lanes that change lanes to enter the managed lane.

3. The number of vehicles leaving the study section in lanes 1, 2, 3, and 4 of the general purpose lanes that entered the study section in the managed lane.
4. Speed in lanes 1, 2, 3, and 4 of the general purpose lanes.

The MAPE was selected as the fitness test. The function used to combine the evaluation of each of the results for each candidate solution was

$$MAPE(P_i^j) = \frac{1}{n}\sum_{k=1}^{n}\left|\frac{S_k(P_i^j) - O_k}{O_k}\right| \bullet 100$$

where $S_k\left(P_i^j\right)$ = simulated value of result *k* of parameter set (candidate solution) *i* in generation *j*,

O_k = observed value of result *k*.

Calibration Process

Separate calibrations were performed on the moderate flow and the heavy flow data sets. As reported in the previous chapter, the moderate flow data was collected during the late morning and the heavy flow data was collected in the mid-afternoon. Separate calibrations were performed because the heavy flow data represented LOS F flow, while the moderate flow data represented flow where the demand was less than capacity.

In the calibration process, ten replications were made of each candidate solution, and twenty generations were used. The average fitness for all candidate solutions in each generation, as well as the best fitness (i.e., candidate solution with the best fitness) for each generation, are shown in figures 5.1 and 5.2 for the moderate flow and heavy flow data, respectively. The eleven parameter values for each candidate solution in each generation are shown in Appendix C.

In general, with each succeeding generation, the fitness values decreased. A value of zero would imply a perfect match between the simulation and the field data. Adding generations would likely improve the simulation results, but, as can be seen in the figures, the additional improvement will likely be small.

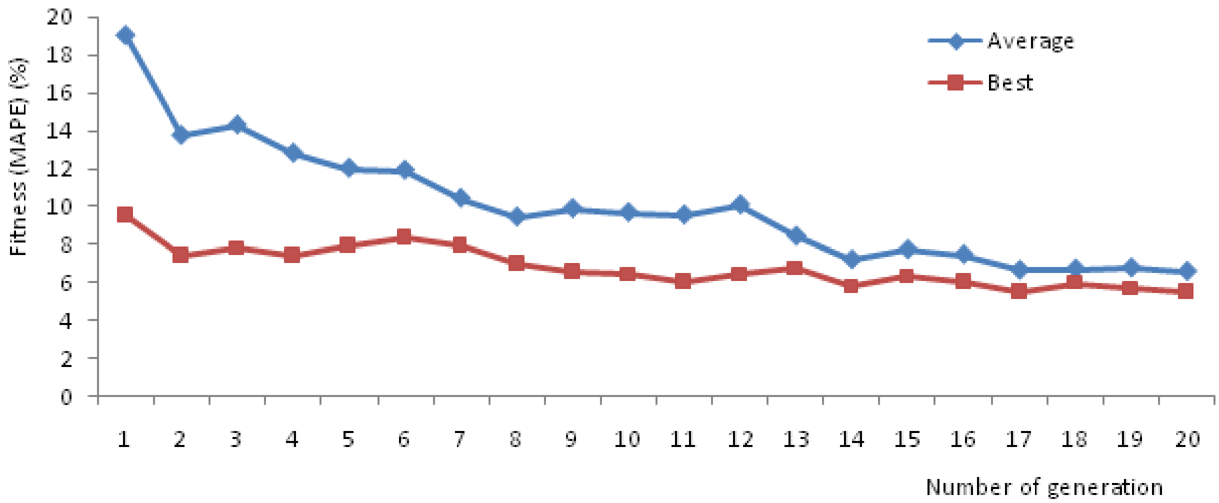


Figure 5.1. Model fitness by generation for moderate flow (late morning).

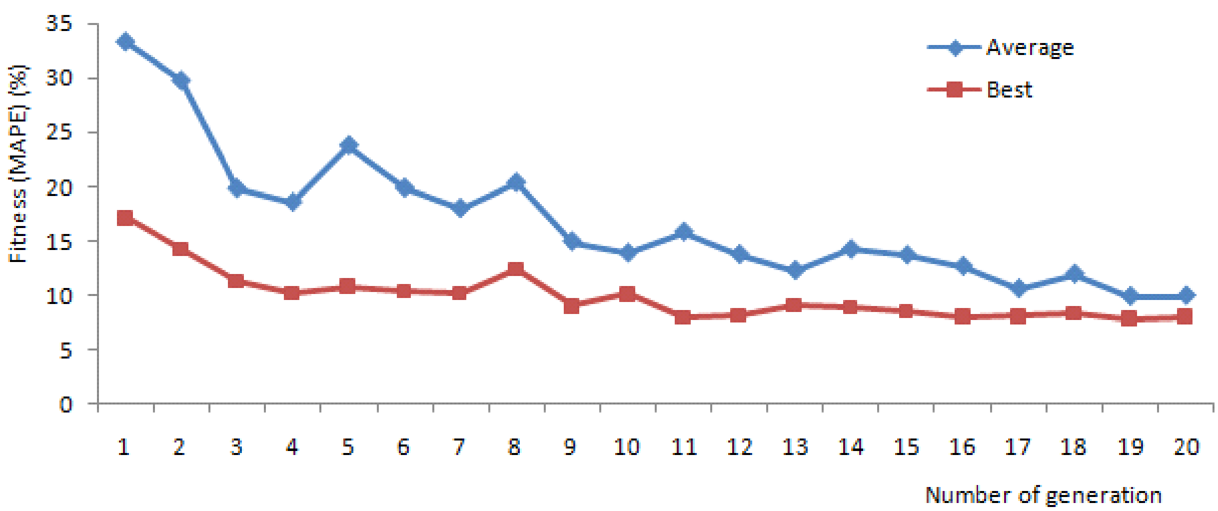


Figure 5.2. Model fitness by generation for heavy flow (early afternoon).

Calibration at Ramp Junctions

Special care was needed to model traffic flow where the entrance ramp met the general purpose lanes. In order to capture the flows found in the field data, the merging process was made more "aggressive." VISSIM appears to model entrance ramps as the parallel type, while most modern entrance ramps are tapered. However, the acceleration lane can be measured from the tip of the gore to the point where the right edge line of the ramp merges with the right edge line of the right through lane in the general purpose lanes.

As drivers approach the end of an entrance ramp, their "lane change" into the right general purpose lane is required. While there is a shoulder to accommodate vehicles that absolutely can not get into the right lane, it is seldom used for this purpose. Especially in the heavy flow conditions, the entering traffic behaved somewhat more aggressively, while some of the right lane traffic would effectively yield and allow an entering vehicle to merge in front.

The maximum deceleration for own vehicle (p_2) and maximum deceleration for following vehicle (p_3) were adjusted to allow the vehicle in the right general purpose lane (the following vehicle) to allow the merging vehicle to enter. The safety distance reduction factor (p_5) was reduced to zero to allow the merging vehicles to accept very small gaps in the right general purpose lane. Finally, the threshold for entering "following" mode (p_9, or CC3) was increased to allow the following vehicle (the one which allowed the merging vehicle to come into the right general purpose lane) to decelerate if needed to match the speed of the merging vehicle.

Best Model

Based on the results of the fitness test for the selected results at Site 1, the best candidate solutions were obtained at the 20th and 19th generation for the moderate and heavy flow data, respectively. The values for each of the eleven parameters for the best solutions are shown in tables 5.2a (for the moderate flow data) and 5.3a (for the heavy flow data). Note the parameters which apply only to the ramp junction area.

A comparison of the calibrated and field data for the 16 values used in the MAPE calculation are shown in table 5.2b (for the moderate flow data) and 5.3b (for the heavy flow data). The locations of these 16 values can be seen in figure 4.7. The values can be assembled into four groups, which are (1) four selected locations for vehicle changing lanes from lane 4 of the general

Table 5.2a. Calibrated parameter values for late morning (moderate flow) traffic.

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	656	-13.1	-9.8	60	0.60	4.9	0.90	13.1	-8.0	-0.35	0.35
Best Model	2750	-16.0 (-20)	-13.0 (-17)	12 (30)	0.40 (0.0)	6.0	0.95	16.0 (30)	-7.0	-0.60	0.60

Note: Values in parentheses are the calibrated parameter values for the ramp junction area only.

Table 5.2b. Field and calibrated data for late morning (moderate flow) traffic.

	Entering ML				No. of HOVs entering section			
Measurements	Z4	Z7	Z10	Z13	L1	L2	L3	L4
Field Data	68	91	108	133	1	2	17	104
Calibrated Data	73	90	120	132	1	6	13	106

	No. of HOVs leaving section				Average Speed				
Measurements	L1	L2	L3	L4	L2	L3	L4	L4	MAPE
Field Data	1	2	15	47	57.0	62.7	63.4	65.9	0.0
Calibrated Data	0	2	11	54	58.4	62.1	63.7	64.0	5.5

Table 5.3a. Calibrated parameter values for early afternoon (heavy flow) traffic.

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	656	-13.1	-9.8	60	0.60	4.9	0.90	13.1	-8.0	-0.35	0.35
Best Model	3000	-17.0 (-20)	-14.0 (-17)	6 (30)	0.50 (0.0)	6.0	0.75	24.0 (35)	-7.0	-1.60	1.60

Note: Values in parentheses are the calibrated parameter values for the ramp junction area only.

Table 5.3b. Field and calibrated data for early afternoon (heavy flow) traffic.

	Entering ML				No. of HOVs entering section			
Measurements	Z4	Z7	Z10	Z13	L1	L2	L3	L4
Field Data	146	198	235	282	2	5	24	199
Calibrated Data	142	193	243	274	0	3	14	210

	No. of HOVs leaving section				Average Speed				
Measurements	L1	L2	L3	L4	L2	L3	L4	L4	MAPE
Field Data	13	18	56	101	22.1	26.5	28.8	31.6	0.0
Calibrated Data	7	20	43	121	19.8	24.8	28.5	31.0	7.8

purpose lanes into the managed lane, (2) the number of vehicles that changed lanes into the managed lane by which lane they entered the study section (line AA' in figure 4.7), (3) the number of vehicles that changed lanes out of the managed lane by which lane they left the study section (line BB' in figure 4.7), and (4) average speeds in each of the general purpose lanes in the study section (between AA' and BB' in figure 4.7).

The MAPE fitness index indicates that the simulation for the moderate flow was 5.5% from the data and 7.8% from the heavy flow data.

Validation

These models were validated with travel times from Site 2. Using the appropriate candidate solutions (sets of parameters), travel times were found along the general purpose lanes through the site (from P_A to P_B, see figure 4.2). Average simulated values were found with twenty replications each for moderate and heavy flow. The results are shown in tables 5.4 and 5.5, where the MAPE fitness test was modified to consider just one parameter, the travel time. As shown in the tables, the results were quite close and the models were considered to be validated.

Table 5.4. Field and validated data for late morning (moderate flow) traffic.

	Travel Time, secs	MAPE
Field Data	123.4	0.0
Calibrated Model	123.6	0.2

Table 5.5. Field and validated data for early afternoon (heavy flow) traffic.

	Travel Time, secs	MAPE
Field Data	392.3	0.0
Calibrated Model	402.0	2.5

Key Findings

Comparing the calibrated and validated simulation models for moderate and heavy flow conditions, several observations can be made.

- Under heavy flow conditions, vehicles tend to change lanes in advance as specified by the lane change parameter (p_1).
- Driver aggressiveness, as specified by the maximum deceleration for own vehicle (p_2), maximum deceleration for following vehicle (p_3), and the safety distance reduction factor (p_5), showed no significant difference between moderate and heavy flow conditions.
- A larger value of the following variation parameter (p_8 or CC2) will create the potential for larger gaps between vehicles in the same lane, allowing vehicles in adjacent lanes a greater opportunity to make lane changes. The calibrated value of this parameter was quite a bit higher for heavy flow (24) than it was for moderate flow (16). This was needed to reflect the number of lane changes observed in the field data when the greater flow in the general purpose lanes would otherwise result in fewer acceptable gaps, thus reflecting the greater aggressiveness of the vehicles making lane changes during heavy flow. The values of this parameter were even higher in the immediate area of the ramp junction (30 and 35 for the moderate and heavy flow data, respectively) as explained in the section on calibration at ramp junctions, above.
- Under heavy flow conditions, the safety distance, as described by the standstill distance (p_6 or CC0) and headway time (p_7 or CC1) parameters, is less sensitive to a given speed, although, under heavy flow conditions, there is a smaller overall range of speeds.
- Lastly, no difference in the "following" thresholds (p_{10} and p_{11}, or CC4 and CC5) were found between the moderate and heavy flow conditions, implying that drivers' car-following behavior is relatively constant between these two flow conditions.

CHAPTER 6
CAPACITY ESTIMATES OF SELECTED MANAGED LANE ACCESS SCENARIOS

Capacity estimates for a variety of scenarios for accessing the managed lane are provided in this chapter. Each scenario is described, and a capacity estimate provided for a range of critical variables within the weaving area created by the access to the managed lane (on the left) and the adjacent upstream entrance ramp to the general purpose lanes or adjacent downstream exit ramp.

As indicated earlier, the weaving area created by the entrance or exit ramp on the right of the general purpose lanes and the access point for the managed lane on the left side of the general purpose lanes is considered a two-sided Type C weave in the 2000 Highway Capacity Manual [Ref. 5]. However, the analysis procedure for Type C weaves is calibrated for a standard weave (see figure 3.3a) rather than the two-sided weave (see figure 3.3b). As such, the HCM can provide only the roughest of approximations when applied to a two-sided weave. The principal focus of this research was to estimate the capacity of these weaves, as relevant to managed lane access.

As demand on a facility increases, the flow increases, until the demand reaches capacity, or maximum flow. Beyond that point, the flow on the facility breaks down, resulting in lower flow and the formation of queues within the traffic stream [e.g., Refs. 38 and 39]. Thus, as demand is increased, capacity is found immediately prior to the formation of queues. Two flow regimes can be identified, stable flow, where demand is less than or equal to capacity, and unstable flow, where demand is greater than capacity.

As reported in the preceding chapter, VISSIM was calibrated for both regimes. The calibration based on the late morning counts (moderate flow) was in the stable flow regime, while the calibration based on the early afternoon counts (heavy flow) was in the unstable flow regime. This is most easily seen in the average speeds for the general purpose lanes. The general procedure in estimating capacity was to gradually increase flow in the general purpose lanes for a given set of conditions (length of weave, ramp flow, number of vehicles entering the managed lane, etc.) until the throughput flows in the simulation model became less than the input flows, indicating the formation of queues. The input flows that resulted in the highest throughput flows were considered to represent capacity. Thus, the VISSIM calibration for stable flow was used in the capacity estimation.

Both sites along IH 635 have four general purpose lanes in each direction. All results in the chapter reflect this geometry. A series of simulation runs were made for three and five general purpose lanes, and their results are shown in appendix D. These results should be read with caution, as VISSIM was not specifically calibrated for these conditions.

In general, no trucks were simulated, i.e., most runs were at 0% trucks. Some runs at 5% trucks were made in scenario 1 to provide a basis for estimating the heavy vehicle factor.

At each level of the flow in the general purpose lanes, five replications were run, due to the stochastic nature of VISSIM. Capacity was considered to have been reached if queue formation was found in three of the five replications.

Five scenarios were used in the capacity estimation. Each involved one or two ramps to the general purpose lanes on the right and access to the managed lane on the left. Figures accompany each discussion.

1. Entrance ramp followed by the managed lane access.
2. Managed lane access followed by an exit ramp.
3. Scenario 1 with a different process to approach capacity in the simulation.
4. Scenario 1 with an intervening exit ramp.
5. Scenario 2 with an intervening entrance ramp.

Each of the scenarios is discussed below, along with the simulation results for each.

Scenario 1

This scenario consists of a right-side entrance ramp followed by the left-side access to the managed lane. The lane configuration and variable definition is provided in figure 6.1. Note that the access to the managed lane is shown as a left-side exit ramp, and is placed at the end of the access area to the managed lane. In reality, this is a Type A ramp weave (see figure 3.1a), which can be modelled separately. However, this was done by Fitzpatrick, et al. [Ref. xxx], and flows on the managed lane are typically small enough to not impact the capacity of the Type C weave across the general purpose lanes.

For given values of the weaving distance (L), the ramp flow (v_r), the ramp to managed lane flow (v_{rm}), and freeway to managed lane flow (v_{fm}), the flow in the general purpose lanes was gradually increased to find the capacity. The specific values for each variable were:

- Weaving distance (L) – 1000 to 4000 feet in 500-foot increments

- Ramp flow (v_r) – 500 to 1250 veh/hour in 250 veh/hour increments
- Ramp to managed lane flow (v_{rm}) – 100 to 400 veh/hour in 100 veh/hour increments
- General purpose lanes to managed lane flow (v_{fm}) – 200 to 800 veh/hour in increments of 200 veh/hour

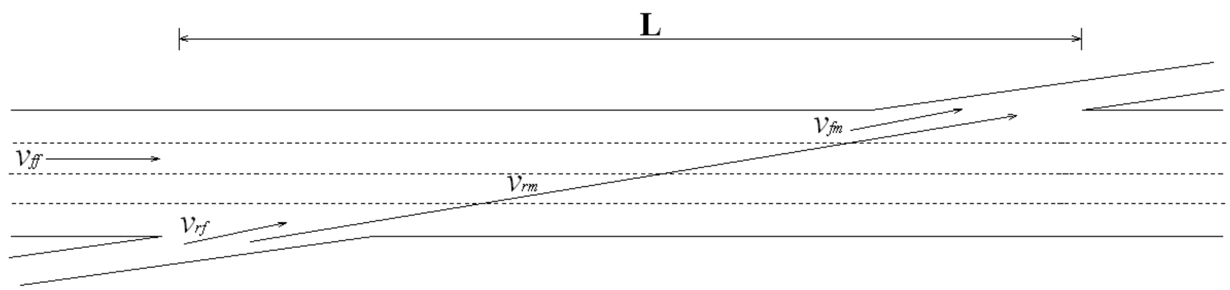
The full set of simulations were run for the no trucks case. For the ramp flow of 750 veh/hour, an additional set of simulation runs were made with 5% trucks. With this information, the heavy vehicle factor, f_{HV}, was estimated.

$$f_{HV} = \frac{V}{v}$$

where V is the capacity with mixed flow in veh/hour, and v is the equivalent capacity in pc/hour (i.e., the case with no trucks). Note that no trucks were placed in the managed lane.

Detailed results for scenario 1 with no trucks are shown in table 6.1. The capacities for 5% trucks (and ramp flow of 750 veh/hour) are shown in table 6.2a, and the estimated values of f_{HV} are shown in table 6.2b.

The impact of the weaving length can be seen on capacity in tables 6.3 through 6.5, which are drawn from table 6.1. In table 6.3, the entrance ramp flow (v_r) is 500 veh/hour, and the flow entering the managed lane from the general purpose lanes (v_{fm}) is 200 veh/hour. Figure 6.2 is a graphical representation of the data in table 6.3. Similar data for an entrance ramp flow of 1000 veh/hour is shown in table 6.4 and figure 6.3. Lastly, the impact of the entrance ramp flow on capacity is shown in table 6.5 and figure 6.4.



L = distance between the ramp and end of the managed lane access, feet
v_{ff} = flow entering from the upstream end of the general purpose lanes and departing at the downstream end, veh/hour
v_{fm} = flow entering the managed lane from the general purpose lanes, veh/hour
v_{rf} = flow from the entrance ramp continuing in the general purpose lanes, veh/hour
v_{rm} = flow from the ramp to the managed lane, veh/hour
Note: $v_f = v_{ff} + v_{fm}$, $v_r = v_{rf} + v_{rm}$, $v_m = v_{fm} + v_{rm}$

Figure 6.1. Lane configuration and traffic movements for scenario 1.

Table 6.1. Scenario 1; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 0% trucks.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
500	100	200	8350	9150	9250	9350	9400	9400	9400
		400	8400	9100	9250	9300	9400	9400	9400
		600	8250	9050	9150	9300	9300	9400	9400
		800	8250	9050	9150	9200	9250	9350	9400
	200	200	7250	8750	9200	9250	9350	9400	9400
		400	7200	8650	9100	9200	9350	9400	9400
		600	7200	8750	9000	9100	9250	9400	9400
		800	7300	8750	9050	9200	9250	9300	9400
	300	200	6250	8150	9000	9150	9250	9400	9400
		400	6200	8200	8950	9200	9300	9350	9400
		600	6250	8250	9000	9100	9250	9350	9400
		800	6100	8150	8850	9150	9200	9300	9400
	400	200	5500	7550	8800	9150	9250	9400	9400
		400	5400	7500	8650	9200	9250	9350	9400
		600	5500	7550	8750	9100	9200	9350	9400
		800	5400	7450	8700	9100	9200	9350	9400

Note: All flows in veh/hour, distance in feet.
Table continued on the next page.

Table 6.1. Scenario 1; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 0% trucks, continued.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
750	100	200	8300	9000	9100	9100	9150	9150	9150
		400	8350	8900	9000	9000	9150	9150	9150
		600	8350	8950	9050	9050	9100	9150	9150
		800	8350	8800	8950	9050	9100	9150	9150
	200	200	7300	8650	9000	9050	9150	9150	9150
		400	7300	8800	9000	9000	9100	9150	9150
		600	7250	8700	8900	9050	9100	9150	9150
		800	7300	8650	8850	9050	9100	9150	9150
	300	200	6350	8100	8850	9050	9100	9150	9150
		400	6350	8150	8750	8950	9100	9150	9150
		600	6350	8150	8700	9050	9100	9150	9150
		800	6350	8250	8700	9050	9050	9150	9150
	400	200	5650	7600	8700	9050	9100	9150	9150
		400	5650	7650	8750	8950	9100	9150	9150
		600	5650	7650	8700	8950	9050	9150	9150
		800	5650	7650	8650	8950	9050	9150	9150

Note: All flows in veh/hour, distance in feet.
Table continued on the next page.

Table 6.1. Scenario 1; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 0% trucks, continued.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
1000	100	200	8300	8850	8900	9000	9000	9000	9000
		400	8300	8800	8900	9000	9000	9000	9000
		600	8350	8800	8950	9000	9000	9000	9000
		800	8300	8750	8950	8950	8950	9000	9000
	200	200	7200	8750	8800	9000	9000	9000	9000
		400	7300	8650	8800	8900	8950	8950	9000
		600	7250	8650	8850	9000	9000	9000	9000
		800	7250	8600	8850	8950	8950	9000	9000
	300	200	6450	8300	8700	8950	9000	9000	9000
		400	6450	8350	8650	8850	8950	8950	9000
		600	6400	8350	8700	8950	8950	8950	9000
		800	6300	8350	8600	8850	8950	9000	9000
	400	200	5700	7650	8650	8900	8950	8950	9000
		400	5700	7650	8600	8850	8950	8950	9000
		600	5750	7600	8600	8900	8950	8950	9000
		800	5800	7600	8500	8800	8900	9000	9000

Note: All flows in veh/hour, distance in feet.

Table continued on the next page.

Table 6.1. Scenario 1; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 0% trucks, continued.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
1250	100	200	8250	8750	8800	8800	8850	8850	8850
		400	8300	8750	8750	8800	8850	8850	8850
		600	8300	8750	8750	8800	8850	8850	8850
		800	8350	8750	8750	8750	8800	8850	8850
	200	200	7350	8700	8750	8750	8800	8850	8850
		400	7300	8650	8750	8750	8800	8850	8850
		600	7450	8650	8750	8800	8800	8850	8850
		800	7450	8550	8650	8750	8800	8850	8850
	300	200	6500	8550	8700	8750	8800	8850	8850
		400	6450	8600	8600	8750	8800	8850	8850
		600	6400	8500	8600	8800	8800	8850	8850
		800	6350	8500	8550	8750	8800	8850	8850
	400	200	5850	7800	8650	8750	8800	8850	8850
		400	5850	7850	8550	8700	8800	8850	8850
		600	5850	7850	8550	8800	8800	8850	8850
		800	5900	7850	8450	8750	8800	8850	8850

Note: All flows in veh/hour, distance in feet.

Table 6.2a. Scenario 1; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 5% trucks.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
750	100	200	8050	8650	8700	8750	8750	8750	8750
		400	8000	8550	8650	8700	8700	8700	8750
		600	8000	8450	8600	8700	8700	8700	8750
		800	7950	8400	8600	8650	8650	8750	8750
	200	200	7150	8400	8500	8700	8750	8750	8750
		400	7100	8350	8600	8700	8700	8700	8750
		600	6950	8250	8500	8600	8650	8700	8750
		800	7000	8250	8350	8550	8650	8700	8750
	300	200	6150	7950	8350	8550	8700	8700	8750
		400	6150	7750	8300	8550	8650	8700	8750
		600	6100	7800	8350	8500	8650	8700	8750
		800	6050	7900	8300	8500	8650	8700	8750
	400	200	5400	7400	8300	8500	8700	8700	8750
		400	5400	7300	8350	8500	8650	8700	8750
		600	5400	7300	8200	8450	8650	8700	8750
		800	5400	7250	8150	8350	8650	8700	8750

Note: All flows in veh/hour, distance in feet.

