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

Calibration of VISSIM for a Congested Freeway

Gabriel Gomes
Adolf May
Roberto Horowitz

California PATH Research Report
UCB-ITS-PRR-2004-4

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

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Report for Task Order 4136

March 2004

ISSN 1055-1425

CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Calibration of VISSIM for a Congested Freeway

Gabriel Gomes
Graduate student
Department of Mechanical Engineering
University of California at Berkeley
gomes@me.berkekeley.edu

Adolf May
Professor Emeritus
Civil and Environmental Engineering
University of California at Berkeley
amay@uclink4.berkeley.edu

Roberto Horowitz
Professor Mechanical Engineering
University of California at Berkeley
horowitz@me.berkeley.edu

Department of Mechanical Engineering and
Institute of Transportation Sciences
University of California at Berkeley

Abstract

A procedure for constructing and calibrating a detailed model of a freeway using VISSIM is presented and applied to a 15-mile stretch of I-210 West in Pasadena, California. This test site provides several challenges for microscopic modeling: an HOV lane with an intermittent barrier, a heavy freeway connector, 20 metered onramps with and without HOV bypass lanes, and three interacting bottlenecks. Field data used as input to the model was compiled from two separate sources: loop-detectors on the onramps and mainline (PeMS), and a manual survey of onramps and offramps. Gaps in both sources made it necessary to use a composite data set, constructed from several typical days. FREQ was used as an intermediate tool to generate a set of OD matrices from the assembled boundary flows. The model construction procedure consisted of: 1) identification of important geometric features, 2) collection and processing of traffic data, 3) analysis of the mainline data to identify recurring bottlenecks, 4) VISSIM coding, and 5) calibration based on observations from 3). A qualitative set of goals was established for the calibration. These were met with relatively few modifications to VISSIM's driver behavior parameters (CC-parameters).

Acknowledgements

This research was funded by Caltrans under PATH T.O. 4136 (*Design, Field Implementation and Evaluation of Adaptive Ramp Metering Algorithms*). The authors wish to acknowledge the help received from Hanh Pham and Jeff Aragaki of the Caltrans D07 ramp metering group, as well as the vast and helpful assistance from Jim Dale, Stefan Orehovec, and Joerg Tonndorf of the VISSIM development team, and thanks to Yanfeng Ouyang for help with the FREQ coding.

Executive Summary

This document summarizes recent accomplishments under PATH Task Order 4136 in regards to the construction of a simulation testbed, based on a microscopic traffic model, for the development and evaluation of several new freeway onramp control designs. The central goal of this project is to incorporate recent advances in the areas of traffic data collection (PeMS - The Performance Measurement System), traffic simulation (VISSIM), and control theory, into the design of new onramp metering methods, and to test these methods in a simulated environment before possible implementation on the Foothill Freeway (I-210 West) in Pasadena, California. Interstate 210 has been selected as the test site for several reasons, including the severity of the congestion problem during the morning commute, and the dedication of the of the District 07 Traffic Operations Group to providing enhanced service to its freeway users. However, the control techniques developed by this research will be general and applicable to other similar freeway facilities.

Recent progress has been made in several areas. First, a part of our team has focused on developing a new macroscopic traffic model that is being used to design an advanced onramp control strategy. The new model, named the switching-mode model, is similar to Daganzo's cell transmission model, but it is cast as a linear-switched hybrid system. We are currently using the PeMS database to validate and calibrate this model.

Another area of research, and the focus of this document, is the creation of the microscopic simulation model that will be used for evaluating and comparing the different onramp control designs. Emphasis is placed on: 1) the techniques used for assembling the data needed as input to the model and for calibration, and 2) the procedures that were followed in the calibration of the microscopic model.

The test site that is being considered for the study is the 15-mile stretch of I-210 West between Vernon St. and the SR-134 junction. This is a large and heavily used facility with several challenging features for microscopic simulation: an HOV lane with an intermittent barrier, a heavy freeway connector, 20 metered onramps with and without HOV bypass lanes, and three interacting bottlenecks. It was decided at an early stage that simulation modeling would be a prerequisite for future implementation of any new onramp controllers on I-210. Microsimulation was favored over macrosimulation for this purpose in order to capture several important aspects of the control hardware used on I-210 West. For example, the one-car-per-phase and queue override policies on I-210 operate under specific rule sets that can only be reproduced with microsimulation. These have significant impacts on the outcomes of the experiments. VISSIM was favored over other microsimulation options based on recommendations from knowledgeable colleagues. VISSIM's programmable signal control module was an important factor.