Table 6.2b. Scenario 1; estimate of heavy vehicle adjustment factor, 5% trucks.

			L						
v_r	v_{rm}	v_{fm}	1000	1500	2000	2500	3000	3500	4000
750	100	200	0.97	0.96	0.96	0.96	0.96	0.96	0.96
		400	0.96	0.96	0.96	0.97	0.95	0.95	0.96
		600	0.96	0.94	0.95	0.96	0.96	0.95	0.96
		800	0.95	0.95	0.96	0.96	0.95	0.96	0.96
	200	200	0.98	0.97	0.94	0.96	0.96	0.96	0.96
		400	0.97	0.95	0.96	0.97	0.96	0.95	0.96
		600	0.96	0.95	0.96	0.95	0.95	0.95	0.96
		800	0.96	0.95	0.94	0.94	0.95	0.95	0.96
	300	200	0.97	0.98	0.94	0.94	0.96	0.95	0.96
		400	0.97	0.95	0.95	0.96	0.95	0.95	0.96
		600	0.96	0.96	0.96	0.94	0.95	0.95	0.96
		800	0.95	0.96	0.95	0.94	0.96	0.95	0.96
	400	200	0.96	0.97	0.95	0.94	0.96	0.95	0.96
		400	0.96	0.95	0.95	0.95	0.95	0.95	0.96
		600	0.96	0.95	0.94	0.94	0.96	0.95	0.96
		800	0.96	0.95	0.94	0.93	0.96	0.95	0.96

Note: All flows in veh/hour, distance in feet.

Table 6.3. Scenario 1; impact of weaving length on capacity in weaving area, with ramp flow of 500 vehicles/hour and 200 vehicles/hour entering the managed lane from the general purpose lanes.

	v_{rm}			
L	100	200	300	400
1000	8350	7250	6250	5500
1500	9150	8750	8150	7550
2000	9250	9200	9000	8800
2500	9350	9250	9150	9150
3000	9400	9350	9250	9250
3500	9400	9400	9400	9400
4000	9400	9400	9400	9400

Note: all flows in veh/hour, distances in feet.
Note: table selected from table 6.1.

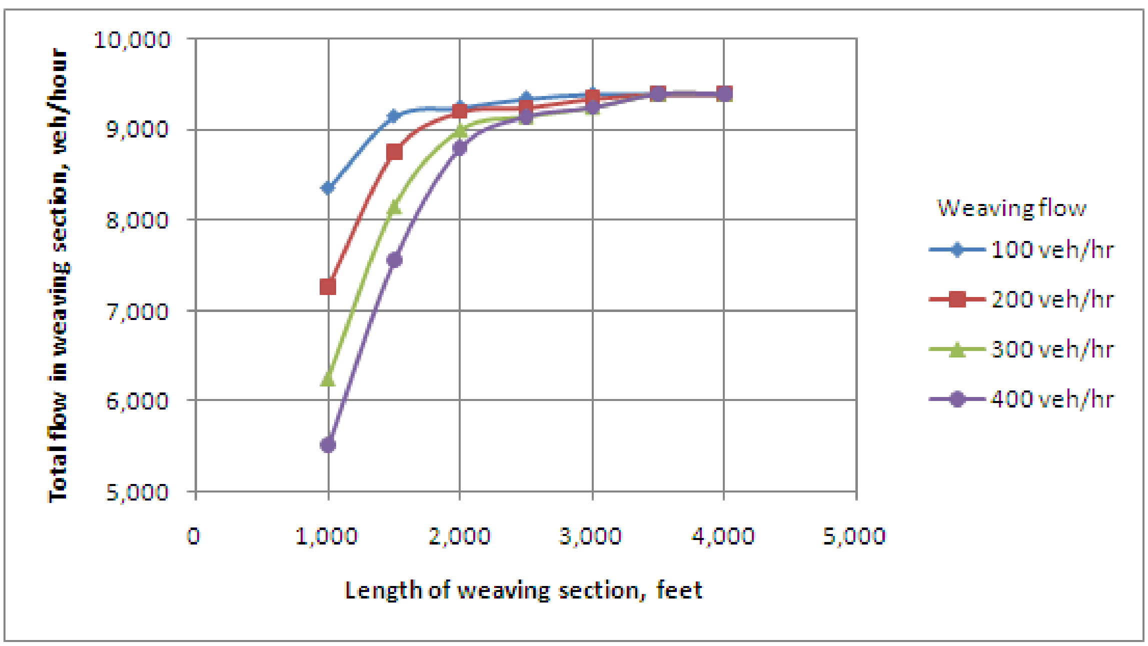


Figure 6.2. Impact of weaving length on capacity in a weaving section for four values of the weaving flow. Ramp flow is set at 500 vehicles/hour and the flow entering the managed lane from the general purpose lanes is set at 200 vehicles/hour.

Table 6.4. Scenario 1; impact of weaving length on capacity in weaving area, with ramp flow of 1000 vehicles/hour and 200 vehicles/hour entering the managed lane from the general purpose lanes.

	v_{rm}			
L	100	200	300	400
1000	8300	7200	6450	5700
1500	8850	8750	8300	7650
2000	8900	8800	8700	8650
2500	9000	9000	8950	8900
3000	9000	9000	9000	8950
3500	9000	9000	9000	8950
4000	9000	9000	9000	9000

Note: all flows in veh/hour, distances in feet.
Note: table selected from table 6.1.

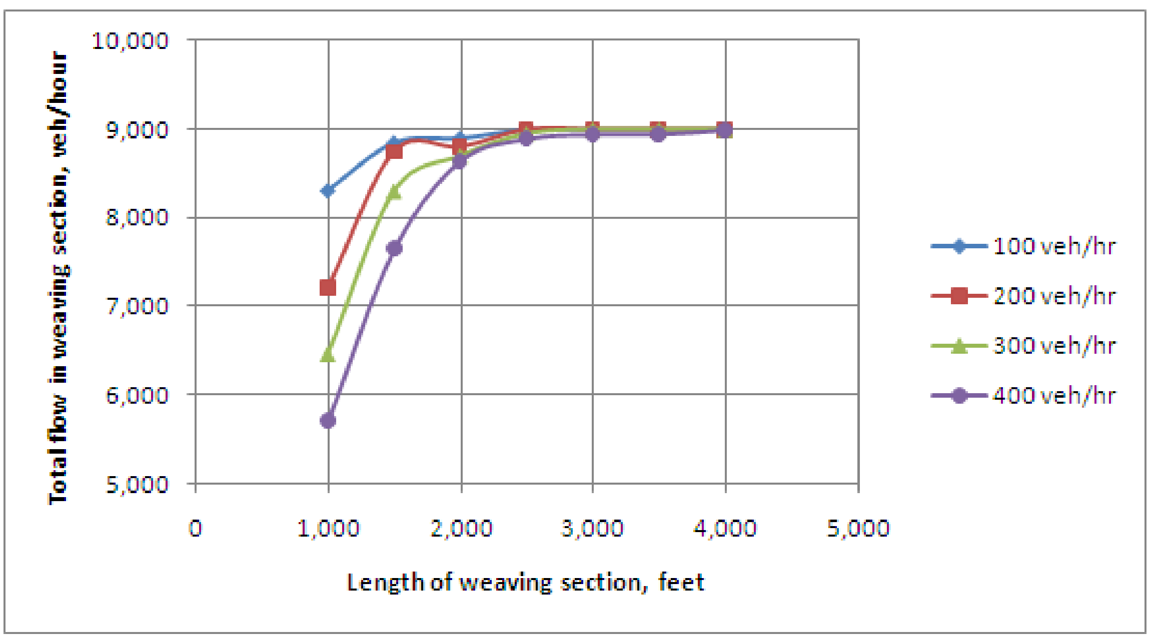


Figure 6.3. Impact of weaving length on capacity in a weaving section for four values of the weaving flow. Ramp flow is set at 1000 vehicles/hour and the flow entering the managed lane from the general purpose lanes is set at 200 vehicles/hour.

Table 6.5. Scenario 1; impact of ramp flow on capacity, for a weaving section length of 1500 feet and 200 vehicles/hour entering the managed lane from the general purpose lanes.

	v_r			
v_{rm}	500	750	1000	1250
100	9150	9000	8850	8750
200	8750	8650	8750	8700
300	8150	8100	8300	8550
400	7550	7600	7650	7800

Note: all flows in veh/hour, distances in feet.
Note: table selected from table 6.1.

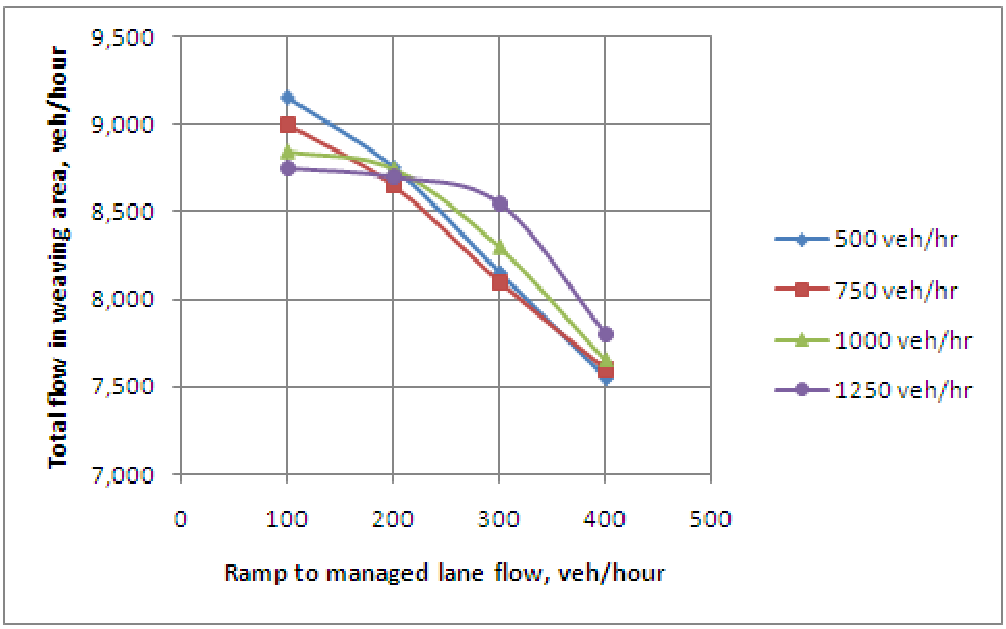


Figure 6.4. Impact of ramp flow on capacity with a weaving length of 1500 feet and 200 vehicles/hour entering the managed lane from the general purpose lanes.

Scenario 1 – Discussion of Results

Several observations can be made from the simulation results for scenario 1:

- As the ramp to managed lane flow (v_{rm}) increases, the capacity decreases. For example, for a ramp flow (v_r) of 500 veh/hour, 200 veh/hour flow from the general purpose lanes to the managed lane (v_{fm}), and a 1000-foot weaving section (L), capacity decreased from 8350 veh/hour to 5500 veh/hour as v_{rm} increased from 100 to 400 (see figure 6.2). This clearly shows the impact of weaving flows on the overall capacity. For weaving lengths of 2500 feet and longer, the impact of the number of vehicles weaving across the general purpose lanes is negligible. Similar observations can be made for higher ramp flows, as shown in figure 6.3 for a ramp flow (v_r) of 1000 veh/hour.
- As the length of the weave (L) increases, the capacity also increases, as is shown for all combinations of variables. In general, the capacity is not sensitive to the weaving length for longer weaving lengths, especially for smaller weaving volumes (smaller v_{rm}). As shown in figures 6.2 and 6.3, for lower weaving flows, increasing weaving distance beyond 1500 feet gained little additional capacity. However, at higher weaving flows (up to 400 veh/hour), increasing the weaving length to as much as 2500 feet resulted in capacity gains.
- The impact of the entrance ramp flow on capacity is minor. Capacities for four levels of entrance ramp flow are shown in figure 6.4 for a range of weaving flows. For each value of the weaving flow, the capacity variation resulting from changes in the ramp flow is small compared to that caused by the weaving flow itself.
- Increasing flows from the general purpose lanes to the managed lane (v_{fm}) tend to reduce capacity for shorter weaving sections, but the impact is relatively minor.
- The ramp junction capacity is found for the cases where $v_{rm} = 0$ and $v_{fm} = 0$, i.e., there is no interaction with the managed lane. (The ramp junction, as defined in the HCM [Ref. 5], is the segment of freeway at an exit or entrance ramp. Its capacity is a combination of the mainlane freeway flow and the ramp flow.) The ramp junction capacity was also shown when the weaving section (L in figure 6.1) was long. The ramp junction capacity was found to be 9400, 9150, 9000, and 8850 veh/hour for ramp flows (v_r) of 500, 750, 1000, and 1250 veh/hour, respectively.

- The heavy vehicle factor (f_{HV}) was found to be somewhat smaller than the calculated value from the 2000 HCM for 5% trucks in level terrain. The HCM value of the heavy vehicle factor is 0.976, simulation results showed that the heavy vehicle factor ranged from 0.94 to 0.97 (table 6.2b), although a pattern with respect to the weaving variables was difficult to discern. It should be noted that the heavy vehicle factor in the HCM is calculated for basic freeway segments (i.e., away from the influence of ramps), however, the same calculation is used throughout the freeway analysis procedures. Before reliable conclusions can be drawn, however, the impact of trucks would have to be examined at the full range of flow levels and additional proportions of truck traffic.

Scenario 2

This scenario consists of a right-side exit ramp following the left-side access to the managed lane. The lane configuration and variable definition is provided in figure 6.5. As before, note that the access to the managed lane is shown as a left-side entrance ramp, and is placed at the beginning of the access area to the managed lane. No trucks are simulated in this scenario.

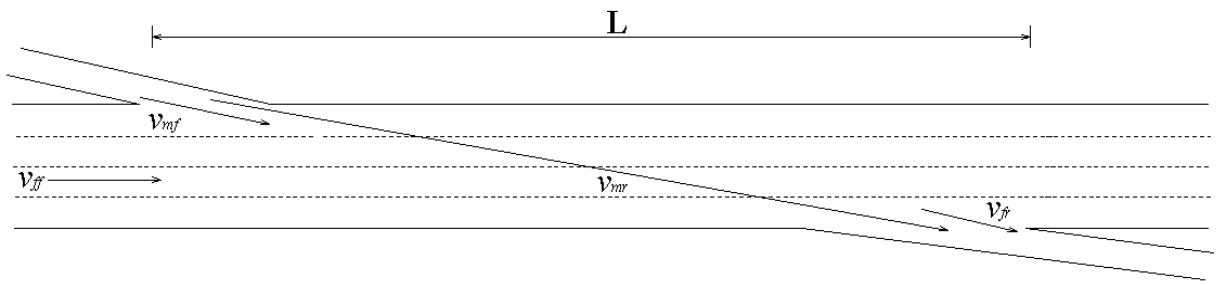
For given values of the weaving distance (L), the managed lane to ramp flow (v_{mr}), and the managed lane to freeway flow (v_{mf}), the flow in the general purpose lanes was gradually increased to find the capacity. The specific values for each variable were:

- Weaving distance (L) – 1000 to 4000 feet in 500-foot increments
- Flow exiting managed lane (v_m) – set at 750 veh/hour
- Managed lane to ramp flow (v_{mr}) – 100 to 400 veh/hour in 100 veh/hour increments
- General purpose lanes to ramp flow (v_{fr}) – 200 to 800 veh/hour in increments of 200 veh/hour

Scenario 2 – Discussion of Results

Only one level of the flow leaving the managed lane was investigated in this scenario (table 6.6). Since this scenario is the reverse of scenario 1, it is not surprising that the results are identical (compare with table 6.1 for a v_r of 750 vehicles/hour). It is assumed that the results of scenario 1 can be directly applied to scenario 2 for the same flow and weaving length conditions. Of course, this is ignoring the impact of the Type A weave at the access point to the managed lanes, but as noted in the discussion of scenario 1, flows on the managed lane are typically small enough to not impact the capacity of the Type C weave across the general purpose lanes.

The impact of the weaving length can be seen on capacity in table 6.7, which is drawn from table 6.6. In table 6.7, the flow leaving the managed lane is 750 vehicles/hour, and the flow exiting the general purpose lanes at the ramp is 200 vehicles/hour (excluding the weaving vehicles). This data is shown graphically in figure 6.6. It is very similar to figures 6.2 and 6.3, representing scenario 1.



L = distance between the beginning of the managed lane access and the exit ramp, feet
v_{ff} = flow entering from the upstream end of the general purpose lanes and departing at the downstream end, veh/hour
v_{fr} = flow from the general purpose lanes to the exit ramp, veh/hour
v_{mr} = flow from the managed lane to the exit ramp, veh/hour
v_{mf} = flow from the managed lane to the general purpose lanes, veh/hour
Note: $v_f = v_{ff} + v_{fr}$, $v_r = v_{fr} + v_{mr}$, $v_m = v_{mf} + v_{mr}$

Figure 6.5. Lane configuration and traffic movements for scenario 2.

Table 6.6. Scenario 2; estimates of capacity of the general purpose lanes between the managed lane access and the exit ramp, 0% trucks.

			L						
v_m	v_{mr}	v_{fr}	1000	1500	2000	2500	3000	3500	4000
750	100	200	8350	9000	9050	9100	9150	9150	9150
		400	8300	8950	9000	9050	9150	9150	9150
		600	8350	8900	9050	9050	9150	9150	9150
		800	8250	8850	8900	9000	9100	9150	9150
	200	200	7350	8700	9000	9050	9100	9150	9150
		400	7300	8750	8950	9050	9100	9150	9150
		600	7300	8700	8900	9050	9100	9150	9150
		800	7300	8600	8800	9000	9100	9150	9150
	300	200	6350	8150	8800	9050	9100	9150	9150
		400	6300	8150	8750	9000	9100	9150	9150
		600	6300	8100	8750	9000	9100	9150	9150
		800	6350	8100	8700	9000	9100	9150	9150
	400	200	5700	7600	8800	9050	9100	9150	9150
		400	5650	7600	8750	9000	9050	9150	9150
		600	5650	7650	8700	8950	9050	9150	9150
		800	5550	7650	8600	8900	9050	9150	9150

Note: All flows in veh/hour, distance in feet.

Table 6.7. Scenario 2; impact of weaving length on capacity in weaving area, with ramp flow of 750 vehicles/hour and 200 vehicles/hour entering the general purpose lanes from the managed lane (excluding the weaving vehicles).

	v_{rm}			
L	100	200	300	400
1000	8350	7350	6350	5700
1500	9000	8700	8150	7600
2000	9050	9000	8800	8800
2500	9100	9050	9050	9050
3000	9150	9100	9100	9100
3500	9150	9150	9150	9150
4000	9150	9150	9150	9150

Note: all flows in veh/hour, distances in feet.
Note: table selected from table 6.6.

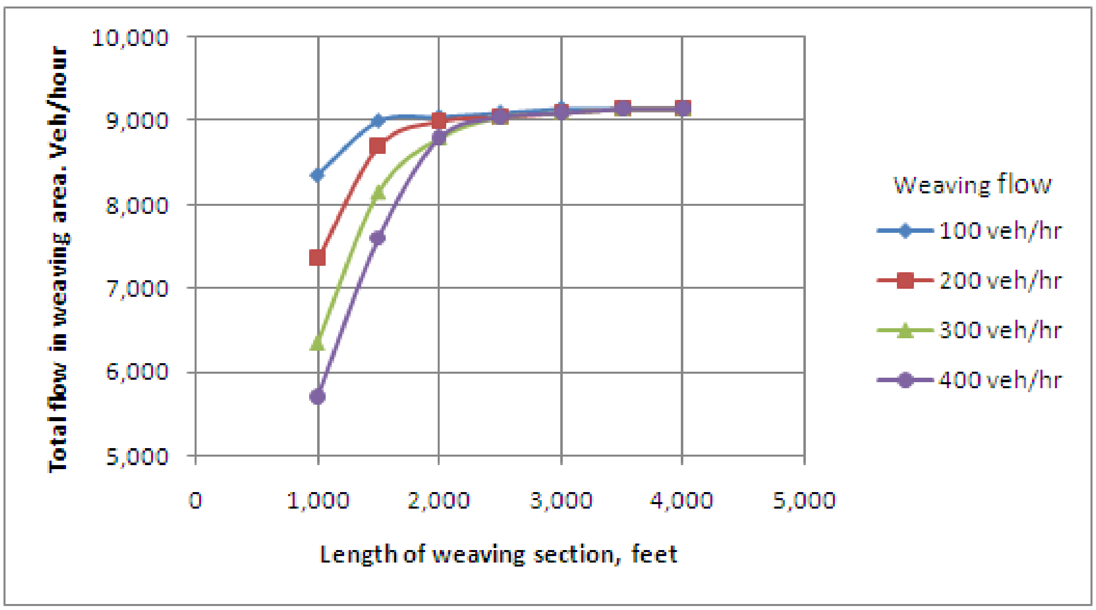


Figure 6.6. Impact of weaving length on capacity in a weaving section for four values of the weaving flow. Ramp flow is set at 750 vehicles/hour and the flow entering the general purpose lanes from the managed lanes is set at 200 vehicles/hour (excluding the weaving vehicles).

Scenario 3

This scenario uses the same lane geometry as scenario 1, but instead of making repeated simulation runs gradually increasing the flow in the general purpose lanes to reach capacity, the ramp to managed lane flow (v_{rm}) is increased to find capacity. The ranges of the other variables for this scenario are:

- Weaving distance (L) – 1000 to 4000 feet in 500-foot increments
- Ramp flow (v_r) – 500 to 1250 veh/hour in 250 veh/hour increments
- Sum of ramp flow (v_r) and flow in the general purpose lanes (v_f) – decreased from 9200 to 8200 veh/hour in 200 veh/hour increments
- Sum of ramp to managed lane flow (v_{rm}) and general purpose lanes to managed lane flow (v_{fm}) – 400 to 1000 veh/hour in 200 veh/hour increments

Scenario 3 – Discussion of Results

The detailed results of the simulation are shown in table 6.8. As expected, increasing flow in the general purpose lanes (v_f+v_r) decreased the capacity of the ramp to managed lane flow (v_{rm}). Similarly, v_{rm} capacity increased with increasing weaving distance (L).

In many cases, the capacity of v_{rm} could not be reached. In these cases, v_{rm} was increased until it was the same as v_m. At this point, all of the traffic entering the managed lane came from the entrance ramp, with none from the general purpose lanes. The values in the tables are shown with a "+" indicating that more vehicles could make the weave for those conditions.

In some cases, the traffic on the general purpose lanes (v_r+v_f) was at or exceeded capacity, resulting in no vehicles able to make the weave. In these cases a "-" is in the table, indicating that the capacity of the weaving flow (v_{rm}) is zero.

Table 6.8. Scenario 3; estimates of capacity of the ramp to managed lane flow, 0% trucks.

			L						
v_r	$v_f + v_r$	v_m	1000	1500	2000	2500	3000	3500	4000
500	9200	400	0	60	180	380	400+	400+	400+
		600	0	60	120	340	500+	500+	500+
		800	0	20	100	260	500+	500+	500+
		1000	0	0	40	260	500+	500+	500+
	9000	400	20	140	320	400+	400+	400+	400+
		600	20	100	320	500+	500+	500+	500+
		800	0	100	300	500+	500+	500+	500+
		1000	0	100	200	500+	500+	500+	500+
	8800	400	40	160	340	400+	400+	400+	400+
		600	40	140	340	500+	500+	500+	500+
		800	40	160	360	500+	500+	500+	500+
		1000	40	160	360	500+	500+	500+	500+
	8600	400	60	240	400+	400+	400+	400+	400+
		600	60	220	440	500+	500+	500+	500+
		800	60	200	440	500+	500+	500+	500+
		1000	40	200	440	500+	500+	500+	500+
	8400	400	80	260	400+	400+	400+	400+	400+
		600	80	260	480	500+	500+	500+	500+
		800	80	240	480	500+	500+	500+	500+
		1000	80	240	500+	500+	500+	500+	500+
	8200	400	100	300	400+	400+	400+	400+	400+
		600	80	300	500+	500+	500+	500+	500+
		800	100	300	500+	500+	500+	500+	500+
		1000	100	300	500+	500+	500+	500+	500+

Note: All flows in veh/hour, distance in feet.
Table continued on the next page.

Table 6.8. Scenario 3; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

			L						
v_r	$v_f + v_r$	v_m	1000	1500	2000	2500	3000	3500	4000
750	9200	400	-	-	-	-	-	-	-
	9000	400	0	80	220	400+	400+	400+	400+
		600	0	60	200	480	600+	600+	600+
		800	0	20	200	500	750+	750+	750+
		1000	0	0	160	400	750+	750+	750+
	8800	400	20	140	380	400+	400+	400+	400+
		600	20	160	360	600+	600+	600+	600+
		800	20	140	260	720	750+	750+	750+
		1000	20	140	240	640	750+	750+	750+
	8600	400	60	260	400+	400+	400+	400+	400+
		600	60	260	480	600+	600+	600+	600+
		800	60	240	440	750+	750+	750+	750+
		1000	40	240	440	750+	750+	750+	750+
	8400	400	80	280	400+	400+	400+	400+	400+
		600	80	280	520	600+	600+	600+	600+
		800	80	280	500	750+	750+	750+	750+
		1000	80	260	480	750+	750+	750+	750+
	8200	400	100	300	400+	400+	400+	400+	400+
		600	100	300	560	600+	600+	600+	600+
		800	100	320	540	750+	750+	750+	750+
		1000	100	320	520	750+	750+	750+	750+

Note: All flows in veh/hour, distance in feet.
Table continued on next page.

Table 6.8. Scenario 3; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

			L						
v_r	$v_f + v_r$	v_m	1000	1500	2000	2500	3000	3500	4000
1000	9200	400	-	-	-	-	-	-	-
	9000	400	-	-	-	-	-	-	-
	8800	400	0	120	320	400+	400+	400+	400+
		600	0	120	300	600+	600+	600+	600+
		800	0	100	240	700	800+	800+	800+
		1000	0	80	240	600	960	1000+	1000+
	8600	400	40	240	400+	400+	400+	400+	400+
		600	40	240	440	600+	600+	600+	600+
		800	20	240	400	800+	800+	800+	800+
		1000	20	220	320	860	1000+	1000+	1000+
	8400	400	60	300	400+	400+	400+	400+	400+
		600	80	300	540	600+	600+	600+	600+
		800	80	300	560	800+	800+	800+	800+
		1000	80	260	520	940	1000+	1000+	1000+
	8200	400	100	340	400+	400+	400+	400+	400+
		600	100	320	600+	600+	600+	600+	600+
		800	100	320	620	800+	800+	800+	800+
		1000	100	300	600	980	1000+	1000+	1000+

Note: All flows in veh/hour, distance in feet.
Table continued on next page.

Table 6.8. Scenario 3; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

			L						
v_r	$v_f + v_r$	v_m	1000	1500	2000	2500	3000	3500	4000
1250	9200	400	-	-	-	-	-	-	-
	9000	400	-	-	-	-	-	-	-
	8800	400	-	-	-	-	-	-	-
	8600	400	40	260	400+	400+	400+	400+	400+
		600	40	260	440	600+	600+	600+	600+
		800	40	240	340	800+	800+	800+	800+
		1000	40	240	240	860	1000+	1000+	1000+
	8400	400	80	300	400+	400+	400+	400+	400+
		600	80	300	560	600+	600+	600+	600+
		800	80	300	580	800+	800+	800+	800+
		1000	80	300	540	940	1000+	1000+	1000+
	8200	400	100	320	400+	400+	400+	400+	400+
		600	100	360	600+	600+	600+	600+	600+
		800	100	360	620	800+	800+	800+	800+
		1000	100	360	620	1000+	1000+	1000+	1000+

Note: All flows in veh/hour, distance in feet.
Table continued on next page.

Scenario 4

This scenario adds a right-side exit ramp between the right-side entrance ramp and left-side managed lane access in scenario 1, and is shown in figure 6.7. To estimate capacity, increasing values of the upstream flow in the general purpose lanes were used in successive simulation runs until capacity was established. As in the prior scenarios, values of the other variables were held constant in each set of runs. No trucks were simulated in this scenario. The other variables, and the range of values that were used in the series of simulation runs were

- Weaving distance (L) - 1000 to 4000 feet in 500-foot increments
- Distance to the intermediate exit ramp (L_{off}) – 1000 to 4000 feet in 1000-foot increments
- Ramp flow (v_r) – 500 and 1000 veh/hour
- Ramp to managed lane flow (v_{rm}) – 200 and 400 veh/hour
- Exit ramp flow (v_{off}) – 500 and 1000 veh/hour

Note that only two levels of the last three variables were evaluated.

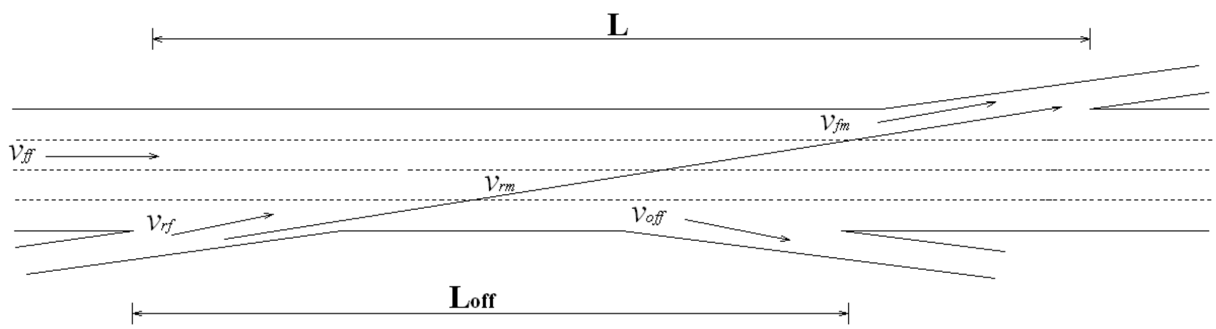
For each of the four cases of v_r and v_{rm}, the capacity values from scenario 1 are shown in italics.

Scenario 4 – Discussion of Results

The simulation results for this scenario are shown in table 6.9. Selected capacity values from scenario 1 (table 6.1) are included in this table and shown in italics. Comparing with scenario 1, the presence of the intermediate exit ramp near the entrance ramp (low values of L_{off}) seems to have little impact on the capacity of the weaving section. One would expect that when the intermediate ramp is close to the entrance ramp, more traffic is trying to share the right general purpose lanes. As the distance to the intermediate ramp increases, more of the weaving traffic from the entrance ramp has made it to the left general purpose lanes, and there is less competition for the same space on the freeway. In addition, after the intermediate ramp, the flow is smaller, easing the lane changing burden on the traffic weaving for the managed lane.

For v_r = 500 vehicles/hour and v_{rm} = 200 vehicles/hour, capacities with the intermediate ramp are largely less than those without the intermediate ramp. However, when v_r is increased to 400 vehicles/hour, capacities with the intermediate ramp are larger, some by as much as 500 vehicles/hour. For the cases where v_r is 1000 vehicles/hour, the capacities with the intermediate ramp are mostly less than those without it, however, there is one case where the capacity is increased by nearly 1000 vehicles/hour (for v_{off} = 1000 vehicles/hour, L_{off} = 1000, and L = 1500 feet).

It is not entirely clear what the impact of an intermediate ramp is, however, by and large, capacities are either reduced or remain about the same in the presence of an intermediate ramp.



L = distance between the ramp and end of the managed lane access, feet
L_{off} = distance between the ramp and the intermediate exit ramp, feet
v_{ff} = flow entering from the upstream end of the general purpose lanes and departing at the downstream end, veh/hour
v_{fm} = flow entering the managed lane from the general purpose lanes, veh/hour
v_{rf} = flow from the entrance ramp continuing in the general purpose lanes, veh/hour
v_{rm} = flow from the ramp to the managed lane, veh/hour
v_{off} = flow on the intermediate exit ramp, veh/hour
Note: $v_f = v_{ff} + v_{fm} + v_{off}$, $v_r = v_{rf} + v_{rm}$, $v_m = v_{fm} + v_{rm}$

Figure 6.7. Lane configuration and traffic movements for scenario 4.

Table 6.9. Scenario 4; estimates of capacity of the general purpose lanes between the entrance ramp and the managed lane access, 0% trucks.

				L						
v_r	v_{rm}	v_{off}	L_{off}	1000	1500	2000	2500	3000	3500	4000
500	*200*	---	---	*7250*	*8750*	*9200*	*9250*	*9350*	*9400*	*9400*
500	200	500	1000	7150	8950	9200	9100	9250	9100	9200
			2000	-	-	9050	9050	9100	9150	9200
			3000	-	-	-	-	9250	9250	9250
			4000	-	-	-	-	-	-	9400
		1000	1000	7250	8950	9000	9000	9050	8950	8950
			2000	-	-	8850	8950	8950	8950	9000
			3000	-	-	-	-	9250	9300	9350
			4000	-	-	-	-	-	-	9350

Note: All flows in veh/hour, distance in feet; figures in italics from tables 6.1a through 6.1d.
Table continued on the next page.

Table 6.9. continued

v_r	v_{rm}	v_{off}	L_{off}	L 1000	1500	2000	2500	3000	3500	4000
500	*400*	---	---	*5500*	*7550*	*8800*	*9150*	*9250*	*9400*	*9400*
500	400	500	1000	5500	7900	8850	9050	9200	9100	9200
			2000	-	-	8800	9000	9100	9150	9200
			3000	-	-	-	-	9250	9250	9250
			4000	-	-	-	-	-	-	9350
		1000	1000	5750	8000	8850	9000	9000	8950	8950
			2000	-	-	8850	8900	8900	8950	9000
			3000	-	-	-	-	9200	9200	9300
			4000	-	-	-	-	-	-	9350
1000	*200*	---	---	*7200*	*8750*	*8800*	*9000*	*9000*	*9000*	*9000*
1000	200	500	1000	7350	8600	8700	8750	8800	8750	8750
			2000	-	-	8600	8650	8700	8600	8600
			3000	-	-	-	-	8950	9000	9000
			4000	-	-	-	-	-	-	9000
		1000	1000	7400	8550	8550	8500	8500	8500	8500
			2000	-	-	8500	8500	8500	8550	8550
			3000	-	-	-	-	8850	9000	9000
			4000	-	-	-	-	-	-	9000
	400	---	---	*5700*	*7150*	*8650*	*8900*	*8950*	*8950*	*9000*
	400	500	1000	5800	8150	8600	8750	8800	8750	8750
			2000	-	-	8500	8650	8700	8600	8600
			3000	-	-	-	-	8900	9000	9000
			4000	-	-	-	-	-	-	9000
		1000	1000	6000	8400	8550	8500	8500	8500	8500
			2000	-	-	8500	8500	8500	8550	8550
			3000	-	-	-	-	8850	9000	9000
			4000	-	-	-	-	-	-	9000

Note: All flows in veh/hour, distance in feet; figures in italics from tables 6.1a through 6.1d.

Scenario 5

This scenario adds a right-side entrance ramp between the left-side managed lane access and the right-side exit ramp in scenario 2, and is shown in figure 6.8. To estimate capacity, increasing values of the upstream flow in the general purpose lanes were used in successive simulation runs until capacity was established. As in the prior scenarios, values of the other variables were held constant in each set of runs. No trucks were simulated in this scenario. The other variables, and the range of values that were used in the series of simulation runs were

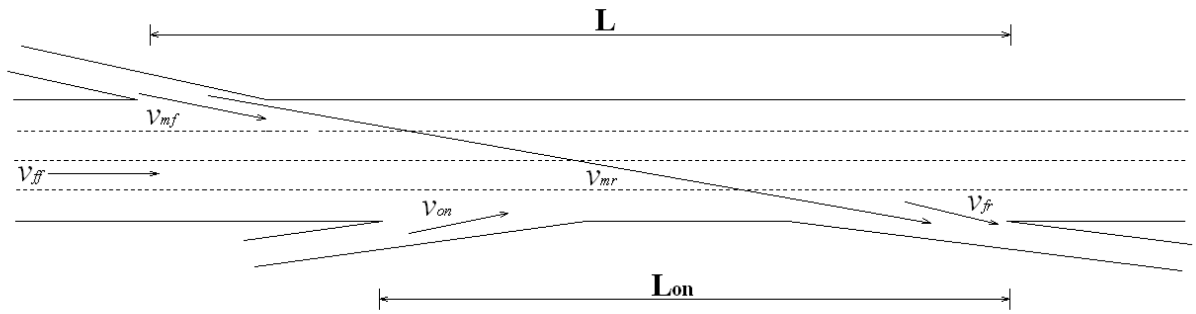
- Weaving distance (L) – 1000 to 4000 feet in 500-foot increments
- Distance from the intermediate entrance ramp to the exit ramp (L_{on}) – 1000 to 4000 feet in 1000-foot increments
- Flow exiting managed lane (v_m) – 500 and 1000 veh/hour
- Managed lane to ramp flow (v_{mr}) – 200 and 400 veh/hour
- Intermediate entrance ramp flow (v_{on}) – 500 and 1000 veh/hour

Note that only two levels of the last three variables were evaluated. An additional variable is added to scenario 2, i.e., the flow on the intermediate ramp. In order to keep the number of cases at a manageable size, only two levels of the last three variables were evaluated.

Scenario 5 – Discussion of Results

The simulation results for this scenario are shown in table 6.10. Comparisons with scenario 2 are not as clear as comparisons with scenario 1 in the previous scenario because runs in scenario 2 were made only for a v_m of 750 vehicles/hour, while scenario 5 was run with v_m at 500 and 1000 vehicles/hour. However, capacity estimates from scenario 2 (table 6.6) are shown in table 6.10 in italics. Note that scenarios 1 and 2 are virtually identical, as modelled in this study, and capacity estimates for scenario 5 (table 6.10) could also be compared with capacity estimates from scenario 1 (in table 6.1 or the italicized values shown in table 6.9).

Once again, the data is not consistent. While the capacities in the presence of an intermediate entrance ramp are less than those with no intermediate ramp, there are a few cases where a higher capacity is shown. In general, though, it appears that the presence of an intermediate ramp reduces capacity of the weaving section.



L = distance between the beginning of the managed lane access and the exit ramp, feet
L_{on} = distance from the intermediate entrance ramp to the exit ramp, feet
v_{ff} = flow entering from the upstream end of the general purpose lanes and departing at the downstream end, veh/hour
v_{fr} = flow from the general purpose lanes to the exit ramp, veh/hour
v_{mr} = flow from the managed lane to the exit ramp, veh/hour
v_{mf} = flow from the managed lane to the general purpose lanes, veh/hour
v_{on} = flow from the intermediate entrance ramp to the general purpose lanes, veh/hour
Note: $v_f = v_{ff} + v_{fr}$, $v_r = v_{fr} + v_{mr}$, $v_m = v_{mf} + v_{mr}$

Figure 6.8. Lane configuration and traffic movements for scenario 5

Table 6.10. Scenario 5; estimates of capacity of the general purpose lanes between the managed lane access and the entrance ramp, 0% trucks.

				L						
v_m	v_{mr}	v_{on}	L_{on}	1000	1500	2000	2500	3000	3500	4000
750	*200*	---	---	*7350*	*8700*	*9000*	*9050*	*9100*	*9150*	*9150*
500	200	500	1000	7550	8550	8950	9100	9250	9250	9350
			2000	-	-	9000	9100	9150	9300	9250
			3000	-	-	-	-	9000	9150	9200
			4000	-	-	-	-	-	-	9050
		1000	1000	7600	8400	8700	8750	8950	8950	9000
			2000	-	-	8750	8600	8800	8800	8850
			3000	-	-	-	-	8750	8700	8800
			4000	-	-	-	-	-	-	8800

Note: All flows in veh/hour, distance in feet; figures in italics from tables 6.6.
Table continued on the next page.

Table 6.10. continued

v_r	v_{rm}	v_{off}	L_{off}	L 1000	1500	2000	2500	3000	3500	4000
750	*400*	---	---	*5700*	*7600*	*8800*	*9050*	*9100*	*9150*	*9150*
500	400	500	1000	5850	7650	8600	8950	9200	9150	9150
			2000			8750	8900	9100	9200	9200
			3000					9000	9150	9200
			4000							9050
		1000	1000	5850	7700	8400	8600	8750	8750	8800
			2000			8750	8600	8750	8750	8750
			3000					8750	8700	8800
			4000							8800
750	*200*	---	---	*7350*	*8700*	*9000*	*9050*	*9100*	*9150*	*9150*
1000	200	500	1000	7550	8650	9000	9150	9400	9300	9250
			2000			8750	8900	9200	9200	9250
			3000					8800	9050	9200
			4000							8800
		1000	1000	7500	8400	8700	8850	8850	8950	8950
			2000			8550	8550	8750	8850	8850
			3000					8600	8650	8850
			4000							8600
750	*400*	---	---	*5700*	*7600*	*8800*	*9050*	*9100*	*9150*	*9150*
	400	500	1000	6050	7700	8750	9000	9100	9150	9150
			2000			8700	8800	9150	9150	9200
			3000					8750	9050	9200
			4000							8800
		1000	1000	6100	7600	8450	8650	8750	8850	8900
			2000			8500	8550	8750	8750	8850
			3000					8600	8650	8850
			4000							8600

Note: All flows in veh/hour, distance in feet.

CHAPTER 7
DEVELOPMENT OF GUIDELINES FOR MANAGED LANE ACCESS LOCATION

The distance required for a driver to enter a freeway on a right-side ramp and weave across the general purpose lanes to the left lane to enter a managed lane is a crucial factor in selecting the access points for a managed lane. Some drivers can manage this weave at even short distances, but one objective of this project was to find the distances that maximized the capacity of the cross-freeway weave. (The reverse is a similar problem, where drivers who exit a manage lane must then weave across the general purpose lanes for a right-side exit ramp.)

Microscopic simulation was selected as the principal tool in estimating the required distances for a range of traffic flow conditions. Simulation has advantages over direct field observation in that a wide range of flow conditions can be tested, and is more reliable and less expensive than extensive field data collection.

Careful calibration and validation of the simulation model must be done in order to provide reliable simulation results. Data was collected along a freeway in Dallas that consisted of four general purpose lanes plus a single managed lane in each direction. Data was collected during moderate flow conditions (when demand was less than capacity) and during heavy flow conditions (when demand exceeded capacity). In addition, data was collected at two sites on this freeway, allowing the second site to serve in the validation of the calibrated simulation model.

A series of scenarios were developed to examine a range of expected geometric conditions. These included a right-hand entrance ramp before the left-side managed lane access point, and a right-hand exit ramp after the left-side managed lane access point. Additional scenarios examined the impact of intermediate right-hand ramps between the entrance (or exit) ramp and the managed lane access point.

Conclusions

Several conclusions can be drawn from the simulation results:

- Throughout the simulations, the ramp to managed lane flow (v_{rm}) (or the managed lane to ramp flow (v_{mr}), in the case of exit ramps) is the key factor to consider when establishing the proper value for the distance between the right-side ramp and the access point for the managed lane.

- The ramp flow itself (v_r), which includes the traffic weaving over to the managed lane, has a significant impact on the capacity of the ramp junction (i.e., in the immediate vicinity of the ramp), which, in turn, can impact the weaving distance for the managed lane, especially at high ramp flows.
- In conditions with no intermediate ramps between the entrance ramp and the access to the managed lane (or between the access point and the exit ramp), maximum capacity was guaranteed for distances of 4000 feet. (In many cases, maximum capacity was found for shorter distances.)
- The flow from the general purpose lanes to the managed lane (v_{fm}, or v_{mf} in the case of exit ramps) was found to have little impact in this work. However, if the access point to the managed lane is modelled as a Type A weaving area instead of an exit or entrance ramp, a more significant impact may be found. This should not have a large impact on the required distance between a right-hand entrance ramp and the access point (or between the access point and a right-hand exit ramp) because the capacity problem will be the ability of the vehicles to weave into the managed lane.
- The impact of trucks in the traffic stream appears to be larger than what is predicted by the Highway Capacity Manual for level terrain.
- The presence of intermediate ramps tend to decrease the capacity, with a greater effect found when the intermediate ramp is close to the entrance ramp (scenario 4) or close to the exit ramp (scenario 5). This is likely due to the concentration of flows in the right lanes of the general purpose lanes in the vicinity of the ramps. The impact is more pronounced at higher ramp flows, as well.

Recommendations

Recommended minimum and desirable weaving distances are summarized in table 7.1. These were developed as follows:

- The key factor in determining the required weaving distance was the ramp to managed lane flow (or the managed lane to ramp flow in the exit ramp case), as mentioned above. In the simulations, the capacity increased as the weaving distance increased to a point where the maximum capacity was found. Minimum required lengths were selected where the increase in capacity levelled off.

- Of course, the flow in the general purpose lanes has a large impact on this distance as well, but the assumption here is that, when capacity is a concern, the flow in the general purpose lanes will not be low. The values summarized here are for flows in the general purpose lanes that are typical for moderate to heavy flows.
- The presence of intermediate ramps had little effect on the overall weaving distance, although they could reduce the realized capacity. The intermediate ramps had a larger impact on ramp junction capacity in the right general purpose lanes.
- Other traffic entering or leaving the managed lane will likely have an impact on the capacity of the access point to the managed lane, but should not affect the overall weaving distance reported here. If many vehicles are entering or leaving the managed lane (by making lane changes into or out of the left general purpose lane), the capacity of the access point may be approached. This was not evaluated in this project.
- For almost all conditions, a weaving distance of 4000 feet yielded maximum capacity. (In many cases, maximum capacity was found for shorter distances.) As such, 4000 feet is recommended here as the desirable weaving distance. At higher flows, the increase in capacity only appeared to level off when the distance was approaching 4000 feet. Given the difficulty in weaving across congested general purpose lanes, a direct connection to the managed lane should be considered if the ramp to managed lane (or managed lane to ramp) flow is also high.
- The simulations (and the data collection) only examined cases with four general purpose lanes. The required weaving distances can be expressed in terms of the distance required for each lane changed. This has not been checked for any condition other than when four general purpose lanes must be crossed.

Future Research

Three areas have an immediate need for further work. First, the interaction of the traffic weaving in and out of the managed lane (a Type A weave) with the traffic weaving over from an upstream entrance ramp or a downstream exit ramp (a Type C weave) should be investigated. Under some flow conditions, the Type A weave may restrict the capacity of the Type C weave, although it does not appear likely to impact the weaving length as investigated in this study.

Table 7.1. Recommendations for minimum weaving distance between a right-side entrance ramp and the left-side access to a managed lane (v_{rm}) or between the left-side access to a managed lane and a right-side exit ramp (v_{mr})

	Weaving Distance			
	Minimum		Desirable	
v_{rm} or v_{mr}, veh/hour	Four general purpose lanes, feet	Per general purpose lane, feet/lane	Four general purpose lanes, feet	Per general purpose lane, feet/lane
up to 200	2000	500	4000	1000
200 to 300	2500	625	4000	1000
300 to 400	3000	750	4000	1000
over 400	3500	875	4000*	1000*

*A direct connection to the managed lane should be considered.

Second, freeway sections with three and five general purpose lanes should be investigated. The weaving distance may be proportional, as suggested in table 7.1, or it may not.

Third, an alternate to finding a desirable weaving length would be to determine the length that results in a (for example) level of service D. While capacity is an important design constraint, traffic flow is generally transient at capacity; a slight fluctuation can cause the traffic to break down. The design could be based on the value of the ramp to managed lane flow that results in the desired level of service for given flow level and weaving length.

REFERENCES

1. *High Occupancy Vehicle (HOV) Guidelines for Planning, Design, and Operations,* Division of Traffic Operations, Department of Transportation (Caltrans), Business, Transportation and Housing Agency, State of California, July 1991.

2. C.A. Fuhs, *High Occupancy Vehicle Facilities: A Planning, Design, and Operation Manual,* Parsons Brinckerhoff, Quade and Douglas, Incorporated, New York, NY, 1990.

3. K. Turnbull , D. Capelle, *HOV Systems Manual*, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, February 1998.

4. S. Venglar, D. Fenno, S. Goel, P. Schrader, *Managed Lanes–Traffic Modeling,* TxDOT Research Report FHWA/TX-02/4160-4, Texas Transportation Institute, January 2002.

5. *Highway Capacity Manual*, Highway Research Board, 2000.

6. B. Kuhn, G. Goodin, A. Ballard, M. Brewer, R. Brydia, J. Carson, S. Chrysler, T. Collier, K. Fitzpatrick, D. Jasek, C. Toycen, G. Ullman, *Managed Lanes Handbook,* TxDOT Research Report FHWA/TX-06/0-4160-24, Texas Transportation Institute, October 2005.

7. *Design Manual,* Washington State Department of Transportation, June 2005.

8. K. Fitzpatrick, M. Brewer, S. Venglar, *Managed Lane Ramp and Roadway Design Issues,*TxDOT Research Report FHWA/TX-03/4160-10, Texas Transportation Institute, January 2003.

9. *HOV System Manual,* NCHRP Report 414, Texas Transportation Institute, 1998.

10. *Highway Capacity Manual*, Highway Research Board, 1950.

11. *Highway Capacity Manual*, Special Report 87, Highway Research Board, 1965.

12. *Highway Capacity Manual*, Special Report 209, Highway Research Board, 1985.

13. *Highway Capacity Manual*, Special Report 209, Highway Research Board, 1994.

14. L.J. Pignataro, W.R. McShane, R.P. Roess, B. Lee, K.W. Crowley, *Weaving Areas: Design and Analysis,* NCHRP Report 159, Transportation Research Board, 1975.

15. J.E. Leisch, *Completion of Procedures for Analysis and Design of Weaving Sections*, Volume I and II, Federal Highway Administration, 1978.

16. W. Reilly, H. Kell, P. Johnson, *Weaving Analysis Procedures for the New Highway Capacity Manual*, JHK and Associates, August 1984.

17. J. Fazio, N.M. Rouphail, *Freeway Weaving Sections: Comparisons and Refinement of Design and Operations Analysis Procedure*, Transportation Research Record 1091, Transportation Research Board, 1986.

18. M. Cassidy, A. Skabardonis, A.D. May, *Operation of Major Freeway Weaving Sections: Recent Empirical Evidence*, Transportation Research Record 1225, Transportation Research Board, 1989.

19. M.J. Cassidy, A.D. May, *Proposed Analytical Technique for Estimating Capacity and Level of Service of Major Freeway Weaving Sections*, Transportation Research Record 1320, Transportation Research Board, 1991.

20. M.H. Wang, M.J. Cassidy, P.Chan, A.D. May, *Evaluating the Capacity of Freeway Weaving Sections,* Journal of Transportation Engineering, Vol. 119, Nr.3, American Society of Civil Engineers, 1993.

21. M.C. Pietrzyk, M.L. Perez, *Weaving Selection Length Analysis: A Planning Design Approach*, ITE Journal, Volume 60, Nr. 6, June 1990.

22. M. Kuwahara, M. Koshi, T. Suzuki, *Capacity and Speed of Weaving Sections of the Tokyo Metropolitan Expressway*, ITE Journal, Volume 61, Nr. 3, March 1991.

23. V. Alexiadias, P.D. Muzzey, O.J. Macdonald, *Weaving Operations in Boston*, ITE Journal, Volume 63, Nr. 5, May 1993.

24. R. Vermijs, *New Dutch Capacity Standards for Freeway Weaving Sections Based on Micro Simulation*, Proceedings of the Third International Symposium on Highway Capacity, R. Rysgaard, editor, Road Directorate, Ministry of Transport, Denmark (publisher), 1998.

25. R.W. Denney, J.C. Williams, *Capacity and Quality of Service of Weaving Zones*, NCHRP 3-55(5), National Cooperative Highway Research Program, Transportation Research Board, 2004.

26. P. Vo, *Capacity Estimation of Two-Sided Type C Weaves on Freeways*, Ph.D. dissertation, University of Texas at Arlington.

27. P. Lertworawanich, L. Elefteriadou, *Capacity Estimations for Type B Weaving Areas Using Gap Acceptance*, Transportation Research Record 1776, National Academy Press, 2001, pp. 24-34.

28. D.R. Drew, L.R. Lamotte, J.H. Buhr, J.A. Wattleworth, *Gap acceptance in the freeway merging process,* HRR 208, 1967, pp. 1-36.

29. P. Lertworawanich, L. Elefteriadou, *A methodology for estimating capacity at ramp weaves based on gap acceptance and linear optimization*, Transportation Research 37B, 2003, pp. 459-483.

30. D. Gerlough, M. Huber, *Traffic Flow Theory: A Monograph*, Transportation Research Board Special Report 165, Transportation Research Board, 1975.

31. VISSIM 4.10 User Manual, PTV Planug Transport Verkehr AG, March 2005.

32. R. L. Cheu, W. W. Recker, S. G. Ritchie, *Calibration of INTRAS for simulation of 30-sec loop detector output*, Transportation Research Record 1457, Transportation Research Board, National Research Council, Washington, D.C., 1994, pp. 202-215.

33. R. L. Cheu, X. Jin, K. C. Ng, Y. L. Ng, D. Srinivasan, *Calibration of FREESIM for Singapore Expressway Using Genetic Algorithm,* Journal of Transportation Engineering, ASCE, December 1998, pp. 526-535.

34. D. Lee, X. Yang, P. Chandrasekar, *Parameter Calibration for PARAMICS Using Genetic Algorithm*, Transportation Research Board 80th Annual Meeting Compendium of Papers (CD-ROM), Transportation Research Board, National Research Council, Washington, D.C., 2001.

35. B. Park, J. D. Schneeberger, *Microscopic Simulation Model Calibration and Validation: A Case Study of VISSIM for a Coordinated Actuated Signal System*, Transportation Research Board 81s Annual Meeting Compendium of Papers (CD-ROM), Transportation Research Board, National Research Council, Washington, D.C., 2002.

36. W. Zhizhou, S. Jian, Y. Xiaoguang, *Calibration of VISSIM for Shanghai Expressway Using Genetic Algorithm,* Proceedings of the 2005 Winter Simulation Conference, ed. L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, 2005, pp. 2645 – 2648.

37. G. Gomes, A.D. May, R. Horowitz, *Calibration of VISSIM for a congested highway*, Presented at the 83th Annual Meeting of the Transportation Research Board, Washington D.C., 2004.

38. J.H. Bank, *Flow Processes at a Freeway Bottleneck,* Transportation Research Record 1287, Transportation Research Board, 1990.

39. K. Agyeman-Duah, F.L. Hall, *Some Issues Regarding the Numerical Value of Freeway Capacity,* Highway Capacity and Level of Service, International Symposium on Highway Capacity, Karlsruhe, 1991, pp. 1-15.

APPENDIX A
FREE FLOW SPEEDS

Free flow speeds were used in the calibration of the simulation model as described in chapter 4. Free flow speeds collected at site 2 on 6 April 2008 from 7:30 to 10:30 am are shown in table A.1, and free flow speeds collected at site 1 on 11 May 2008 from 7:30 to 10:30 am are shown in table A.2. Speeds for cars and trucks are listed separately for each data set. Both data sets were collected on Sunday mornings, when traffic is generally lightest on IH 635, and drivers are more likely to be travelling at their desired speeds. Cars or trucks which were following other vehicles were not included in the data set, as these drivers were not travelling at their desired speeds.

Table A.1. Free-flow speeds (miles/hr), 7:30 - 10:30 am on Sunday, 6 April 2008, at site 2.

Free-Flow Speeds for Cars									
67	67	72	73	70	67	62	71	73	71
71	62	69	66	72	68	71	68	65	64
61	68	70	64	74	78	66	76	74	66
68	70	69	69	70	67	65	64	66	70
68	64	66	75	73	68	71	69	72	68
74	72	63	77	69	69	67	62	73	69
69	71	68	65	69	73	75	66	72	67
59	73	65	62	70	72	66	66	71	71
68	76	66	65	69	73	69	73	63	68
62	75	71	69	75	71	65	69	67	68
74	63	67	59	70	65	68	73	78	72
73	68	71	71	69	72	73	73	71	72
70	64	72	65	70	71	76	60	69	74
71	63	75	67	70	64	72	60	63	71
70	66	67	66	75	69	73	69	66	70
69	63	72	72	72	67	72	75	65	60
64	62	69	64	72	65	68	72	67	70
61	60	68	66	77	60	70	61	71	67
67	76	70	61	69	65	64	67	68	68
70	63	75	61	73	61	74	73	69	71
60	65	66	71	71	68	71	76	70	68
70	73	71	71	69	76	68	58	59	72
69	76	69	67	74	71	69			
Free-Flow Speeds for Trucks									
66	60	59	65	63	65	63	63	62	61
69	61	65	63	64	64	69	59	66	64
67	65	63	64	61	67	67	62	67	66
65	66	58	65	64	67	70	70	73	68
63	66	60	62	66	66	60	59	65	63
62	62	66	65	58	64	64	63	61	66
62	60	64	65	65	65	61	64	63	61
62	64	64	65	62					

Table A.2. Free-flow speeds (miles/hr), 7:30 - 10:30 am on Sunday, 11 May 2008, at site 1.

Free-Flow Speeds for Cars									
70	65	70	74	70	67	63	75	64	71
67	75	64	72	61	66	65	75	67	73
65	68	70	74	78	62	62	75	75	67
69	74	71	73	72	70	68	72	67	69
73	71	68	69	73	68	67	69	70	68
74	69	68	67	61	60	74	67	73	66
62	67	67	61	65	65	73	70	75	76
61	66	70	74	60	64	74	67	72	66
73	72	67	63	61	65	70	71	73	76
69	68	70	73	64	72	76	71	64	66
64	67	67	63	77	65	70	64	65	71
68	58	66	70	75	72	63	67	67	76
63	74	62	71	78	69	69	72	66	74
67	65	66	69	77	68	72	71	59	68
58	67	69	68	67	67	68	75	60	73
61	68	68	70	65	71	60	67	76	62
60	75	63	61	76	70	71	68	63	72
69	59	62	62	65	69	69	67	73	67
69	75	70	69	72	63	67	67	68	68
65	65	75	68	59	69	75	73	69	70
71	68	61	67	64	66	77	71	71	71
72	66	74	66	62	65	70	69	70	70
72	65	75	60	63	69	75	65	65	64
71	73	72	70	61	68	74	60	66	67
72	78	67	69	68	72	71	59	67	77
69	66	69	61	75	72	65			
Free-Flow Speeds for Trucks									
62	67	66	70	68	62	63	63	66	64
61	68	64	65	66	65	66	69	65	62
66	65	62	62	66	64	62	64	66	63
64	64	64	64	63	63	66	66	63	62
67	62	66	64	65	60	67	63	61	65
66	61	67	67	65	67	66	62	62	58
65	68	64	64	66	64	63	67	65	60
64	67	66	66	66	66	64	62		

APPENDIX B
ORIGIN-DESTINATION FLOWS

Origin-destination flows were drawn from the data collected during the two study periods at the two sites on IH 635 in Dallas. (The data collection was described in Chapter XX.) Each hour of data collection was broken into ten minute time periods, and origin-destination flows are reported for each of these periods in the four tables in this appendix.

In these tables, the origins are listed in the left column of each table, with the destinations across the top row. In site 1, the origins (where traffic entered the site) are:

- GPL (up) – upstream end of the general purpose lanes
- ML (up) – upstream end of the managed lane
- NB DNT – entrance ramp from northbound Dallas North Tollway
- SB DNT – entrance ramp from southbound Dallas North Tollway
- Dallas Parkway entrance ramp
- Midway entrance ramp

The destinations in site 1 (where traffic left the site) are:

- Midway exit ramp
- Marsh exit ramp
- Webb Chapel exit ramp
- GPL (down) – downstream end of the general purpose lanes
- ML (down) – downstream end of the managed lane

The origins in site 2 are:

- GPL (up) – upstream end of the general purpose lanes
- ML (up) – upstream end of the manage lane
- NB IH 35E – entrance ramp from northbound IH 35E
- SB IH 35E – entrance ramp from southbound IH 35E
- Denton Drive entrance ramp
- Webb Chapel entrance ramp

The destinations in site 2 are:

- Josey exit ramp

- Webb Chapel exit ramp
- GPL (down) – downstream end of the general purpose lanes
- ML (down) – downstream end of the managed lane

These locations are shown in figures XXXXX (site 1) and XXXX (site 2). All values in the tables represent 10-minute counts.

Special symbols indicate the provenance of each of the counts, and are defined below, along with other notes regarding the origin-destination counts.

Notes:

[xx] – traffic volume counted from video recorded from a DalTrans surveillance camera

(xx) – traffic volume directly counted by an observer

{xx} – traffic volume counted from video recorded on a research team camera

xx* – no camera or observer at this location, however, traffic volumes could be derived based on volumes counted by the above three methods

xx^ – no camera or observer at this location, assumed traffic volume

1, 2, 3, 6, and 7 (superscripts) – approximately 1, 2, 3, 6, and 7 minute travel times between the origin and destination, respectively. Traffic data were collected for one hour at each location. The missed traffic volume due to the travel time was estimated as: (matched traffic volume)×(travel time)÷(60-travel time)

m1 (superscript) – the volume count at the entrance ramp from the SB Dallas North Tollway was started two minutes late by mistake. The missed traffic volume was estimated as: (traffic volume for 58 minutes)×2÷58.

m2 (superscript) – the volume count at the entrance ramp from Midway was ended five minutes early by mistake. The missed traffic was estimated as: (traffic volume for 55 minutes)×5÷55.

m3 (superscript) – the volume count at the entrance ramp from SB IH 35E was started two minutes late by mistake. The missed traffic was estimated as: (traffic volume for 58 minutes)×2÷58.

Table B.1. Origin-destination volumes at site 1 during AM study.

Origin-Destination Volume Matrix, 10:20 - 10:30 AM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 107*	Marsh (61)	Webb Chapel (94)	GPL (down) 1077*	ML (down) {65}
GPL (up) [891]	95*	44*	76*	660*	16*
ML (up) {50}	–	0	1	9*	40
NB DNT [31](32)	7^	4[2]	0[2]	18*	2[1]
SB DNT [141](142)[m1]	5^	3[2]	12[2]	119*	2[1]
Dallas Parkway (143)	0^	5[2]	3[2]	133*	2[1]
Midway {148}(149)	–	5[1]	2[1]	138*	3

Origin-Destination Volume Matrix, 10:30 - 10:40 AM at Site 1.

Origin \ Destination (vehs/ 10 mins)	Midway 146*	Marsh (74)	Webb Chapel (94)	GPL (down) 1020*	ML (down) {70}
GPL (up) [920]	136*	60*	80*	624*	20*
ML (up) {59}	–	0	0	15*	44
NB DNT [37](38)	4^	2	2	28*	1
SB DNT [142](143)	6^	3	3	128*	2
Dallas Parkway[127](127)	0^	4	6	114*	3
Midway {119}(120)	–	5	3	111*	0

Origin-Destination Volume Matrix, 10:40 - 10:50 AM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 131*	Marsh (82)	Webb Chapel (95)	GPL (down) 1045*	ML (down) {75}
GPL (up) [913]	126*	69*	74*	625*	19*
ML (up) {63}	–	0	1	13*	49
NB DNT [35](36)	3^	2	0	29*	1
SB DNT [151](152)	2^	1	7	141*	0
Dallas Parkway[130](131)	0^	7	6	111*	6
Midway {136}(137)	–	3	7	126*	0

Origin-Destination Volume Matrix, 11:00 - 11:10 AM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 141*	Marsh (83)	Webb Chapel (94)	GPL (down) 998*	ML (down) {71}
GPL (up) [872]	122*	61*	75*	604*	10*
ML (up) {62}	–	2	0	7*	53
NB DNT [53](54)	12^	7	2	31*	1
SB DNT [138](139)	7^	4	7	116*	4
Dallas Parkway[127](128)	0^	5	7	115*	0
Midway {135}(136)	–	4	3	125*	3

Table B.1. Origin-destination volumes at site 1 during AM study, continued.

Origin-Destination Volume Matrix, 11:10 - 11:20 AM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 136*	Marsh (82)	Webb Chapel (94)	GPL (down) 1018*	ML (down) {77}
GPL (up) [880]	124*	66*	72*	608*	10*
ML (up) {70}	–	0	1	10*	59
NB DNT [45](47)	7^	4	0	34*	0
SB DNT [123](124)	5^	3	6	104*	5
Dallas Parkway[145](146)	0^	6	11	125*	3
Midway {144}(145)	–	3	4	137*	0

Origin-Destination Volume Matrix, 11:20 - 10:30 AM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 115*	Marsh (83)	Webb Chapel (95)	GPL (down) 1093*	ML (down) {81}
GPL (up) [928]	104*	56*	75*	684*	9*
ML (up) {67}	–	2[2]	1[2]	3*	61
NB DNT [35](36)	8^	6	1	19*	1
SB DNT [116](117)	3^	2	6	99*	6
Dallas Parkway[162](162)	0^	8	8	144*	2
Midway {159}(160)	–	9	4	144*	2

Table B.2. Origin-destination volumes at site 1 during PM study.

Origin-Destination Volume Matrix, 3:25 - 3:35 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 219*	Marsh (91)	Webb Chapel (163)	GPL (down) 1005*	ML (down) {191}
GPL (up) [960]	193*	63*	126*	570*	8*
ML (up) {166}	–	6	6	6*	148
NB DNT [46](47)	9^	3[6]	2[6]	30*	2[3]
SB DNT [124](124)	17^	6[6]	8[6]	79*	14[3]
Dallas Parkway[207](207)	0^	6[6]	11[6]	177*	13[3]
Midway (166)	–	7[3]	10[3]	143*	6

Origin-Destination Volume Matrix, 3:35 - 3:45 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 177*	Marsh (104)	Webb Chapel (163)	GPL (down) 1072*	ML (down) {240}
GPL (up) [959]	157*	79*	128*	569*	26*
ML (up) {202}	–	3	3	16*	180
NB DNT [60](61)	7^	3	3	44*	3
SB DNT [147](147)	13^	6	7	110*	11
Dallas Parkway[222](222)	0^	6	11	195*	10
Midway (166)	–	7	11	138*	10

Origin-Destination Volume Matrix, 3:45 - 3:55 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 230*	Marsh (83)	Webb Chapel (169)	GPL (down) 1045*	ML (down) {233}
GPL (up) [971]	213*	56*	123*	568*	11*
ML (up) {215}	–	6	10	19*	180
NB DNT 62 (63)	10^	3	1	44*	4
SB DNT [156](157)	7^	2	10	123*	14
Dallas Parkway[189](189)	0^	13	12	152*	12
Midway (167)	–	3	13	139*	12

Origin-Destination Volume Matrix, 3:55 - 4:05 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 245*	Marsh (83)	Webb Chapel (149)	GPL (down) 974*	ML (down) {220}
GPL (up) [921]	200*	52*	111*	548*	10*
ML (up) {196}	–	4	12	11*	169
NB DNT [60](61)	14^	4	4	36*	2
SB DNT [140](140)	31^	9	5	81*	14
Dallas Parkway[188](188)	0^	5	8	160*	15
Midway (166)	–	9	9	138*	10

Table B.2. Origin-destination volumes at site 1 during PM study, continued.

Origin-Destination Volume Matrix, 4:05 - 4:15 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 128*	Marsh (78)	Webb Chapel (150)	GPL (down) 969*	ML (down) {248}
GPL (up) [769]	103*	48*	101*	503*	14*
ML (up) {253}	–	7	16	29*	201
NB DNT [68](69)	7^	3	4	52*	2
SB DNT [159](159)	18^	8	8	113*	12
Dallas Parkway[158](158)	0^	6	12	131*	9
Midway (166)	–	6	9	141*	10

Origin-Destination Volume Matrix, 4:15 - 4:25 PM at Site 1.

Origin \ Destination (vehs/10 mins)	Midway 170*	Marsh (78)	Webb Chapel (185)	GPL (down) 991*	ML (down) {204}
GPL (up) [920]	148*	55*	129*	587*	1*
ML (up) {210}	–	6 [3]	17 [3]	11*	176
NB DNT [59](61)	8^	3	6	40*	2
SB DNT [130](131)	14^	5	11	90*	10
Dallas Parkway[142](142)	0^	3	12	116*	11
Midway (167) [m2]	–	6	10	147*	4

Table B.3. Origin-destination volumes at site 2 during AM study.

Origin-Destination Volume Matrix, 10:40 - 10:50 AM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [75] (76)	Webb Chapel [44] (43)	GPL (down) 1065*	ML (down) {116}
GPL (up) [465]	54*	23*	358	30*
ML (up) {59}	0	0	7*	52 [2]
NB IH 35E [350](354)	15 [1]	15 [1]	309*	11 [2]
SB IH 35E [199](199) [m3]	6 [1]	4 [1]	167*	22 [2]
Denton [85](85)	0	2	82*	1 [2]
Webb Chapel [142]	–	–	142	–

Origin-Destination Volume Matrix, 10:50 - 11:00 AM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [71] (72)	Webb Chapel [54] (53)	GPL (down) 1108*	ML (down) {115}
GPL (up) [466]	48*	38*	339*	41*
ML (up) {39}	0	0	4*	35
NB IH 35E [361](365)	14	9	332*	6
SB IH 35E [250](250)	6	4	209*	31
Denton [88](88)	3	3	80*	2
Webb Chapel [144]	–	–	144	–

Origin-Destination Volume Matrix, 11:00 - 11:10 AM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [89] (91)	Webb Chapel [54] (53)	GPL (down) 1112*	ML (down) {118}
GPL (up) [498]	59*	34*	370*	35*
ML (up) {47}	1	0	6*	40
NB IH 35E [417](421)	22	14	369*	12
SB IH 35E [203](203)	5	5	164*	29
Denton [74](74)	2	1	69*	2
Webb Chapel [134]	–	–	134	–

Origin-Destination Volume Matrix, 11:10 - 11:20 AM at Site 2

Origin \ Destination (vehs/10 mins)	Josey [71] (72)	Webb Chapel [62] (61)	GPL (down) 1195*	ML (down) {112}
GPL (up) [510]	51*	43*	379*	37*
ML (up) {55}	0	1	11*	43
NB IH 35E [405](409)	12	15	367*	11
SB IH 35E [231](231)	5	2	205*	19
Denton [98](98)	3	1	92*	2
Webb Chapel [141]	–	–	141	–

Table B.3. Origin-destination volumes at site 2 during AM study, continued.

Origin-Destination Volume Matrix, 11:20 - 11:30 AM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [86] (88)	Webb Chapel [59] (58)	GPL (down) 1178*	ML (down) {111}
GPL (up) [470]	54*	35*	354*	27*
ML (up) {55}	1	0	4*	50
NB IH 35E [406](410)	20	11	361*	14
SB IH 35E [230](230)	7	6	199*	18
Denton [97](97)	4	7	84*	2
Webb Chapel [176]	–	–	176	–

Origin-Destination Volume Matrix, 11:30 - 11:40 AM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [81] (82)	Webb Chapel [65] (64)	GPL (down) 1223*	ML (down) {146}
GPL (up) [527]	53*	45*	385*	44*
ML (up) {66}	0[1]	0[1]	8*	58
NB IH 35E [412](416)	17	13	368*	14
SB IH 35E [247](247)	9	4	206*	28
Denton [105](105)	2	3	98*	2
Webb Chapel [158]	–	–	158	–

Table B.4. Origin-destination volumes at site 2 during PM study.

Origin-Destination Volume Matrix, 3:45 - 3:55 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [148] (149)	Webb Chapel (130)	GPL (down) 1004*	ML (down) {214}
GPL (up) [483]	68*	82*	308*	25*
ML (up) {137}	8	5	13*	111 [7]
NB IH 35E [486](487)	51 [2]	31 [2]	367*	37 [7]
SB IH 35E [143](142)	11 [3]	6 [3]	96*	30 [7]
Denton [101](101)	10	6	74*	11 [7]
Webb Chapel [146]	–	–	146	–

Origin-Destination Volume Matrix, 3:55 - 4:05 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [166] (167)	Webb Chapel (92)	GPL (down) 910*	ML (down) {189}
GPL (up) [453]	88*	48*	274*	43*
ML (up) {112}	3	3	17*	89
NB IH 35E [460](461)	52	30	348*	30
SB IH 35E [124](123)	10	7	90*	17
Denton [103] (103)	13	4	76*	10
Webb Chapel [105]	–	–	105	–

Origin-Destination Volume Matrix, 4:05 - 4:15 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [191] (192)	Webb Chapel (93)	GPL (down) 902*	ML (down) {199}
GPL (up) [458]	93*	46*	273*	46*
ML (up) {130}	4	4	30*	92
NB IH 35E [447](448)	66	32	314*	35
SB IH 35E 130 (129)	15	6	89*	20
Denton [96](96)	13	5	72*	6
Webb Chapel [124]	–	–	124	–

Origin-Destination Volume Matrix, 4:15 - 4:25 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [154] (155)	Webb Chapel (99)	GPL (down) 931*	ML (down) {209}
GPL (up) [436]	59*	51*	299*	27*
ML (up) {133}	7	7	17*	102
NB IH 35E [462](463)	62	24	341*	35
SB IH 35E [131](130)	14	10	74*	33
Denton [100](100)	12	7	69*	12
Webb Chapel [131]	–	–	131	–

Table B.4. Origin-destination volumes at site 2 during PM study, continued.

Origin-Destination Volume Matrix, 4:25 - 4:35 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [183] (184)	Webb Chapel (85)	GPL (down) 910*	ML (down) {228}
GPL (up) [465]	91*	54*	273*	47*
ML (up) {157}	11	5	40*	101
NB IH 35E [424](425)	61	20	303*	40
SB IH 35E [129](128)	4	4	91*	30
Denton [89](89)	16	2	61*	10
Webb Chapel [142]	–	–	142	–

Origin-Destination Volume Matrix, 4:35 - 4:45 PM at Site 2.

Origin \ Destination (vehs/10 mins)	Josey [112] (114)	Webb Chapel (99)	GPL (down) 1029*	ML (down) {285}
GPL (up) [464]	41*	52*	308*	63*
ML (up) {188}	17 [3]	8 [3]	51*	112
NB IH 35E [459](460)	35	29	350*	45
SB IH 35E [145](144)	10	4	82*	49
Denton [123](123)	9	6	92*	16
Webb Chapel [146]	–	–	146	–

APPENDIX C
CALIBRATION OF THE SIMULATION MODEL

The simulation model was calibrated with a genetic algorithm process as described in chapter 5. Eleven user-adjustable parameters (listed and defined in table 5.1) were selected for the calibration process. The process started with the first generation:

- ten models were created, each one consisting of a randomly selected value for each of the eleven parameters (within the acceptable range of each parameter),
- each of the ten models were then evaluated against sixteen selected results,
- each model (candidate solution) then ranked by how close each came to the field data, and
- the better ranked solutions (models) were used to "breed" the next "generation" of candidate solutions (models).

The process was followed for twenty generations for both data sets (moderate flow and heavy flow conditions).

The sixteen selected results that were used to compare the simulations with the observed data were

- volumes entering the managed lane from the general purpose lanes at four specific locations within the entry area for the managed lane,
- volume of high occupant vehicles entering the study section in lanes 1, 2, 3, and 4,
- volume of high occupant vehicles leaving the study section in lanes 1, 2, 3, and 4, and
- average speeds in lanes 1, 2, 3, and 4 of the general purpose lanes.

In this appendix, the calibration data for the moderate flow condition is shown in table C.1, and for the heavy flow condition, table C.2. Within each table, each generation is represented in two sub-tables. The first shows the parameter values used in each of the ten models in that generation. "Default" refers to the default value of each of the parameters in the simulation model. The second shows the simulated values for the sixteen selected results along with the fitness value for each. "Field data" is the collected data that is used as a basis in evaluating the fitness of each of the ten models in that generation.

Table C.1. Calibration of moderate flow traffic (AM).

Generation1: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2250	-12	-9	10	0.15	9.5	1.05	15	-15	-1.8	1.8
Model 2	4750	-18	-15	6	0.50	6.5	1.10	23	-5	-1.4	1.4
Model 3	4250	-13	-10	4	0.00	8.5	0.85	10	-14	-2.4	2.4
Model 4	3250	-20	-17	18	0.20	7.0	1.15	18	-11	-0.8	0.8
Model 5	4500	-15	-12	12	0.25	4.5	0.95	11	-7	-0.6	0.6
Model 6	1750	-14	-11	20	0.80	9.0	1.00	20	-9	-1.0	1.0
Model 7	2000	-11	-8	14	0.05	7.5	0.70	28	-10	-1.6	1.6
Model 8	3500	-19	-16	16	0.65	10.0	0.80	30	-13	-2.0	2.0
Model 9	4000	-16	-13	28	0.70	5.5	1.20	24	-12	-0.2	0.2
Model 10	1500	-17	-14	20	0.35	4.0	0.75	35	-8	-1.2	1.2

Generation1: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	70	103	124	133	1	10	21	93	0	2	10	54	53.0	56.4	58.3	58.6	11.8
Model 2	82	104	125	132	0	0	1	125	1	3	12	50	50.6	54.1	56.5	57.6	14.7
Model 3	81	105	128	133	0	0	0	124	2	3	13	49	49.6	53.6	56.4	57.3	14.9
Model 4	80	94	125	134	0	1	2	122	1	2	9	54	55.4	59.3	61.8	62.5	10.6
Model 5	81	93	124	133	0	1	1	124	1	2	9	55	57.6	62.2	64.7	65.1	9.55
Model 6	62	102	115	122	9	26	32	51	0	1	4	52	24.9	27.0	28.2	29.1	48.7
Model 7	62	82	120	133	4	13	33	75	0	1	9	56	57.9	61.2	62.5	62.1	13.3
Model 8	80	100	125	132	0	1	5	120	1	4	9	53	49.7	51.9	53.4	54.4	16.8
Model 9	79	100	123	131	0	1	4	120	1	2	8	56	44.8	47.8	49.2	51.1	21.5
Model 10	35	64	109	130	30	34	32	29	0	1	8	57	54.7	57.0	57.3	57.6	28.8

Generation 2: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4750	-18	-15	10	0.60	6.5	1.10	15	-15	-1.8	1.8
Model 2	2250	-12	-9	6	0.50	9.5	1.05	23	-5	-1.4	1.4
Model 3	3250	-20	-17	18	0.00	8.5	0.85	10	-11	-0.8	0.8
Model 4	4250	-13	-10	30	0.20	7.0	1.15	18	-14	-2.4	2.4
Model 5	3500	-19	-16	16	0.65	10.0	0.70	30	-13	-1.6	1.6
Model 6	2000	-19	-16	14	0.05	7.5	0.80	28	-10	-2.0	2.0
Model 7	4000	-16	-13	12	0.25	5.5	1.20	11	-7	-0.2	0.2
Model 8	2750	-15	-12	28	0.70	4.5	0.95	24	-12	-2.4	2.4
Model 9	2750	-15	-12	12	0.20	9.0	0.95	11	-11	-0.8	0.8
Model 10	3250	-20	-17	18	0.25	4.5	1.15	26	-7	-0.6	0.6

Generation 2: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	106	125	131	0	0	1	123	1	4	12	49	47.8	51.2	53.8	55.3	17.1
Model 2	62	93	120	130	5	18	30	74	0	1	12	53	50.9	53.5	54.9	55.3	18.2
Model 3	81	90	125	134	0	1	1	123	2	2	8	55	59.4	63.3	65.4	65.7	10.0
Model 4	77	108	121	126	0	0	0	118	2	3	14	48	43.2	47.2	50.2	51.7	19.5
Model 5	79	90	122	132	0	1	5	119	1	2	9	55	56.2	59.2	60.7	61.3	10.0
Model 6	64	87	121	134	2	9	32	82	0	2	8	57	57.9	60.8	62.5	62.2	11.5
Model 7	81	91	125	133	0	1	2	123	2	2	8	55	55.3	59.8	62.5	63.4	10.6
Model 8	69	99	120	131	2	12	20	92	0	2	10	54	44.0	45.7	45.7	46.0	22.2
Model 9	75	88	122	133	1	3	12	110	0	1	9	57	58.3	61.9	63.9	63.9	7.4
Model 10	80	95	124	133	0	1	3	122	2	2	7	55	55.3	59.4	61.6	62.3	11.3

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 3: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-15	-12	12	0.60	6.5	0.95	35	-11	-1.8	1.8
Model 2	4750	-18	-15	10	0.75	9.0	1.10	15	-15	-2.2	2.2
Model 3	3250	-12	-9	18	0.00	7.5	0.80	10	-10	-2.0	2.0
Model 4	2000	-19	-16	14	0.05	8.5	0.85	28	-11	-0.8	0.8
Model 5	2250	-12	-9	6	0.50	4.5	1.15	23	-5	-0.6	0.6
Model 6	3250	-20	-17	18	0.25	9.5	1.05	13	-7	-1.4	1.4
Model 7	3500	-19	-16	26	0.65	10.0	0.95	11	-11	-0.8	0.8
Model 8	2750	-15	-12	12	0.20	9.0	0.70	30	-13	-1.6	1.6
Model 9	3500	-16	-13	12	0.65	5.5	0.75	30	-7	-0.2	0.2
Model 10	1500	-19	-16	16	0.25	10.0	0.70	11	-13	-1.6	1.6

Generation 3: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	75	104	124	131	2	7	17	100	0	2	9	54	43.3	45.2	45.9	46.2	21.2
Model 2	77	108	119	125	0	0	0	118	1	4	12	48	42.6	46.1	48.5	50.4	20.9
Model 3	81	92	126	134	0	1	2	123	1	2	8	56	59.2	62.8	64.7	64.8	10.2
Model 4	65	86	120	133	2	9	31	83	0	1	8	58	58.6	62.5	64.2	64.4	11.0
Model 5	61	85	116	130	5	18	30	73	0	1	7	59	54.7	57.5	58.9	59.3	17.1
Model 6	80	95	125	134	0	1	3	122	1	2	10	53	55.7	59.4	61.4	62.1	10.1
Model 7	78	91	122	131	0	1	5	119	0	3	8	55	56.4	59.5	61.1	62.0	10.1
Model 8	76	88	124	134	1	2	9	114	0	1	11	57	58.7	62.1	64.0	63.8	7.8
Model 9	79	88	122	131	0	2	5	119	1	2	8	56	59.1	63.1	65.2	65.5	8.9
Model 10	35	59	109	131	29	34	34	28	0	1	8	58	59.0	62.0	63.3	63.1	26.0

Generation 4: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3250	-19	-16	14	0.00	7.5	0.85	28	-10	-2.0	2.0
Model 2	2000	-12	-9	18	0.05	8.5	0.80	10	-11	-0.8	0.8
Model 3	4750	-18	-15	10	0.50	4.5	1.15	15	-15	-0.6	0.6
Model 4	2250	-12	-9	6	0.75	5.0	1.10	23	-5	-2.2	2.2
Model 5	3750	-16	-13	18	0.25	9.5	0.75	13	-13	-0.2	0.2
Model 6	3250	-20	-17	12	0.40	5.5	1.05	30	-7	-1.4	1.4
Model 7	3500	-16	-13	12	0.65	9.0	0.75	11	-7	-1.6	1.6
Model 8	2750	-15	-12	8	0.20	5.5	0.70	30	-13	-0.2	0.2
Model 9	2750	-15	-12	12	0.20	10.0	1.00	11	-11	-0.8	0.8
Model 10	3500	-19	-16	26	0.65	9.0	0.95	30	-13	-1.6	1.6

Generation 4: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	94	125	134	0	0	1	124	1	2	9	54	56.5	60.2	62.1	62.3	10.4
Model 2	61	79	118	132	5	12	32	77	0	1	8	58	59.5	63.0	64.4	64.2	13.3
Model 3	81	93	124	131	0	0	1	125	1	2	10	53	54.3	58.4	60.9	62.0	11.2
Model 4	72	107	119	127	4	13	24	82	1	2	10	51	40.6	42.5	43.4	44.2	26.3
Model 5	80	89	124	134	0	1	2	123	2	2	8	56	59.1	63.2	65.4	65.6	10.1
Model 6	78	95	124	133	0	2	4	120	1	2	11	52	53.5	57.0	59.2	59.7	11.1
Model 7	78	89	122	132	1	2	5	118	1	2	8	55	59.0	62.1	63.9	64.1	8.5
Model 8	75	87	121	132	0	4	8	114	0	0	10	54	59.9	64.1	65.9	65.7	8.2
Model 9	75	88	123	133	1	3	10	111	0	1	10	57	57.7	61.5	63.5	63.9	7.4
Model 10	80	104	125	132	0	1	3	121	1	3	9	55	45.5	47.4	48.5	49.3	21.8

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 5: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4250	-15	-12	8	0.00	7.5	0.85	30	-13	-2.0	2.0
Model 2	3250	-19	-16	14	0.10	5.5	0.70	28	-14	-0.2	0.2
Model 3	3250	-20	-17	12	0.40	9.5	0.75	13	-7	-0.2	0.2
Model 4	3750	-16	-13	18	0.25	5.5	1.05	30	-13	-1.4	1.4
Model 5	4750	-15	-12	12	0.50	4.5	1.00	15	-15	-0.6	0.6
Model 6	2750	-18	-15	10	0.55	10.0	1.15	27	-11	-0.8	0.8
Model 7	2750	-15	-12	8	0.20	6.5	0.70	30	-11	-0.8	0.8
Model 8	2750	-18	-15	28	0.20	5.5	1.00	11	-13	-0.2	0.2
Model 9	2000	-12	-9	12	0.65	9.0	0.80	11	-11	-1.6	1.6
Model 10	3500	-16	-13	18	0.05	8.5	0.75	10	-7	-1.6	1.6

Generation 5: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	98	126	134	0	0	0	125	2	2	9	54	53.1	57.1	59.3	59.6	13.6
Model 2	79	88	124	133	0	1	3	122	2	2	8	56	59.9	64.2	66.3	66.1	10.5
Model 3	78	88	122	132	1	1	4	119	1	2	7	57	59.9	63.9	65.6	65.7	9.8
Model 4	82	95	126	133	0	0	1	125	1	2	9	54	52.6	56.4	58.7	59.2	14.0
Model 5	81	92	124	132	0	0	1	125	1	2	12	52	56.4	60.8	63.4	64.2	8.6
Model 6	76	107	124	130	1	3	15	104	0	2	9	55	43.6	46.9	48.3	49.2	19.1
Model 7	76	87	122	133	0	3	7	116	0	1	10	56	59.0	62.9	65.0	64.5	8.4
Model 8	75	87	121	133	1	3	8	113	0	1	9	57	58.5	62.4	64.2	64.8	7.9
Model 9	52	76	111	126	11	23	33	58	0	2	9	54	57.4	59.6	60.1	60.8	17.9
Model 10	80	92	124	134	0	1	1	124	2	2	7	56	59.1	62.9	65.1	65.2	10.4

Generation 6: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3250	-20	-17	12	0.20	6.5	0.75	13	-11	-0.8	0.8
Model 2	1500	-15	-12	20	0.40	9.5	0.70	30	-7	-0.2	0.2
Model 3	4250	-15	-12	8	0.25	5.5	0.85	14	-13	-1.4	1.4
Model 4	3750	-16	-13	18	0.00	7.5	1.05	30	-13	-2.0	2.0
Model 5	3500	-15	-12	12	0.50	4.5	1.00	10	-15	-0.6	0.6
Model 6	4750	-16	-13	18	0.05	8.5	0.75	15	-7	-1.6	1.6
Model 7	4750	-15	-12	28	0.20	6.5	0.70	11	-13	-0.2	0.2
Model 8	2750	-18	-15	8	0.55	5.5	1.00	30	-11	-0.8	0.8
Model 9	3250	-19	-16	28	0.50	5.5	1.00	28	-9	-0.2	0.2
Model 10	2750	-18	-15	14	0.10	5.5	1.15	11	-13	-0.2	0.2

Generation 6: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	88	123	133	0	1	3	122	1	2	8	56	60.1	63.9	65.9	66.1	10.4
Model 2	37	63	105	129	32	30	31	32	0	1	9	56	56.9	59.6	60.2	59.7	25.7
Model 3	81	90	125	134	0	0	1	124	2	2	7	55	57.9	62.0	64.4	64.9	10.0
Model 4	79	107	127	130	0	0	0	123	2	4	14	46	45.8	49.4	52.1	53.4	18.5
Model 5	80	88	122	132	0	1	4	121	1	2	8	55	57.8	61.9	63.9	64.8	9.0
Model 6	81	91	126	134	0	0	1	125	2	3	11	51	57.3	61.2	63.4	63.4	8.9
Model 7	81	89	124	134	0	0	1	125	2	2	10	53	59.1	63.5	65.8	66.0	9.6
Model 8	74	90	120	131	1	6	15	104	0	2	9	56	55.4	58.4	60.0	60.5	8.4
Model 9	80	92	122	132	0	1	4	120	1	2	8	56	55.5	59.6	61.3	61.9	10.5
Model 10	78	93	125	137	1	3	6	119	0	2	9	56	57.0	61.4	63.4	64.0	8.4

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 7: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4250	-15	-12	8	0.25	6.5	0.75	14	-11	-0.8	0.8
Model 2	3250	-20	-17	12	0.20	5.5	0.85	13	-13	-1.4	1.4
Model 3	4750	-16	-13	18	0.40	9.5	0.75	15	-7	-1.6	1.6
Model 4	3750	-15	-12	20	0.05	8.5	0.90	30	-7	-0.2	0.2
Model 5	3500	-17	-14	12	0.20	6.5	0.70	10	-13	-0.2	0.2
Model 6	4750	-15	-12	28	0.50	4.5	1.00	11	-15	-1.2	1.2
Model 7	3000	-15	-12	20	0.55	9.5	1.00	20	-11	-0.8	0.8
Model 8	2750	-18	-15	8	0.40	5.5	0.70	30	-7	-0.2	0.2
Model 9	2500	-18	-15	8	0.10	5.0	1.00	11	-13	-0.2	0.2
Model 10	2750	-18	-15	14	0.55	5.5	1.15	30	-11	-0.8	0.8

Generation 7: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	80	90	124	134	0	0	0	125	2	2	9	55	58.8	63.1	65.6	65.8	10.1
Model 2	79	89	124	134	0	1	3	122	1	2	9	55	59.3	63.1	65.0	65.4	9.5
Model 3	81	91	124	134	0	0	1	125	1	2	12	52	57.3	61.1	63.2	63.3	8.5
Model 4	80	91	125	134	0	0	2	124	2	1	7	57	57.4	61.9	64.3	64.8	10.6
Model 5	79	87	124	133	0	1	2	123	2	1	8	56	60.1	64.3	66.4	66.4	11.1
Model 6	82	92	124	132	0	0	0	125	1	3	9	53	56.1	59.7	61.8	62.8	10.6
Model 7	73	91	120	131	1	6	13	105	0	2	9	55	55.3	58.4	59.7	60.6	8.6
Model 8	74	84	119	131	1	5	10	111	0	0	11	56	60.0	64.3	65.8	65.6	8.0
Model 9	75	89	122	133	1	4	10	111	0	1	8	58	58.8	63.0	65.0	65.3	8.1
Model 10	74	99	122	131	1	7	17	101	0	1	9	57	45.0	47.6	48.8	48.9	19.3

Generation 8: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3750	-15	-12	20	0.40	9.5	0.90	15	-7	-1.6	1.6
Model 2	4750	-16	-13	18	0.05	8.5	0.75	30	-7	-0.2	0.2
Model 3	2250	-15	-12	20	0.50	4.5	1.00	11	-11	-0.8	0.8
Model 4	3000	-15	-12	28	0.55	9.5	0.95	20	-15	-1.2	1.2
Model 5	2500	-18	-15	8	0.10	5.5	1.00	30	-7	-0.8	0.8
Model 6	2750	-18	-15	8	0.40	5.0	0.70	11	-13	-0.6	0.6
Model 7	4250	-15	-12	8	0.25	6.5	0.75	30	-7	-0.2	0.2
Model 8	2750	-13	-10	8	0.40	8.0	0.70	14	-11	-0.8	0.8
Model 9	2500	-18	-15	8	0.10	5.0	1.00	13	-13	-1.4	1.4
Model 10	3250	-20	-17	12	0.20	5.5	0.85	11	-13	-0.2	0.2

Generation 8: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	93	123	131	0	0	2	121	0	2	8	56	54.6	58.2	60.2	60.9	12.3
Model 2	81	92	125	134	0	0	1	125	2	3	9	53	57.6	62.3	64.8	65.0	9.4
Model 3	60	80	115	129	6	15	25	80	0	1	9	57	58.0	61.1	61.7	62.5	12.5
Model 4	72	91	121	132	1	5	15	104	0	2	9	56	55.7	58.5	59.7	60.2	8.2
Model 5	74	90	123	134	1	4	10	112	0	1	8	58	57.5	61.4	63.5	63.5	8.2
Model 6	73	85	120	132	1	5	10	110	0	1	8	57	60.5	64.5	66.3	66.1	8.6
Model 7	82	91	124	134	0	0	1	125	1	2	8	54	58.1	62.7	65.2	65.3	9.7
Model 8	73	85	121	132	1	6	16	104	0	1	9	56	60.2	63.8	65.7	65.5	7.0
Model 9	77	92	124	134	0	4	10	112	0	1	7	58	58.2	61.9	63.8	64.0	8.5
Model 10	79	89	123	133	0	1	3	122	1	1	8	56	59.5	63.8	65.8	65.8	10.1

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 9: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2500	-18	-15	8	0.05	8.5	1.00	18	-7	-0.2	0.2
Model 2	4750	-16	-13	18	0.80	5.5	0.75	30	-7	-0.8	0.8
Model 3	2750	-18	-15	8	0.55	5.0	0.70	11	-15	-1.2	1.2
Model 4	3000	-15	-12	28	0.40	9.5	0.95	16	-13	-0.6	0.6
Model 5	2500	-18	-15	20	0.25	6.5	1.00	13	-7	-0.2	0.2
Model 6	4250	-15	-12	8	0.10	5.0	1.05	30	-13	-1.4	1.4
Model 7	3000	-15	-12	28	0.55	8.0	0.70	20	-11	-0.8	0.8
Model 8	1750	-13	-10	8	0.40	9.5	0.95	14	-15	-1.2	1.2
Model 9	3250	-20	-17	12	0.20	8.0	0.70	11	-13	-0.8	0.8
Model 10	2750	-11	-8	8	0.40	5.5	0.85	14	-11	-0.2	0.2

Generation 9: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	75	89	122	133	1	3	10	111	0	1	6	59	58.2	62.2	64.2	64.1	8.6
Model 2	80	89	121	131	0	0	3	122	1	2	10	53	57.0	60.8	62.6	63.1	8.8
Model 3	71	82	119	132	2	7	14	103	0	1	10	56	60.1	63.6	65.4	65.2	6.9
Model 4	74	89	121	132	1	5	10	110	0	2	8	57	57.3	61.0	62.4	63.2	8.0
Model 5	72	87	120	133	2	5	12	107	0	0	7	59	58.5	62.5	64.2	64.4	8.0
Model 6	83	99	129	137	0	0	1	128	1	2	9	54	52.6	56.7	59.4	59.4	14.4
Model 7	74	87	121	131	1	3	12	109	0	2	9	55	58.9	62.4	63.5	63.8	6.6
Model 8	49	79	115	131	12	31	36	48	0	2	9	56	57.1	60.2	61.3	61.9	20.0
Model 9	80	90	124	134	0	1	2	122	2	2	7	56	60.2	64.0	66.0	65.9	10.6
Model 10	73	84	119	131	2	6	14	105	0	1	8	57	59.5	63.4	64.8	65.0	7.1

Generation 10: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	1500	-18	-15	8	0.05	9.5	0.95	18	-7	-0.6	0.6
Model 2	2500	-15	-12	12	0.40	8.5	1.00	16	-13	-0.2	0.2
Model 3	2750	-18	-15	8	0.55	5.0	0.70	11	-15	-1.2	1.2
Model 4	2500	-18	-15	20	0.25	6.5	1.00	13	-7	-1.0	1.0
Model 5	4750	-16	-13	18	0.80	5.5	0.70	30	-7	-0.2	0.2
Model 6	2750	-11	-8	8	0.40	5.5	0.75	14	-11	-0.8	0.8
Model 7	2750	-18	-15	8	0.55	8.0	1.10	11	-11	-0.8	0.8
Model 8	4000	-15	-12	28	0.55	5.0	0.70	20	-15	-1.2	1.2
Model 9	3000	-15	-12	28	0.20	8.0	1.05	11	-13	-0.8	0.8
Model 10	3250	-20	-17	12	0.55	8.0	0.85	20	-11	-0.8	0.8

Generation 10: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	75	89	122	133	1	3	10	111	0	1	6	59	58.2	62.2	64.2	64.1	25.7
Model 2	80	89	121	131	0	0	3	122	1	2	10	53	57.0	60.8	62.6	63.1	7.7
Model 3	71	82	119	132	2	7	14	103	0	1	10	56	60.1	63.6	65.4	65.2	7.0
Model 4	74	89	121	132	1	5	10	110	0	2	8	57	57.3	61.0	62.4	63.2	6.4
Model 5	72	87	120	133	2	5	12	107	0	0	7	59	58.5	62.5	64.2	64.4	8.3
Model 6	83	99	129	137	0	0	1	128	1	2	9	54	52.6	56.7	59.4	59.4	7.7
Model 7	74	87	121	131	1	3	12	109	0	2	9	55	58.9	62.4	63.5	63.8	7.8
Model 8	49	79	115	131	12	31	36	48	0	2	9	56	57.1	60.2	61.3	61.9	9.4
Model 9	80	90	124	134	0	1	2	122	2	2	7	56	60.2	64.0	66.0	65.9	9.1
Model 10	73	84	119	131	2	6	14	105	0	1	8	57	59.5	63.4	64.8	65.0	7.7

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 11: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2500	-18	-15	20	0.25	8.5	1.00	13	-9	-1.2	1.2
Model 2	2500	-15	-12	12	0.40	6.5	1.00	16	-7	-1.0	1.0
Model 3	1500	-18	-15	8	0.55	5.5	0.70	30	-15	-0.2	0.2
Model 4	4750	-16	-13	18	0.80	5.0	0.70	16	-7	-0.2	0.2
Model 5	3000	-15	-12	28	0.20	8.0	0.75	11	-13	-0.8	0.8
Model 6	2750	-11	-8	8	0.40	5.5	1.05	14	-11	-0.8	0.8
Model 7	2750	-18	-15	8	0.55	5.0	1.00	13	-7	-1.2	1.2
Model 8	2500	-18	-15	20	0.25	6.5	0.95	18	-15	-1.0	1.0
Model 9	3250	-20	-17	12	0.45	8.0	1.10	20	-11	-0.8	0.8
Model 10	2750	-18	-15	8	0.55	7.0	0.85	11	-11	-0.8	0.8

Generation 11: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	74	94	121	133	1	6	13	106	0	2	9	56	57.2	60.4	62.2	62.4	7.3
Model 2	69	90	120	132	2	7	19	97	0	1	7	58	57.7	60.9	62.5	62.9	8.3
Model 3	34	58	103	126	32	33	32	29	0	2	9	56	59.7	63.0	63.9	63.9	25.2
Model 4	80	88	120	130	0	1	3	121	0	2	10	55	59.1	63.0	64.9	65.2	8.9
Model 5	78	91	124	133	0	2	6	117	0	3	7	56	60.2	63.8	65.6	65.6	9.4
Model 6	73	90	121	131	1	5	14	105	0	1	9	56	58.1	61.6	63.6	64.3	6.2
Model 7	71	91	120	131	1	7	16	101	0	2	9	56	58.2	61.4	63.2	63.9	6.1
Model 8	73	92	121	133	2	4	15	104	0	1	8	57	58.5	62.0	63.8	64.1	6.5
Model 9	79	97	124	133	0	1	5	120	1	2	9	55	54.7	58.0	60.1	61.2	11.2
Model 10	70	88	119	130	3	7	15	101	0	1	10	55	59.4	63.0	64.6	65.1	6.4

Generation 12: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4750	-16	-13	20	0.25	5.0	0.70	13	-9	-1.2	1.2
Model 2	2500	-18	-15	18	0.80	8.5	1.00	16	-7	-0.2	0.2
Model 3	3000	-16	-13	8	0.20	8.0	0.75	20	-7	-1.2	1.2
Model 4	2750	-15	-12	28	0.55	5.0	1.00	13	-13	-0.8	0.8
Model 5	3250	-11	-8	8	0.40	6.5	1.00	14	-11	-1.0	1.0
Model 6	2500	-15	-12	12	0.45	5.5	1.05	16	-7	-0.8	0.8
Model 7	2750	-18	-15	8	0.40	5.5	1.05	13	-7	-0.8	0.8
Model 8	2750	-11	-8	12	0.55	5.0	1.00	14	-11	-1.2	1.2
Model 9	3500	-18	-15	8	0.25	6.5	0.85	18	-15	-1.0	1.0
Model 10	2500	-18	-15	20	0.65	7.0	0.95	11	-11	-0.8	0.8

Generation 12: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	93	124	133	0	1	1	124	2	2	10	53	57.8	62.4	64.6	64.9	8.8
Model 2	64	91	115	127	6	16	27	76	1	2	8	54	45.3	47.4	47.4	49.1	24.0
Model 3	77	91	122	133	1	3	5	117	0	3	10	54	59.6	63.4	65.4	65.3	8.3
Model 4	69	90	120	130	2	8	20	96	0	2	9	56	57.4	60.4	61.6	62.4	8.1
Model 5	79	93	123	132	0	2	6	118	1	3	7	56	57.8	61.8	63.7	64.3	8.7
Model 6	69	89	119	131	3	8	21	94	0	1	10	56	57.4	60.7	61.8	62.5	8.1
Model 7	74	92	121	132	1	5	12	108	0	1	10	55	57.8	61.6	63.4	63.9	6.4
Model 8	68	90	119	129	2	10	20	94	0	2	10	55	57.7	60.7	62.1	62.7	7.7
Model 9	80	93	123	132	0	0	2	121	2	4	7	54	58.8	62.8	65.1	65.3	9.7
Model 10	64	86	117	129	4	13	23	85	0	2	8	56	57.5	60.4	61.0	61.8	10.9

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 13: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4750	-11	-8	12	0.25	6.0	0.70	14	-9	-1.2	1.2
Model 2	2750	-16	-13	20	0.55	5.0	1.00	13	-11	-0.6	0.6
Model 3	3250	-11	-8	8	0.40	8.0	0.75	14	-11	-0.4	0.4
Model 4	3000	-16	-13	8	0.20	6.5	0.90	20	-7	-1.0	1.0
Model 5	2750	-18	-15	8	0.40	6.5	0.95	13	-15	-1.0	1.0
Model 6	3500	-18	-15	8	0.25	5.5	0.85	18	-7	-0.8	0.8
Model 7	2750	-11	-8	12	0.55	5.0	1.00	18	-9	-0.8	0.8
Model 8	3000	-18	-15	8	0.40	5.5	1.05	14	-8	-1.2	1.2
Model 9	2500	-15	-12	12	0.45	5.0	1.05	13	-13	-0.8	0.8
Model 10	2750	-15	-12	28	0.55	5.5	1.00	16	-7	-0.8	0.8

Generation 13: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	81	92	124	133	0	0	0	126	2	2	10	53	58.6	62.9	65.1	65.5	9.4
Model 2	70	89	119	130	2	8	20	96	0	1	9	56	58.0	61.1	62.4	63.2	7.7
Model 3	78	89	121	131	0	2	6	118	1	2	7	57	59.8	63.6	65.3	65.6	9.4
Model 4	77	93	123	133	0	3	5	118	0	2	8	56	58.9	62.7	64.7	65.0	8.9
Model 5	75	89	121	132	1	5	12	108	0	2	9	56	58.7	62.2	64.0	64.3	6.8
Model 6	80	93	123	133	1	1	2	122	2	1	7	57	59.2	63.4	65.6	65.9	10.3
Model 7	72	92	119	130	1	8	20	97	0	1	8	56	57.3	60.5	61.6	62.6	8.0
Model 8	77	94	122	133	0	3	10	113	0	2	8	56	57.7	61.0	63.2	63.7	7.7
Model 9	69	90	118	132	2	10	20	94	0	1	9	57	57.4	60.8	62.5	63.2	8.3
Model 10	70	88	119	131	2	9	17	98	0	1	9	56	57.4	60.5	61.5	62.6	7.8

Generation 14: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-16	-13	20	0.50	5.5	1.00	16	-7	-0.6	0.6
Model 2	2750	-15	-12	28	0.45	5.0	1.00	13	-11	-0.8	0.8
Model 3	2750	-18	-15	8	0.20	6.5	0.95	13	-7	-1.0	1.0
Model 4	3000	-16	-13	8	0.40	6.5	0.90	20	-7	-1.0	1.0
Model 5	3000	-18	-15	12	0.55	5.5	1.05	14	-9	-0.8	0.8
Model 6	2750	-11	-8	8	0.40	5.0	1.00	18	-8	-1.2	1.2
Model 7	2500	-15	-12	12	0.45	8.0	0.75	14	-11	-0.4	0.4
Model 8	3250	-11	-8	8	0.55	5.0	1.05	16	-13	-0.8	0.8
Model 9	2750	-14	-11	8	0.50	5.5	1.05	14	-8	-1.2	1.2
Model 10	3000	-18	-15	8	0.40	6.5	0.95	18	-15	-1.0	1.0

Generation 14: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	72	91	121	131	2	7	15	102	0	1	8	57	57.4	60.6	61.8	62.3	7.5
Model 2	72	88	121	132	1	7	14	103	0	2	9	56	58.0	61.3	62.7	63.5	6.7
Model 3	76	92	123	133	0	3	8	115	0	1	11	56	58.5	62.3	64.2	64.4	7.7
Model 4	76	91	124	133	1	3	9	113	0	2	7	57	58.4	62.2	63.9	64.4	8.0
Model 5	73	91	120	131	1	5	14	106	0	2	10	54	57.5	60.9	62.5	63.1	5.8
Model 6	72	89	120	132	1	7	16	102	0	1	9	56	57.9	61.4	63.2	63.6	6.3
Model 7	68	86	120	132	2	10	18	97	0	0	8	58	60.0	63.5	65.1	65.1	8.6
Model 8	77	91	121	130	1	3	8	115	1	3	9	53	57.0	60.6	62.5	63.5	7.4
Model 9	72	89	120	130	2	6	17	101	0	1	10	55	56.9	60.1	61.8	62.2	6.6
Model 10	76	93	122	132	1	3	9	113	0	3	9	55	58.1	61.9	63.7	64.1	7.2

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 15: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-18	-15	12	0.45	5.0	1.00	13	-6	-0.8	0.8
Model 2	2750	-15	-12	28	0.55	5.5	0.85	14	-11	-2.4	2.4
Model 3	2750	-16	-13	20	0.50	5.5	1.05	16	-8	-1.2	1.2
Model 4	3000	-14	-11	8	0.50	6.0	1.00	35	-7	-0.6	0.6
Model 5	2750	-11	-8	12	0.55	5.5	1.05	18	-9	-0.8	0.8
Model 6	3000	-18	-15	8	0.40	5.0	1.00	14	-8	-1.2	1.2
Model 7	3000	-18	-15	8	0.40	6.5	0.95	13	-7	-1.0	1.0
Model 8	2750	-18	-15	10	0.20	6.5	0.95	18	-7	-0.2	0.2
Model 9	3250	-11	-8	8	0.55	5.0	1.00	18	-13	-1.2	1.2
Model 10	2750	-11	-8	8	0.40	5.0	1.05	16	-8	-0.8	0.8

Generation 15: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	75	91	121	132	1	4	10	111	0	2	9	56	58.3	61.9	63.8	64.4	7.1
Model 2	69	90	119	131	3	9	17	97	0	2	9	55	56.3	58.9	59.9	59.9	8.7
Model 3	72	92	120	131	2	8	17	100	0	1	10	55	56.3	59.2	60.6	61.3	7.7
Model 4	73	94	121	131	1	5	12	108	0	2	8	56	53.7	56.9	58.5	59.0	10.6
Model 5	71	91	119	129	2	7	18	99	0	1	9	55	57.1	60.2	61.7	62.5	7.2
Model 6	75	90	121	132	2	4	10	111	0	3	8	56	58.1	61.7	63.4	63.8	7.4
Model 7	75	91	122	132	1	3	9	113	0	2	8	56	58.5	62.2	64.2	64.5	7.6
Model 8	76	92	123	133	0	3	9	114	0	1	10	56	58.6	62.8	64.8	64.8	7.5
Model 9	77	92	121	130	0	3	8	114	0	2	11	53	57.4	60.6	62.4	63.2	7.1
Model 10	72	90	121	131	1	7	15	102	0	1	10	56	57.7	61.2	63.1	63.6	6.3

Generation 16: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-16	-13	20	0.45	5.0	1.00	16	-6	-0.8	0.8
Model 2	3000	-18	-15	12	0.50	5.5	0.95	13	-8	-1.2	1.2
Model 3	3000	-17	-14	12	0.40	5.5	1.05	14	-8	-0.6	0.6
Model 4	2750	-11	-8	8	0.50	5.0	1.00	18	-9	-0.8	0.8
Model 5	3000	-18	-15	8	0.55	6.5	0.95	18	-13	-1.2	1.2
Model 6	3250	-15	-12	8	0.40	5.0	1.00	13	-7	-1.0	1.0
Model 7	3250	-14	-11	8	0.55	5.0	1.05	16	-13	-1.2	1.2
Model 8	2750	-11	-8	8	0.40	6.0	1.00	18	-8	-0.8	0.8
Model 9	2750	-18	-15	10	0.20	6.5	1.05	16	-8	-0.8	0.8
Model 10	2750	-11	-8	8	0.40	5.0	0.95	18	-7	-0.2	0.2

Generation 16: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	72	91	120	132	1	6	14	105	0	2	9	56	58.1	61.7	63.0	63.3	6.4
Model 2	75	90	121	131	2	4	9	111	0	3	8	55	58.5	62.0	63.4	63.9	7.3
Model 3	77	94	122	132	1	2	9	113	0	3	7	56	57.6	61.4	63.4	64.1	7.9
Model 4	72	89	119	130	2	8	15	101	0	1	8	57	57.9	61.5	63.2	63.6	7.3
Model 5	73	90	121	131	2	4	13	107	0	2	7	57	57.4	60.5	62.3	62.8	7.6
Model 6	80	94	122	132	0	1	4	120	1	2	7	56	58.2	61.8	63.6	64.2	9.4
Model 7	78	92	122	130	0	3	8	115	1	3	8	55	56.6	60.0	61.8	62.9	8.6
Model 8	72	91	121	132	2	6	14	104	0	1	9	57	57.8	61.6	63.2	63.6	6.4
Model 9	76	95	123	133	1	3	8	114	0	1	10	56	57.7	61.5	63.6	63.9	7.6
Model 10	72	89	119	131	2	4	16	104	0	1	9	57	58.7	62.4	64.0	64.2	6.1

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 17: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-18	-15	20	0.45	5.0	0.95	16	-6	-0.8	0.8
Model 2	2750	-16	-13	12	0.50	5.5	1.00	13	-8	-1.2	1.2
Model 3	3000	-17	-14	12	0.45	5.5	1.00	18	-8	-0.8	0.8
Model 4	2750	-11	-8	8	0.40	6.0	0.95	14	-8	-0.6	0.6
Model 5	2750	-16	-13	20	0.20	6.5	1.05	16	-6	-0.8	0.8
Model 6	2750	-18	-15	10	0.45	5.0	1.00	16	-8	-0.8	0.8
Model 7	2750	-18	-15	8	0.40	6.5	0.95	18	-13	-1.2	1.2
Model 8	3000	-11	-8	8	0.55	5.0	0.95	18	-7	-0.2	0.2
Model 9	2750	-15	-12	8	0.40	5.0	1.00	16	-8	-0.8	0.8
Model 10	2750	-15	-12	8	0.50	6.0	0.90	18	-9	-0.8	0.8

Generation 17: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	75	89	120	132	1	4	11	110	0	2	9	56	58.2	61.6	63.3	63.8	6.7
Model 2	70	88	120	130	2	8	18	99	0	1	10	55	58.2	61.2	62.7	63.4	6.5
Model 3	76	92	121	132	1	5	8	112	0	2	8	56	58.0	61.7	63.4	64.0	7.8
Model 4	73	90	120	130	1	6	14	105	0	1	10	56	58.4	62.3	64.1	64.5	6.3
Model 5	77	95	123	133	1	3	8	114	0	1	10	55	57.6	61.4	63.0	63.7	7.6
Model 6	70	86	116	128	2	4	14	101	0	1	11	54	58.3	62.1	64.0	64.3	5.5
Model 7	74	92	121	133	1	2	12	111	0	1	9	56	57.9	61.5	63.4	63.7	7.0
Model 8	72	89	121	128	1	7	14	103	0	1	8	56	58.6	62.2	63.8	64.5	6.5
Model 9	73	94	123	132	1	6	14	104	0	1	10	53	58.3	61.9	64.0	64.1	5.6
Model 10	74	91	121	134	2	7	14	106	0	0	10	58	58.9	62.6	64.3	64.4	6.9

Generation 18: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-18	-15	10	0.45	7.0	1.00	16	-8	-0.8	0.8
Model 2	3000	-18	-15	20	0.45	5.0	0.95	16	-6	-0.8	0.8
Model 3	2750	-15	-12	8	0.40	6.0	0.90	18	-9	-1.2	1.2
Model 4	2750	-15	-12	8	0.50	6.5	0.95	18	-13	-0.8	0.8
Model 5	3000	-11	-8	8	0.40	5.0	1.00	16	-8	-0.8	0.8
Model 6	2750	-15	-12	8	0.55	5.0	0.95	18	-7	-0.2	0.2
Model 7	2750	-15	-12	8	0.50	5.5	1.00	13	-8	-0.8	0.8
Model 8	2750	-16	-13	12	0.40	5.0	1.00	16	-8	-0.6	0.6
Model 9	2750	-11	-8	8	0.45	5.0	0.90	14	-8	-0.8	0.8
Model 10	2750	-18	-15	10	0.40	6.0	0.95	16	-8	-0.6	0.6

Generation 18: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	71	89	120	131	1	6	13	105	0	1	8	56	57.7	61.2	62.7	63.1	7.0
Model 2	73	87	118	130	1	4	10	109	0	2	10	55	58.2	61.6	63.3	63.8	6.4
Model 3	72	90	119	132	1	6	14	105	0	1	9	57	58.6	62.0	63.8	64.0	6.5
Model 4	72	90	119	133	2	7	18	100	0	1	8	57	58.2	61.9	63.5	64.0	6.8
Model 5	75	91	121	130	1	4	9	112	0	2	9	57	57.6	61.7	63.6	64.2	7.4
Model 6	69	86	117	128	3	10	19	95	0	1	8	56	58.5	62.1	63.6	64.0	7.8
Model 7	72	91	121	132	1	7	18	100	0	1	9	56	58.0	61.4	63.2	63.7	6.6
Model 8	73	89	122	133	1	4	17	104	0	1	9	57	58.3	62.2	64.1	64.4	6.1
Model 9	71	86	119	130	2	6	16	102	0	1	10	56	59.4	63.0	64.6	65.0	6.4
Model 10	73	89	121	132	1	5	11	109	0	2	9	56	57.0	62.7	63.4	65.9	6.0

Table C.1. Calibration of moderate flow traffic (AM), continued.

Generation 19: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-15	-12	8	0.50	6.0	0.90	18	-13	-0.6	0.6
Model 2	2750	-15	-12	8	0.40	6.5	0.95	13	-9	-1.2	1.2
Model 3	2750	-15	-12	8	0.50	5.5	1.00	16	-8	-0.6	0.6
Model 4	2750	-16	-13	12	0.40	5.0	1.00	13	-8	-0.8	0.8
Model 5	2750	-18	-15	10	0.40	5.0	0.90	14	-7	-0.8	0.8
Model 6	2750	-11	-8	8	0.45	6.0	0.95	16	-8	-0.6	0.6
Model 7	2750	-18	-15	10	0.40	6.0	0.90	16	-8	-0.6	0.6
Model 8	2750	-16	-13	12	0.40	5.0	0.95	16	-8	-0.6	0.6
Model 9	3000	-15	-12	20	0.45	7.0	1.00	16	-6	-0.8	0.8
Model 10	2750	-18	-15	10	0.45	5.0	0.95	16	-8	-0.8	0.8

Generation 19: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	73	88	120	132	2	6	16	103	0	1	9	57	58.5	62.1	63.8	64.2	6.4
Model 2	73	91	122	132	1	6	14	105	0	1	11	55	58.4	61.9	63.6	64.2	5.7
Model 3	70	89	119	130	1	9	17	98	0	1	8	58	57.9	61.6	63.3	63.8	7.6
Model 4	72	90	120	131	1	6	13	105	0	1	9	56	58.2	62.0	63.6	64.0	6.5
Model 5	76	91	124	136	1	4	15	109	0	1	10	56	59.3	63.0	64.8	65.0	6.8
Model 6	71	90	120	131	2	7	17	100	0	1	9	57	58.5	61.9	63.5	64.0	6.6
Model 7	77	92	124	135	1	5	11	112	0	1	9	57	59.1	62.7	64.5	64.7	8.0
Model 8	73	89	120	132	1	5	13	106	0	1	9	56	58.6	62.4	64.0	64.2	6.5
Model 9	76	92	122	132	1	3	12	111	0	2	9	56	57.4	61.0	62.5	63.2	7.3
Model 10	72	90	121	132	1	5	15	105	0	1	10	57	58.6	62.3	63.8	64.3	6.2

Generation 20: Parameter Values (AM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2750	-16	-13	12	0.40	6.5	0.95	13	-9	-1.2	1.2
Model 2	2750	-15	-12	8	0.40	5.0	1.00	13	-8	-0.8	0.8
Model 3	2750	-18	-15	10	0.45	5.0	0.95	14	-7	-0.8	0.8
Model 4	2750	-14	-11	10	0.40	5.0	0.90	16	-8	-0.8	0.8
Model 5	3000	-15	-12	20	0.45	7.0	1.00	18	-13	-0.6	0.6
Model 6	2750	-15	-12	8	0.50	6.0	0.90	16	-6	-0.8	0.8
Model 7	2750	-18	-15	10	0.45	6.5	0.95	13	-9	-1.2	1.2
Model 8	2750	-15	-12	8	0.40	5.0	0.90	16	-8	-0.8	0.8
Model 9	2750	-16	-13	12	0.40	6.0	0.95	16	-7	-0.6	0.6
Model 10	2750	-11	-8	8	0.45	5.0	0.95	20	-8	-0.6	0.6

Generation 20: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**68**	**91**	**108**	**133**	**1**	**2**	**17**	**104**	**1**	**2**	**15**	**47**	**57.0**	**62.7**	**63.4**	**65.9**	**0.0**
Model 1	74	91	121	132	2	5	13	107	0	1	11	54	58.4	62.0	63.8	64.2	5.7
Model 2	73	92	120	131	1	6	13	105	0	2	9	56	58.5	62.3	64.1	64.5	6.3
Model 3	73	90	120	131	1	5	12	107	0	1	9	56	58.8	62.3	64.0	64.4	6.9
Model 4	70	87	118	133	2	6	17	102	0	1	7	59	59.2	62.8	64.6	64.9	7.2
Model 5	73	91	121	130	1	5	12	107	0	3	8	57	57.0	60.5	62.0	62.7	7.5
Model 6	69	85	118	130	1	8	15	100	0	1	8	57	58.9	62.4	64.0	64.4	7.3
Model 7	69	88	116	128	2	5	12	102	0	2	11	53	59.4	61.3	63.5	63.8	5.7
Model 8	71	87	119	131	2	6	13	104	0	1	8	57	59.3	63.0	64.8	65.0	7.0
Model 9	73	90	120	132	1	6	13	106	0	2	11	54	58.4	62.1	63.7	64.0	5.5
Model 10	71	87	120	129	2	6	17	101	0	1	8	57	58.3	62.1	63.5	64.0	6.7

Table C.2. Calibration of heavy flow traffic (PM).

Generation 1: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	1750	-13	-10	4	0.25	4.5	0.70	11	-14	-2.4	2.4
Model 2	2000	-20	-17	18	0.80	7.0	0.80	20	-11	-0.8	0.8
Model 3	2250	-19	-16	14	0.55	5.5	0.75	13	-10	-0.8	0.8
Model 4	4750	-16	-13	28	0.65	6.0	0.75	13	-9	-0.4	0.4
Model 5	1500	-17	-14	20	0.70	5.5	1.05	24	-10	-1.6	1.6
Model 6	3250	-12	-9	10	0.35	4.0	1.10	15	-13	-2.0	2.0
Model 7	2750	-18	-15	16	0.15	9.5	0.85	10	-12	-0.2	0.2
Model 8	3500	-15	-12	12	0.50	6.5	1.15	10	-8	-1.2	1.2
Model 9	4000	-14	-11	20	0.00	8.5	0.95	18	-15	-1.8	1.8
Model 10	1500	-11	-8	14	0.20	9.0	1.00	35	-5	-1.4	1.4

Generation 1: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	52	105	187	261	32	66	61	71	8	17	35	124	15.7	21.8	25.5	27.2	34.2
Model 2	71	112	166	243	15	47	62	95	4	12	28	142	22.3	24.0	23.1	23.6	31.1
Model 3	84	134	191	265	11	30	59	139	5	14	34	133	19.3	24.7	27.2	29.4	20.7
Model 4	139	182	224	278	0	1	11	225	5	20	34	127	17.1	22.8	25.5	26.1	17.1
Model 5	31	65	116	210	47	61	42	39	6	16	26	142	24.9	25.6	23.8	23.3	39.3
Model 6	153	194	244	281	0	1	4	228	17	35	43	97	33.9	40.5	44.7	46.7	36.6
Model 7	148	206	262	281	1	3	18	208	5	19	42	127	12.5	19.5	25.8	29.7	17.8
Model 8	147	189	240	273	0	0	3	222	16	38	45	93	41.0	46.5	49.4	50.9	48.8
Model 9	154	196	253	279	0	0	3	222	32	46	40	75	43.1	47.8	51.1	52.9	56.3
Model 10	35	74	157	238	48	62	46	44	16	21	40	115	25.2	29.2	30.8	31.0	30.8

Generation 2: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4250	-18	-15	14	0.50	7.5	1.05	20	-9	-1.8	1.8
Model 2	1750	-13	-10	18	0.80	7.0	0.80	25	-14	-0.8	0.8
Model 3	2250	-19	-16	12	0.55	5.5	0.75	13	-11	-0.8	0.8
Model 4	4750	-16	-13	16	0.65	10.0	1.00	13	-9	-0.4	0.4
Model 5	3250	-17	-14	20	0.70	5.5	1.05	24	-13	-2.0	2.0
Model 6	1500	-12	-9	10	0.35	4.0	1.10	15	-10	-1.6	1.6
Model 7	2750	-18	-15	14	0.15	9.5	0.85	10	-5	-0.2	0.2
Model 8	1500	-11	-8	6	0.20	9.0	1.00	35	-12	-1.4	1.4
Model 9	2250	-13	-10	10	0.35	10.0	1.15	30	-7	-1.8	1.8
Model 10	5000	-12	-9	16	0.65	4.0	1.10	15	-13	-2.0	2.0

Generation 2: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	148	188	238	276	0	0	3	224	21	34	49	90	42.5	46.7	49.5	51.1	50.0
Model 2	38	69	116	218	38	67	57	52	5	15	27	138	26.4	24.8	21.2	20.1	42.7
Model 3	84	134	193	263	11	33	61	134	3	16	31	132	18.2	24.2	27.0	28.8	22.7
Model 4	148	187	229	266	0	1	3	223	8	25	35	118	24.0	29.9	32.9	35.0	14.2
Model 5	144	185	231	275	0	1	9	220	7	24	40	120	27.2	31.7	35.0	36.7	18.0
Model 6	31	64	142	241	49	77	60	43	9	25	37	119	33.2	37.1	35.8	33.9	46.6
Model 7	144	206	259	281	1	3	15	210	4	19	42	126	13.0	20.0	25.9	29.3	17.6
Model 8	33	75	158	231	47	64	51	42	15	23	37	118	24.0	28.3	30.9	32.1	30.7
Model 9	99	144	196	231	1	10	28	143	9	20	35	128	19.7	25.6	30.0	32.6	14.3
Model 10	139	177	226	267	0	0	4	225	12	31	49	98	39.9	43.3	44.6	44.8	40.3

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 3: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2250	-18	-15	10	0.55	5.5	0.75	13	-9	-0.8	0.8
Model 2	4500	-20	-17	28	0.15	6.0	0.75	30	-11	-1.8	1.8
Model 3	2250	-19	-16	28	0.15	5.5	1.05	30	-7	-2.0	2.0
Model 4	3250	-17	-14	20	0.70	6.0	0.75	27	-13	-0.6	0.6
Model 5	2250	-16	-13	16	0.35	10.0	1.15	30	-9	-1.8	1.8
Model 6	4750	-13	-10	10	0.70	10.0	1.00	13	-7	-0.4	0.4
Model 7	5000	-12	-9	16	0.65	4.0	0.80	25	-14	-0.8	0.8
Model 8	1750	-13	-10	18	0.80	7.0	1.10	15	-13	-2.0	2.0
Model 9	2750	-11	-8	24	0.35	4.0	0.85	15	-10	-1.6	1.6
Model 10	1500	-12	-9	14	0.15	9.5	1.10	10	-5	-0.2	0.2

Generation 3: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	87	133	192	262	11	33	55	140	4	14	31	130	18.5	24.3	27.3	29.6	21.2
Model 2	152	201	250	270	0	1	6	210	26	34	41	92	23.5	29.0	32.2	33.3	11.6
Model 3	126	180	234	253	0	4	19	176	15	25	39	114	22.1	28.4	33.3	35.9	11.2
Model 4	145	189	236	272	0	2	8	213	8	20	39	124	18.1	21.2	23.6	26.0	16.7
Model 5	108	159	206	231	1	6	25	148	11	23	37	122	19.7	25.6	30.3	33.2	13.1
Model 6	143	177	219	258	0	0	4	220	6	18	37	117	22.3	28.6	32.3	34.1	11.4
Model 7	146	189	233	270	0	0	3	221	9	20	33	123	17.3	21.6	24.2	25.7	18.1
Model 8	35	57	98	187	27	60	46	44	6	12	28	136	25.3	25.2	22.5	20.9	40.5
Model 9	119	161	215	279	2	11	36	187	5	17	38	128	16.3	22.7	26.5	27.8	16.0
Model 10	36	76	167	258	35	78	61	46	5	15	28	143	16.4	23.2	27.2	27.1	38.2

Generation 4: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	5000	-20	-17	28	0.65	4.0	0.80	30	-11	-0.8	0.8
Model 2	4250	-18	-15	16	0.15	6.0	0.75	25	-14	-1.8	1.8
Model 3	3250	-13	-10	15	0.35	4.0	1.10	15	-9	-2.0	2.0
Model 4	2250	-16	-13	20	0.35	10.0	1.15	30	-13	-0.6	0.6
Model 5	4750	-13	-10	10	0.70	5.5	1.05	30	-7	-0.8	0.8
Model 6	2250	-19	-16	28	0.15	10.0	1.00	13	-7	-2.0	2.0
Model 7	2250	-19	-16	24	0.35	4.0	0.85	15	-10	-2.4	2.4
Model 8	2750	-11	-8	4	0.25	4.5	1.15	20	-7	-1.6	1.6
Model 9	1750	-13	-10	4	0.05	4.5	0.70	15	-13	-2.0	2.0
Model 10	2250	-19	-16	18	0.80	7.0	1.10	20	-7	-2.4	2.4

Generation 4: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	154	199	245	274	0	1	3	219	10	24	40	117	18.2	21.8	24.2	26.5	16.1
Model 2	152	201	250	270	0	1	6	210	26	34	41	92	23.5	29.0	32.2	33.3	11.6
Model 3	150	192	248	282	0	0	5	227	17	35	48	92	37.0	43.0	46.4	47.8	41.1
Model 4	98	153	213	246	2	12	42	140	10	21	35	126	20.6	25.8	30.0	33.3	14.4
Model 5	137	176	219	259	0	0	3	220	8	21	37	119	20.6	25.1	28.4	30.4	10.1
Model 6	132	189	238	253	0	2	15	183	10	23	39	121	19.2	26.5	32.8	37.0	12.5
Model 7	129	184	241	281	2	11	36	180	9	20	40	124	21.5	27.7	32.1	34.5	10.4
Model 8	133	179	232	262	0	2	11	207	7	22	43	119	22.0	29.9	36.0	39.3	14.6
Model 9	55	113	198	273	27	67	62	77	11	20	36	124	17.3	23.7	27.5	28.9	29.1
Model 10	99	139	186	245	5	20	40	142	7	15	38	129	30.5	33.0	33.5	34.0	25.3

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 5: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2000	-16	-13	28	0.65	10.0	0.80	13	-11	-0.8	0.8
Model 2	5000	-20	-17	20	0.00	4.0	1.15	16	-13	-0.6	0.6
Model 3	3250	-13	-10	15	0.35	4.0	1.10	15	-9	-2.0	2.0
Model 4	4750	-13	-10	22	0.70	5.5	0.75	27	-7	-0.8	0.8
Model 5	2250	-11	-8	24	0.35	4.0	0.85	20	-10	-2.4	2.4
Model 6	2750	-19	-16	4	0.25	4.5	1.15	15	-7	-1.6	1.6
Model 7	4250	-18	-15	16	0.55	10.0	1.00	25	-7	-1.8	1.8
Model 8	2250	-19	-16	28	0.15	6.0	0.75	13	-14	-0.4	0.4
Model 9	4750	-13	-10	4	0.05	4.5	0.70	15	-10	-2.0	2.0
Model 10	1750	-13	-10	10	0.70	5.5	1.05	30	-13	-0.8	0.8

Generation 5: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	62	103	154	246	16	53	68	83	4	14	31	138	28.2	27.4	24.1	23.3	35.0
Model 2	158	214	264	271	0	0	1	215	25	32	40	96	14.8	22.6	28.7	30.6	14.9
Model 3	150	192	248	282	0	0	5	227	17	35	48	92	37.0	43.0	46.4	47.8	41.1
Model 4	151	191	229	270	0	0	4	218	10	21	35	122	19.3	22.7	24.7	26.2	15.2
Model 5	110	150	211	269	4	17	42	161	11	22	40	120	28.5	32.7	34.1	33.7	20.6
Model 6	152	198	255	282	0	0	5	224	10	32	51	101	29.4	37.3	43.0	46.7	29.7
Model 7	135	179	227	258	0	0	3	204	14	27	42	110	23.1	28.9	32.6	34.8	10.8
Model 8	113	179	238	284	3	15	42	175	8	19	32	134	14.8	22.0	26.9	29.3	18.3
Model 9	151	202	254	286	0	1	10	225	19	32	37	101	16.4	23.9	28.5	30.4	12.2
Model 10	37	61	112	204	40	66	51	49	7	13	26	138	27.2	26.8	24.4	23.5	39.7

Generation 6: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	2250	-19	-16	10	0.10	6.0	0.75	13	-11	-0.4	0.4
Model 2	2000	-16	-13	26	0.60	10.0	0.80	13	-14	-0.8	0.8
Model 3	4500	-13	-10	22	0.55	5.5	0.75	25	-9	-0.8	0.8
Model 4	4250	-18	-15	16	0.70	10.0	1.00	23	-7	-1.8	1.8
Model 5	2750	-20	-17	4	0.25	4.0	1.15	15	-13	-0.6	0.6
Model 6	3750	-19	-16	20	0.35	4.5	1.15	30	-7	-1.6	1.6
Model 7	4750	-13	-10	4	0.35	4.5	0.70	15	-13	-0.6	0.6
Model 8	5000	-20	-17	20	0.05	4.0	1.15	30	-10	-2.0	2.0
Model 9	2250	-11	-8	6	0.70	6.0	0.85	18	-10	-2.4	2.4
Model 10	3250	-17	-14	24	0.50	7.5	1.05	20	-9	-1.8	1.8

Generation 6: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	123	183	243	283	3	12	38	182	7	22	32	130	14.6	21.9	27.1	28.9	17.5
Model 2	68	108	160	254	15	51	68	92	4	14	28	140	24.6	26.8	25.2	24.3	30.4
Model 3	148	190	238	274	0	0	6	219	10	23	42	115	18.4	22.5	25.3	26.5	14.4
Model 4	140	184	226	264	0	0	4	215	11	29	42	108	27.7	32.6	35.6	37.7	19.0
Model 5	150	208	255	270	0	1	6	210	4	15	43	129	12.2	19.7	27.2	33.4	18.5
Model 6	143	193	241	263	0	0	2	206	18	34	43	98	22.0	28.7	33.9	36.7	11.7
Model 7	136	183	235	279	0	0	14	226	10	26	41	108	18.4	24.9	28.3	29.0	10.3
Model 8	143	195	240	252	0	0	3	196	32	36	39	87	20.9	28.5	33.6	35.8	13.9
Model 9	97	133	187	240	7	25	51	144	9	20	39	115	35.6	38.2	38.7	39.0	36.2
Model 10	149	193	245	281	0	1	5	224	9	34	44	105	30.0	35.9	39.8	42.5	26.6

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 7: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4500	-13	-10	22	0.10	6.0	0.75	25	-11	-0.4	0.4
Model 2	2250	-19	-16	10	0.55	5.5	0.75	13	-9	-0.8	0.8
Model 3	3500	-13	-10	4	0.25	4.0	0.90	15	-13	-0.6	0.6
Model 4	2750	-20	-17	12	0.35	4.5	1.15	15	-13	-0.6	0.6
Model 5	4250	-18	-15	16	0.50	7.5	1.05	20	-7	-1.8	1.8
Model 6	3250	-17	-14	24	0.70	10.0	1.00	23	-9	-1.8	1.8
Model 7	5000	-20	-17	20	0.25	8.0	1.15	30	-13	-0.6	0.6
Model 8	2750	-15	-12	4	0.05	4.0	0.95	15	-10	-2.0	2.0
Model 9	4750	-13	-10	4	0.40	4.5	1.15	30	-13	-0.6	0.6
Model 10	3750	-19	-16	20	0.35	6.0	0.70	15	-7	-1.6	1.6

Generation 7: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	154	204	253	275	0	0	4	217	18	29	44	102	16.7	21.5	24.2	25.1	17.0
Model 2	85	131	188	263	11	31	59	137	3	14	32	131	18.2	24.2	27.4	29.3	22.1
Model 3	146	188	241	277	0	2	13	219	6	26	37	117	14.0	20.8	26.1	28.5	17.4
Model 4	145	201	250	271	0	1	8	208	3	12	36	142	13.0	20.4	27.4	32.9	18.7
Model 5	146	189	240	277	0	0	3	225	20	38	47	88	41.9	45.7	48.4	49.8	48.4
Model 6	135	179	223	269	0	1	10	210	9	21	40	121	24.2	29.1	32.5	34.7	12.1
Model 7	138	187	233	251	0	0	2	195	22	36	40	95	20.6	26.9	31.6	34.2	10.3
Model 8	150	204	264	282	0	2	13	214	10	27	42	113	16.7	24.6	31.5	36.2	13.4
Model 9	141	183	231	260	0	0	2	212	11	28	40	113	19.1	24.4	29.4	32.4	10.1
Model 10	149	202	254	286	0	1	12	223	12	27	43	109	17.1	24.2	29.1	31.3	10.2

Generation 8: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4500	-13	-10	4	0.25	6.0	0.75	25	-11	-0.6	0.6
Model 2	3500	-13	-10	22	0.10	8.0	0.90	15	-13	-0.4	0.4
Model 3	3250	-17	-14	12	0.35	4.5	1.00	23	-13	-0.6	0.6
Model 4	2750	-20	-17	24	0.70	10.0	1.15	15	-9	-1.8	1.8
Model 5	2750	-13	-10	4	0.40	4.5	1.15	15	-10	-2.0	2.0
Model 6	4750	-15	-12	4	0.05	4.0	0.95	30	-13	-0.6	0.6
Model 7	3750	-13	-10	4	0.40	6.0	0.70	30	-13	-0.6	0.6
Model 8	4750	-19	-16	20	0.35	4.5	1.05	26	-7	-1.6	1.6
Model 9	5000	-20	-17	8	0.35	6.0	0.85	16	-7	-1.6	1.6
Model 10	3750	-19	-16	10	0.25	8.0	0.90	18	-13	-1.8	1.8

Generation 8: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	155	201	248	273	0	0	5	218	18	28	41	104	17.3	22.0	24.8	26.3	15.7
Model 2	159	205	253	277	0	1	4	221	10	27	41	114	13.0	20.0	25.9	29.0	18.8
Model 3	155	205	251	273	0	1	4	215	7	21	46	118	14.0	19.9	25.3	29.4	17.6
Model 4	120	163	208	251	1	3	19	182	6	17	39	128	24.9	30.2	33.5	35.4	15.4
Model 5	136	175	231	265	0	3	12	207	9	32	55	96	39.9	45.6	48.7	49.8	44.1
Model 6	150	204	250	264	0	0	4	207	20	32	42	98	16.3	21.5	25.3	27.3	15.9
Model 7	152	196	243	269	0	0	5	218	16	28	40	105	19.4	22.4	24.6	25.9	14.3
Model 8	149	199	250	273	0	0	3	217	16	30	45	101	22.6	29.5	34.4	36.8	12.4
Model 9	152	206	259	286	0	0	7	228	11	28	39	115	17.5	25.2	30.5	33.1	12.4
Model 10	158	203	257	282	0	0	3	226	19	40	45	89	33.2	39.4	44.1	47.1	36.6

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 9: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3500	-13	-10	12	0.35	4.5	0.90	15	-10	-0.6	0.6
Model 2	3250	-17	-14	22	0.10	8.0	1.00	23	-13	-0.4	0.4
Model 3	4750	-15	-12	4	0.05	4.0	0.75	30	-8	-2.0	2.0
Model 4	4500	-13	-10	4	0.25	6.0	0.95	25	-13	-1.4	1.4
Model 5	2750	-20	-17	24	0.70	6.0	1.15	30	-13	-1.8	1.8
Model 6	3750	-13	-10	4	0.40	10.0	0.70	15	-9	-0.6	0.6
Model 7	5000	-13	-10	2	0.40	6.0	0.85	35	-13	-0.6	0.6
Model 8	3750	-20	-17	8	0.35	6.0	0.70	16	-7	-1.6	1.6
Model 9	5000	-20	-17	10	0.35	6.0	0.85	18	-13	-1.6	1.6
Model 10	3750	-19	-16	8	0.25	8.0	0.90	16	-7	-1.8	1.8

Generation 9: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	147	192	239	278	0	2	14	217	6	19	39	124	13.3	19.9	25.0	27.4	18.9
Model 2	149	198	246	261	0	0	2	204	13	34	45	101	15.3	22.0	28.2	32.2	12.2
Model 3	153	201	254	276	0	0	6	217	22	38	42	91	21.8	27.7	30.4	31.6	9.0
Model 4	146	197	249	273	0	0	3	221	16	28	42	105	20.9	27.7	32.0	34.0	10.0
Model 5	121	166	211	247	0	3	12	183	5	17	40	129	21.7	26.6	30.4	32.8	9.6
Model 6	156	196	244	275	0	1	7	223	8	21	38	117	16.9	23.3	27.6	29.5	13.3
Model 7	146	193	237	263	0	0	4	213	17	28	38	107	18.5	22.0	24.8	27.2	14.6
Model 8	146	200	256	285	0	1	12	222	13	27	40	111	17.2	24.3	29.2	31.3	10.3
Model 9	153	211	262	285	0	0	7	226	11	26	42	113	17.4	24.9	30.2	32.7	11.7
Model 10	161	202	256	283	0	0	3	228	24	38	46	85	34.5	40.8	45.3	47.9	39.8

Generation 10: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3500	-13	-10	22	0.40	6.0	1.00	35	-13	-0.6	0.6
Model 2	3250	-17	-14	2	0.10	8.0	0.85	23	-13	-0.4	0.4
Model 3	4500	-13	-10	4	0.25	6.0	0.95	15	-9	-0.6	0.6
Model 4	3750	-13	-10	6	0.40	10.0	0.80	25	-13	-1.4	1.4
Model 5	5000	-18	-15	10	0.35	6.0	0.70	16	-7	-1.6	1.6
Model 6	3750	-20	-17	8	0.35	6.0	0.85	18	-13	-1.6	1.6
Model 7	4750	-15	-12	4	0.70	6.0	0.75	30	-6	-2.0	2.0
Model 8	2750	-20	-17	24	0.50	5.5	1.15	30	-8	-1.8	1.8
Model 9	3000	-15	-12	4	0.05	6.0	1.15	20	-8	-2.0	2.0
Model 10	4000	-20	-17	24	0.70	4.0	0.75	18	-13	-1.8	1.8

Generation 10: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	146	193	237	263	0	0	4	213	17	28	38	107	18.5	22.0	24.8	27.2	14.6
Model 2	153	204	250	265	0	0	3	207	15	29	44	104	14.7	20.6	25.8	29.6	15.5
Model 3	151	198	251	275	0	0	4	224	9	23	39	116	14.5	21.5	26.5	28.2	17.1
Model 4	148	191	244	274	0	0	5	221	13	27	44	107	23.9	29.5	33.8	36.1	12.8
Model 5	145	197	248	285	0	1	12	224	13	26	38	112	17.3	24.3	28.3	29.9	11.2
Model 6	155	207	258	283	0	1	6	227	10	31	42	107	18.5	26.1	32.0	35.2	12.4
Model 7	150	191	236	268	0	0	8	221	13	24	42	108	25.4	29.9	32.3	33.5	11.8
Model 8	130	177	227	253	0	0	6	194	8	22	42	120	20.7	26.5	31.6	35.0	10.1
Model 9	146	189	249	267	0	0	4	208	16	37	49	91	24.0	32.4	39.0	42.9	20.5
Model 10	148	195	244	281	0	1	11	223	9	22	37	123	17.5	23.6	27.6	29.9	12.6

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 11: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-15	-12	2	0.10	8.0	1.15	20	-8	-1.2	1.2
Model 2	3250	-17	-14	4	0.05	7.0	0.85	23	-10	-0.4	0.4
Model 3	4750	-15	-12	6	0.30	6.0	0.75	25	-13	-2.0	2.0
Model 4	3750	-17	-14	4	0.40	10.0	0.80	24	-6	-1.4	1.4
Model 5	3750	-20	-17	10	0.35	6.0	0.70	16	-13	-1.6	1.6
Model 6	5000	-18	-15	8	0.35	6.0	0.85	18	-7	-1.6	1.6
Model 7	4000	-20	-17	24	0.70	6.0	1.00	18	-13	-1.8	1.8
Model 8	3500	-13	-10	22	0.40	4.0	0.75	35	-13	-0.6	0.6
Model 9	2750	-18	-15	24	0.25	6.0	0.95	30	-8	-1.8	1.8
Model 10	4500	-13	-10	4	0.50	5.5	1.15	15	-9	-0.6	0.6

Generation 11: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	141	192	246	262	0	1	4	205	12	30	47	104	17.3	25.4	32.8	37.7	12.9
Model 2	154	200	249	262	0	0	2	207	14	31	48	100	14.4	20.3	25.4	28.9	15.9
Model 3	156	199	252	280	0	0	8	223	19	29	41	104	23.1	29.3	33.0	34.6	11.6
Model 4	153	196	247	271	0	0	4	218	15	33	46	98	23.9	29.6	34.0	36.2	13.2
Model 5	147	198	252	285	0	1	14	220	11	27	41	112	16.9	24.1	29.2	31.6	10.3
Model 6	153	202	254	282	0	0	7	225	10	25	44	111	17.9	25.3	30.3	32.9	10.7
Model 7	147	188	239	279	0	0	3	230	15	34	45	98	40.5	43.9	45.9	47.1	43.1
Model 8	146	192	239	270	0	0	7	213	17	29	41	103	17.6	20.4	22.7	24.5	17.7
Model 9	140	191	242	264	0	1	9	199	12	28	53	101	22.0	28.2	32.8	35.7	7.9
Model 10	141	183	233	264	0	0	2	222	8	22	40	116	23.2	29.9	34.7	37.1	14.8

Generation 12: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4750	-15	-12	4	0.05	7.0	0.85	25	-10	-2.0	2.0
Model 2	3250	-17	-14	6	0.30	6.0	0.75	23	-7	-2.0	2.0
Model 3	3000	-17	-14	4	0.40	10.0	0.80	24	-8	-1.2	1.2
Model 4	3750	-15	-12	2	0.10	8.0	1.15	20	-6	-1.4	1.4
Model 5	3750	-20	-17	4	0.50	6.0	0.80	16	-9	-1.6	1.6
Model 6	4500	-13	-10	10	0.35	5.5	1.15	15	-13	-0.6	0.6
Model 7	3750	-20	-17	24	0.25	6.0	0.70	30	-8	-1.8	1.8
Model 8	2750	-18	-15	10	0.35	7.0	0.95	16	-13	-1.6	1.6
Model 9	4000	-18	-15	10	0.25	6.0	0.85	18	-7	-1.6	1.6
Model 10	3750	-18	-15	8	0.35	6.0	0.95	22	-8	-1.8	1.8

Generation 12: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	152	203	255	277	0	0	7	217	25	38	41	90	23.7	31.1	35.7	37.8	17.3
Model 2	157	204	251	281	0	0	7	223	16	28	47	101	21.1	27.1	31.7	34.1	8.7
Model 3	146	190	245	269	0	1	10	209	9	23	45	115	20.2	26.4	30.8	33.7	8.1
Model 4	144	195	246	262	0	0	1	208	21	35	43	94	19.3	27.5	34.2	37.4	14.1
Model 5	147	198	250	280	0	1	12	220	9	23	40	115	16.9	24.2	29.6	32.8	11.2
Model 6	143	190	245	273	0	0	1	223	8	30	39	111	21.4	29.0	34.3	35.9	13.7
Model 7	153	196	250	274	0	0	5	214	24	35	43	90	24.7	29.3	32.0	32.9	12.4
Model 8	142	198	254	279	0	4	14	210	4	20	41	127	17.5	25.0	31.9	36.6	13.4
Model 9	156	205	258	284	0	0	5	227	12	30	42	108	18.4	26.2	31.9	34.6	12.0
Model 10	157	201	255	281	0	0	2	228	16	35	43	99	28.8	35.2	40.0	42.8	26.4

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 13: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	4250	-20	-17	24	0.65	8.0	1.15	30	-8	-1.8	1.8
Model 2	3750	-15	-12	2	0.25	6.0	0.70	20	-6	-1.4	1.4
Model 3	3750	-13	-10	10	0.50	6.0	0.80	16	-9	-1.6	1.6
Model 4	4500	-14	-11	4	0.35	5.5	1.15	15	-13	-0.6	0.6
Model 5	2750	-18	-15	10	0.35	7.0	0.80	24	-8	-1.2	1.2
Model 6	3000	-17	-14	4	0.40	10.0	0.95	16	-13	-1.6	1.6
Model 7	4750	-18	-15	10	0.25	7.0	0.85	25	-10	-2.0	2.0
Model 8	4000	-15	-12	4	0.45	6.0	0.85	18	-7	-1.6	1.6
Model 9	3750	-18	-15	6	0.30	6.0	0.75	22	-8	-1.8	1.8
Model 10	3250	-17	-14	8	0.35	6.0	0.95	23	-7	-1.0	1.0

Generation 13: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	128	176	220	249	0	0	2	194	13	24	40	116	21.4	27.2	31.1	33.9	9.4
Model 2	150	201	250	279	0	1	11	221	14	28	38	110	17.8	24.6	28.8	29.9	10.4
Model 3	144	187	234	275	1	1	11	221	8	19	39	120	18.1	25.0	29.7	31.8	9.9
Model 4	144	195	249	272	0	0	2	222	8	23	44	116	19.0	26.5	32.6	35.6	12.2
Model 5	148	195	247	272	0	1	10	209	7	21	50	114	18.6	23.8	28.0	30.5	9.1
Model 6	146	194	246	278	0	1	12	216	7	26	44	115	26.1	33.1	38.7	42.3	21.4
Model 7	153	201	252	277	0	0	7	216	18	31	48	96	24.9	31.7	36.2	38.3	16.7
Model 8	147	193	244	275	0	1	7	225	8	25	42	112	19.0	26.2	31.4	33.8	10.7
Model 9	155	207	258	282	0	1	5	224	15	29	42	105	19.2	25.9	30.4	33.0	9.8
Model 10	153	203	249	274	0	0	4	219	7	24	45	115	16.1	22.4	27.7	31.7	13.0

Generation 14: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3750	-14	-11	4	0.35	5.5	0.85	20	-6	-0.6	0.6
Model 2	3000	-15	-12	8	0.40	6.5	0.85	24	-7	-1.4	1.4
Model 3	2750	-18	-15	8	0.50	7.0	0.80	24	-9	-1.2	1.2
Model 4	3750	-13	-10	10	0.35	6.0	0.80	16	-8	-1.6	1.6
Model 5	4000	-15	-12	4	0.30	6.5	0.85	18	-8	-1.8	1.8
Model 6	3750	-18	-15	6	0.45	6.0	0.75	22	-7	-1.6	1.6
Model 7	3000	-18	-15	10	0.35	7.0	1.15	30	-8	-2.0	2.0
Model 8	4250	-20	-17	24	0.65	8.0	0.80	24	-8	-1.8	1.8
Model 9	3250	-17	-14	24	0.65	6.0	0.95	23	-7	-1.0	1.0
Model 10	1500	-20	-17	8	0.35	7.5	1.15	30	-8	-1.8	1.8

Generation 14: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	159	201	248	271	0	0	3	221	9	21	39	122	14.5	20.5	25.1	28.0	18.8
Model 2	146	192	243	271	0	2	11	210	7	24	44	116	18.8	24.7	29.3	32.4	8.9
Model 3	142	192	239	270	0	4	16	202	6	16	45	123	18.8	23.7	27.8	30.6	8.9
Model 4	146	190	243	280	0	1	10	223	9	26	39	116	17.5	24.7	29.9	32.5	11.2
Model 5	153	200	255	280	0	0	4	227	15	27	44	104	21.9	29.2	34.7	37.9	13.3
Model 6	158	205	252	280	0	0	7	224	13	25	38	114	19.0	25.2	29.6	31.9	9.7
Model 7	131	180	227	247	0	1	5	187	12	28	44	108	20.1	26.3	31.8	35.4	10.4
Model 8	148	193	242	280	0	0	7	223	11	25	46	110	27.5	32.5	36.0	38.0	18.5
Model 9	144	190	234	272	0	1	9	213	6	19	37	129	17.8	22.8	26.8	30.1	13.1
Model 10	34	88	168	227	45	59	45	38	9	24	41	120	22.4	28.0	31.3	33.2	29.3

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 15: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-15	-12	6	0.45	6.5	0.85	24	-7	-1.4	1.4
Model 2	4250	-20	-17	2	0.25	8.0	0.80	15	-8	-1.8	1.8
Model 3	3000	-20	-17	8	0.80	7.0	1.20	30	-8	-2.0	2.0
Model 4	2000	-18	-15	10	0.35	7.5	1.15	30	-15	-1.8	1.8
Model 5	4000	-15	-12	4	0.35	5.5	0.85	20	-6	-0.6	0.6
Model 6	3000	-17	-14	6	0.50	7.0	0.75	22	-7	-1.2	1.2
Model 7	3750	-13	-10	10	0.35	6.0	0.75	22	-8	-1.6	1.6
Model 8	3750	-18	-15	6	0.45	6.5	0.80	16	-7	-0.2	0.2
Model 9	2750	-18	-15	8	0.50	6.0	0.95	23	-9	-1.2	1.2
Model 10	3250	-17	-14	24	0.65	7.0	0.80	24	-7	-1.0	1.0

Generation 15: Simulated Data vs. Field Data.

Measurement	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	141	186	239	271	0	2	12	211	7	22	43	118	18.9	24.7	29.4	33.0	9.2
Model 2	155	201	259	282	0	0	7	224	18	33	42	100	24.1	31.2	36.4	39.4	17.4
Model 3	117	160	203	237	0	2	12	177	6	15	36	130	21.1	26.0	29.7	32.5	11.0
Model 4	86	149	207	236	3	19	48	117	12	22	37	122	20.1	26.1	30.8	33.3	17.2
Model 5	157	203	251	272	0	0	2	223	9	23	41	116	14.9	20.6	25.3	28.0	18.1
Model 6	145	192	244	274	0	2	13	212	6	17	42	125	18.4	23.5	27.4	29.9	11.2
Model 7	151	195	245	278	0	1	7	223	13	24	44	109	19.2	25.6	30.1	31.8	8.5
Model 8	157	205	253	274	0	1	7	221	6	19	37	123	14.4	20.1	24.5	27.3	19.7
Model 9	139	186	236	269	0	5	16	198	5	15	37	133	17.1	23.0	28.0	31.9	11.7
Model 10	147	189	236	273	0	1	8	213	7	20	36	127	18.6	22.9	26.7	29.5	12.8

Generation 16: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-20	-17	10	0.35	7.0	1.20	30	-15	-2.0	2.0
Model 2	2000	-18	-15	8	0.80	7.5	1.00	30	-8	-1.8	1.8
Model 3	3750	-13	-10	10	0.30	6.5	0.75	18	-8	-1.8	1.8
Model 4	3000	-15	-12	10	0.50	6.0	0.85	24	-7	-1.8	1.8
Model 5	3000	-17	-14	8	0.40	6.0	0.75	24	-7	-1.6	1.6
Model 6	4250	-20	-17	8	0.50	8.0	0.80	15	-8	-1.8	1.8
Model 7	4500	-15	-12	24	0.65	6.0	0.70	22	-8	-1.4	1.4
Model 8	3750	-13	-10	10	0.35	6.0	0.75	24	-13	-1.6	1.6
Model 9	3250	-17	-14	6	0.40	6.0	0.85	16	-7	-1.0	1.0
Model 10	3500	-17	-14	24	0.65	7.0	0.80	17	-6	-1.4	1.4

Generation 16: Simulated Data vs. Field Data.

Measurement	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	132	183	225	242	0	0	2	185	14	26	48	106	19.0	25.4	31.2	35.1	11.0
Model 2	70	108	164	225	16	38	58	93	5	12	34	135	26.1	29.0	29.5	30.5	26.5
Model 3	149	197	248	279	0	1	9	222	13	27	44	107	19.0	26.0	30.9	33.4	9.3
Model 4	139	186	240	273	0	2	13	212	7	23	40	121	22.2	27.6	31.4	33.9	8.9
Model 5	150	196	251	279	0	2	11	215	9	25	44	113	19.4	24.9	28.9	30.8	8.0
Model 6	153	196	249	281	0	0	5	227	13	29	38	112	24.5	31.2	35.7	38.6	17.5
Model 7	147	190	235	278	0	1	9	221	10	19	38	123	20.2	25.2	27.5	28.0	10.5
Model 8	153	195	248	279	0	1	5	225	13	29	41	109	20.9	26.8	30.4	32.0	8.1
Model 9	143	196	244	277	1	2	16	214	5	20	38	123	14.3	21.3	27.0	30.5	15.1
Model 10	145	191	237	278	0	2	15	215	5	17	38	127	17.5	23.7	27.8	30.3	11.6

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 17: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3750	-20	-17	10	0.35	7.0	0.75	24	-10	-1.6	1.6
Model 2	3000	-13	-10	6	0.35	6.0	1.20	30	-15	-2.0	2.0
Model 3	2750	-18	-15	8	0.25	6.0	0.95	18	-6	-1.4	1.4
Model 4	3000	-17	-14	10	0.65	6.0	0.85	24	-6	-1.6	1.6
Model 5	3250	-17	-14	6	0.35	6.0	0.85	22	-8	-1.0	1.0
Model 6	3000	-15	-12	10	0.45	6.0	0.80	22	-6	-1.4	1.4
Model 7	3500	-16	-13	10	0.30	6.5	0.75	24	-13	-1.6	1.6
Model 8	3750	-15	-12	10	0.35	6.0	0.80	18	-6	-1.8	1.8
Model 9	3000	-17	-14	8	0.35	7.0	0.80	24	-6	-1.2	1.2
Model 10	3750	-13	-10	10	0.65	6.0	0.70	18	-8	-1.8	1.8

Generation 17: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	153	201	257	281	0	0	4	224	18	30	44	101	21.8	28.0	32.2	34.2	9.7
Model 2	129	174	219	244	0	0	5	190	11	31	41	109	19.8	26.1	31.5	35.0	11.2
Model 3	144	200	255	280	1	3	15	211	5	18	43	127	15.6	23.1	29.6	33.9	13.0
Model 4	140	186	236	272	1	2	15	208	6	16	38	128	21.1	26.4	30.2	33.1	8.1
Model 5	157	203	252	277	0	1	6	220	8	23	40	120	15.8	21.8	26.5	29.8	15.4
Model 6	142	187	238	275	1	2	17	209	7	22	43	119	17.9	23.6	27.9	30.5	10.1
Model 7	156	204	253	281	0	0	6	223	12	31	42	108	19.7	25.9	30.4	32.8	9.4
Model 8	152	201	251	282	1	0	7	225	12	25	42	113	19.0	26.0	31.1	33.7	10.4
Model 9	153	199	250	273	0	2	8	212	7	27	46	113	18.2	23.6	28.0	30.6	10.3
Model 10	145	185	232	272	1	2	14	217	7	21	40	115	19.6	25.2	28.9	30.7	8.2

Generation 18: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3750	-20	-17	10	0.65	6.0	0.70	24	-10	-1.8	1.8
Model 2	3000	-17	-14	10	0.45	7.0	0.75	22	-7	-1.2	1.2
Model 3	3750	-15	-12	24	0.40	6.0	0.75	22	-7	-1.4	1.4
Model 4	3000	-15	-12	8	0.35	6.5	0.85	24	-7	-1.4	1.4
Model 5	3000	-17	-14	8	0.35	6.5	0.80	22	-6	-1.6	1.6
Model 6	3750	-15	-12	10	0.35	6.0	0.75	18	-6	-1.6	1.6
Model 7	3000	-15	-12	6	0.55	6.5	0.80	24	-6	-1.8	1.8
Model 8	3750	-15	-12	8	0.50	6.0	0.95	18	-7	-1.8	1.8
Model 9	3500	-17	-14	24	0.35	7.0	0.80	23	-9	-2.0	2.0
Model 10	3000	-13	-10	6	0.65	6.0	1.20	30	-15	-1.2	1.2

Generation 18: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	Z7	Z10	Z13	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	L 1	L 2	L 3	L 4	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	157	203	247	280	0	0	7	224	11	25	42	112	22.5	27.5	30.9	32.4	8.3
Model 2	150	197	248	276	0	2	11	211	8	21	44	118	18.5	23.7	27.4	29.7	10.4
Model 3	158	202	249	279	0	0	7	223	13	24	42	113	18.9	24.6	28.6	30.2	9.8
Model 4	150	196	249	275	0	1	12	213	9	24	41	118	18.8	24.6	29.1	32.4	9.4
Model 5	151	200	251	278	0	2	9	217	11	22	43	116	18.5	24.8	29.7	32.9	9.7
Model 6	146	195	249	281	0	1	12	221	9	24	40	117	17.4	24.5	29.4	31.4	10.4
Model 7	141	183	236	270	0	3	14	211	7	19	41	122	22.4	27.8	31.7	34.0	8.8
Model 8	148	192	244	277	0	0	5	226	12	30	47	103	31.4	37.2	41.3	43.6	29.0
Model 9	153	203	254	282	0	0	6	223	15	29	45	104	23.7	29.9	34.4	37.0	13.7
Model 10	121	159	206	245	0	4	20	190	6	17	43	123	22.8	27.6	31.3	34.2	9.9

Table C.2. Calibration of heavy flow traffic (PM), continued.

Generation 19: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3750	-16	-13	10	0.35	7.0	0.75	24	-13	-1.8	1.8
Model 2	3000	-17	-14	6	0.55	7.0	0.80	24	-6	-1.2	1.2
Model 3	3750	-15	-12	4	0.40	6.0	0.75	16	-7	-1.6	1.6
Model 4	3000	-15	-12	10	0.65	6.0	0.85	24	-7	-1.8	1.8
Model 5	3000	-20	-17	10	0.65	6.0	1.20	30	-15	-1.8	1.8
Model 6	3750	-13	-10	6	0.65	6.0	0.70	24	-10	-1.2	1.2
Model 7	3000	-17	-14	6	0.50	6.0	0.75	24	-7	-1.6	1.6
Model 8	3750	-13	-10	10	0.35	7.0	0.85	22	-8	-1.6	1.6
Model 9	3000	-15	-12	8	0.40	6.5	0.85	24	-7	-1.4	1.4
Model 10	3750	-15	-12	10	0.65	6.0	0.80	18	-6	-1.8	1.8

Generation 19: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	153	199	249	282	0	0	6	224	16	32	44	100	23.3	29.4	33.7	35.6	12.3
Model 2	143	186	240	272	0	3	11	210	7	21	44	118	19.1	24.0	27.7	30.6	9.3
Model 3	146	192	243	278	0	1	13	220	11	24	40	114	17.2	24.3	29.4	32.0	10.3
Model 4	132	178	227	270	0	4	17	208	6	18	38	126	23.2	28.1	31.2	33.2	9.3
Model 5	129	174	218	244	0	1	6	190	7	19	43	122	20.1	25.7	30.5	34.0	10.5
Model 6	155	194	237	269	0	1	6	221	11	21	40	112	20.2	24.7	27.5	28.6	10.0
Model 7	142	193	243	274	0	3	14	210	7	20	43	121	19.8	24.8	28.5	31.0	7.8
Model 8	152	192	243	277	0	0	5	225	13	29	40	109	21.9	28.5	33.4	36.1	11.9
Model 9	141	188	242	274	0	2	13	210	7	19	44	121	19.2	24.9	29.3	32.1	8.4
Model 10	148	190	239	274	0	1	8	223	8	18	39	119	21.2	27.2	31.1	33.4	9.1

Generation 20: Parameter Values (PM).

Parameter	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}
Default	**656**	**-13.1**	**-9.8**	**60**	**0.60**	**4.9**	**0.90**	**13.1**	**-8.0**	**-0.35**	**0.35**
Model 1	3000	-17	-14	10	0.50	6.5	0.80	22	-6	-1.6	1.6
Model 2	3000	-15	-12	8	0.40	6.5	0.80	24	-6	-1.8	1.8
Model 3	3750	-20	-17	10	0.50	6.0	1.20	30	-10	-1.2	1.2
Model 4	3000	-17	-14	6	0.45	6.0	0.85	24	-6	-1.6	1.6
Model 5	3750	-15	-12	10	0.35	6.0	0.80	21	-10	-1.8	1.8
Model 6	3000	-15	-12	8	0.35	6.0	0.80	22	-6	-1.4	1.4
Model 7	3750	-15	-12	10	0.40	6.0	0.80	18	-7	-1.6	1.6
Model 8	3750	-15	-12	4	0.65	6.0	0.75	16	-6	-1.8	1.8
Model 9	3750	-13	-10	10	0.30	6.0	0.75	24	-10	-1.6	1.6
Model 10	3500	-15	-12	10	0.45	6.5	0.80	18	-8	-1.6	1.6

Generation 20: Simulated Data vs. Field Data.

Measure-ment	Entering ML from GPL and Midway				Number of oncoming HOVs				Number of outgoing HOVs				Speed				MAPE
	Z4	**Z7**	**Z10**	**Z13**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	**L 1**	**L 2**	**L 3**	**L 4**	
Field data	**146**	**198**	**235**	**282**	**2**	**5**	**24**	**199**	**13**	**18**	**56**	**101**	**22.1**	**26.5**	**28.8**	**31.6**	**0.0**
Model 1	143	192	242	276	0	4	14	211	7	17	39	127	18.7	24.5	29.0	32.0	9.2
Model 2	153	199	247	278	0	3	10	216	10	23	46	112	21.5	27.2	31.7	34.0	8.0
Model 3	138	186	234	261	0	0	1	209	13	31	44	104	23.3	29.4	34.7	38.3	13.7
Model 4	141	191	243	274	0	3	13	210	8	21	45	117	19.9	25.9	30.5	33.7	8.3
Model 5	156	200	252	280	0	1	6	224	12	27	42	110	19.5	26.3	31.8	34.4	10.7
Model 6	147	197	246	276	1	2	14	210	9	21	41	121	17.6	23.6	27.7	30.7	10.4
Model 7	145	198	248	281	0	1	12	220	8	24	42	115	17.9	25.0	30.4	33.0	10.5
Model 8	145	189	237	275	1	1	13	219	8	19	38	113	18.6	24.6	29.2	31.8	8.9
Model 9	154	201	252	281	0	1	4	225	14	29	40	109	20.1	26.3	30.4	32.3	9.0
Model 10	148	199	242	276	0	1	10	220	7	21	40	121	17.4	24.1	29.2	32.3	10.9

APPENDIX D
THREE AND FIVE GENERAL PURPOSE LANES

The bulk of the simulation work in this project assumed four general purpose lanes with a single managed lane on the left and one or more ramps on the right. Limited simulation runs were made with three and five general purpose lanes for scenario 3 (see figure 6.1). The simulation results are reported in table D.1 for three general purpose lanes and in table D.2 for five general purpose lanes. The table format follows that used in table 6.4.

Table D.1. Three general purpose lanes; estimates of capacity of the ramp to managed lane flow, 0% trucks.

v_r	v_f	v_m	L: 1000	1500	2000	2500	3000	3500	4000
500	6900	400	0	80	400+	400+	400+	400+	400+
		800	0	60	500+	500+	500+	500+	500+
	6700	400	60	380	400+	400+	400+	400+	400+
		800	40	420	500+	500+	500+	500+	500+
	6500	400	120	400+	400+	400+	400+	400+	400+
		800	120	500+	500+	500+	500+	500+	500+
	6300	400	200	400+	400+	400+	400+	400+	400+
		800	200	500+	500+	500+	500+	500+	500+
	6100	400	260	400+	400+	400+	400+	400+	400+
		800	260	500+	500+	500+	500+	500+	500+
	5900	400	260	400+	400+	400+	400+	400+	400+
		800	280	500+	500+	500+	500+	500+	500+
750	6900		-	-	-	-	-	-	-
	6700	400	60	280	360	400+	400+	400+	400+
		800	0	180	260	750+	750+	750+	750+
	6500	400	100	400+	400+	400+	400+	400+	400+
		800	120	460	750+	750+	750+	750+	750+
	6300	400	200	400+	400+	400+	400+	400+	400+
		800	200	620	750+	750+	750+	750+	750+
	6100	400	260	400+	400+	400+	400+	400+	400+
		800	240	750+	750+	750+	750+	750+	750+
	5900	400	300	400+	400+	400+	400+	400+	400+
		800	300	750+	750+	750+	750+	750+	750+

Note: All flows in veh/hour, distance in feet.

Table D.1. Three general purpose lanes; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

v_r	v_f	v_m	L						
			1000	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**
1000	**6900**		-	-	-	-	-	-	-
	6700		-	-	-	-	-	-	-
	6500	**400**	80	400+	400+	400+	400+	400+	400+
		800	40	380	740	800+	800+	800+	800+
	6300	**400**	220	400+	400+	400+	400+	400+	400+
		800	180	640	800+	800+	800+	800+	800+
	6100	**400**	240	400+	400+	400+	400+	400+	400+
		800	240	760	800+	800+	800+	800+	800+
	5900	**400**	340	400+	400+	400+	400+	400+	400+
		800	320	800+	800+	800+	800+	800+	800+
1250	**6900**		-	-	-	-	-	-	-
	6700		-	-	-	-	-	-	-
	6500	**400**	100	400+	400+	400+	400+	400+	400+
		800	40	400	720	800+	800+	800+	800+
	6300	**400**	180	400+	400+	400+	400+	400+	400+
		800	200	620	800+	800+	800+	800+	800+
	6100	**400**	260	400+	400+	400+	400+	400+	400+
		800	260	740	800+	800+	800+	800+	800+
	5900	**400**	320	400+	400+	400+	400+	400+	400+
		800	340	800+	800+	800+	800+	800+	800+

Note: All flows in veh/hour, distance in feet.

Table D.2. Five general purpose lanes; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

Four Lanes Freeway: Maximum Allowable Ramp to ML Flow (0% Truck).

v_r	v_f	v_m	L (ft)						
			1000	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**
500	**11400**	**400**	0	40	140	340	400+	400+	400+
		800	0	20	80	260	460	460	460
	11200	**400**	20	80	180	400+	400+	400+	400+
		800	0	40	140	320	500+	500+	500+
	11000	**400**	20	120	200	400+	400+	400+	400+
		800	0	100	160	400	500+	500+	500+
	10800	**400**	40	120	220	400+	400+	400+	400+
		800	20	120	220	460	500+	500+	500+
	10600	**400**	60	140	280	400+	400+	400+	400+
		800	40	140	260	500+	500+	500+	500+
	10400	**400**	60	160	320	400+	400+	400+	400+
		800	40	140	280	500+	500+	500+	500+
750	**11400**	**400**	0	20	60	280	400+	400+	400+
		800	-	-	0	60	280	500	500
	11200	**400**	0	40	120	380	400+	400+	400+
		800	0	40	100	320	600	620	620
	11000	**400**	20	100	140	400+	400+	400+	400+
		800	0	80	140	400	700	720	720
	10800	**400**	40	120	220	400+	400+	400+	400+
		800	20	100	220	480	750+	750+	750+
	10600	**400**	60	160	300	400+	400+	400+	400+
		800	40	140	260	520	750+	750+	750+
	10400	**400**	60	180	320	400+	400+	400+	400+
		800	60	160	320	600	750+	750+	750+

Note: All flows in veh/hour, distance in feet.

Table D.2. Five general purpose lanes; estimates of capacity of the ramp to managed lane flow, 0% trucks, continued.

Four Lanes Freeway: Maximum Allowable Ramp to ML Flow (0% Truck).

v_r	v_f	v_m	L (ft)						
			1000	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**
1000	**11400**		-	-	-	-	-	-	-
	11200	**400**	0	40	100	340	400+	400+	400+
		800	-	0	40	80	380	640	640
	11000	**400**	20	100	180	400+	400+	400+	400+
		800	0	60	100	340	680	740	740
	10800	**400**	20	140	280	400+	400+	400+	400+
		800	20	120	280	560	800+	800+	800+
	10600	**400**	60	160	300	400+	400+	400+	400+
		800	40	140	300	580	800+	800+	800+
	10400	**400**	60	200	320	400+	400+	400+	400+
		800	60	180	320	600	800+	800+	800+
1250	**11400**		-	-	-	-	-	-	-
	11200		-	-	-	-	-	-	-
	11000	**400**	0	80	180	400+	400+	400+	400+
		800	0	60	80	320	720	760	760
	10800	**400**	20	120	280	400+	400+	400+	400+
		800	20	120	260	540	800+	800+	800+
	10600	**400**	40	180	300	400+	400+	400+	400+
		800	40	160	280	560	800+	800+	800+
	10400	**400**	60	220	320	400+	400+	400+	400+
		800	60	200	300	620	800+	800+	800+

Note: All flows in veh/hour, distance in feet.