The present document covers the entire model construction process, which can be divided into 5 stages:

1. Identification of important geometric features: The precise layout of the site, including topology and the control infrastructure, was determined from several sources. These included aerial photographs and Caltrans "as-built" maps.
2. Collection and processing of traffic data: Two data sources provided the traffic demands. PeMS was used to generate contour plots for the calibration stage. The onramp and offramp volumes were obtained from a biennial survey conducted between 11/01 and 2/02 by Caltrans D07 Traffic Operations. Unfortunately, both of these sources were incomplete, and a composite data set had to be created by combining typical measurements from each of the two sources.
3. Analysis of the mainline data to identify recurring bottlenecks: Three major recurring bottlenecks were identified in the test site. A study of the mainline flow and speed contours offered insight into the causes of congestion. These turned out to be a combination of geometric and traffic related causes.
4. VISSIM coding: All of the important characteristics of the site were encoded in the VISSIM model, with help from the VISSIM support staff. Several interesting coding "tips" have been included in this document which may be of interest to other researchers wishing to use VISSIM to model similar freeway systems.
5. Calibration: Several qualitative calibration goals were established and met with relatively few changes

to VISSIM's default driver behavioral parameters. The speculated causes for the three identified bottlenecks (from stage 3) played a vital role in the calibration process. They allowed us to identify a small number of driver behavior parameters and modifications to those parameters that would most likely produce the desired result. The main criteria for judging the calibration was the agreement between simulated and field measured speed contour plots. The contour plots were compared in terms of 9 indicators: activation time, spatial extent of congestion, and dissipation time, for each of the three bottlenecks.

The calibrated VISSIM testbed is now ready for experiments using various onramp control alternatives. A first series of experiments will focus on well-known local-traffic responsive strategies, such as Alinea and Percent-Occupancy. Later experiments will involve more sophisticated system-wide (or coordinated) controllers such as SWARM, and the Mixed Kalman Filtering and Linear Programming methods recently developed by this team.

Contents

1 Introduction

This report documents the procedure that was followed to construct and calibrate a detailed model of a freeway using VISSIM. The purpose of the model is to serve as a testbed for the design and evaluation of an improved onramp metering strategy for a congested freeway. The chosen test site is a stretch of Interstate 210 in Pasadena, California, under the jurisdiction of Caltrans District 07. This freeway sustains heavy congestion in the westbound direction, between around 5:30 and 10:30 am. District 07 Traffic Operations has actively sought to improve the performance of I-210 with onramp metering, and has tested several strategies including local traffic-responsive metering and SWARM, with positive results. They have agreed to consider implementing the control strategies developed by PATH T.O. 4136 if these can be shown in simulation to improve upon their current practices.

This document covers the entire model construction process, including data collection, data checking, VISSIM coding, and model calibration. I-210 presents several challenges to microscopic simulation: an HOV lane with an intermittent barrier, a heavy freeway connector, 20 metered onramps with and without HOV bypass lanes, and three interacting bottlenecks. Another complicating factor is the lack of reliable traffic counts from the ramps and mainline. As is demonstrated in Table 1, many of the loop detector stations on I-210 are unreliable and several ramps lack sensors altogether. These "real-world" obstacles were faced in ways that may be of interest to future practitioners wishing to construct detailed models of freeways.

The report is organized as follows:

Sections 2 through 7 describe the methods that were used to gather and process geometric and traffic information. Section 8 describes the translation of boundary flow data into a set of OD matrices (using FREQ). Section 9 presents a study of the mainline data which identifies three recurring bottlenecks and speculates on their causes. The VISSIM model is introduced in Section 10. Sections 11 provides definitions of the model parameters that were varied in the calibration phase, and Sections 12 and 13 provide the calibration methodology and results.

2 The test site - Sources of geometric information

The site and time period chosen for the simulation study is the westbound direction of I-210 from Vernon St. to Fair Oaks (on SR-134, just beyond the 210/134 junction), between 5:30 am and 10:30 am (see Figure 1). These temporal and spatial ranges were chosen to ensure a freeflow state at the boundaries. This is a 15-mile stretch of freeway that sustains heavy congestion during the morning commute. Congestion usually begins around 6:00 am, peaks at 7:30 am, and finally dissipates at around 10:00 am. The site has 21 onramps, 20 of which are metered and equipped with a complete set of loop-detectors (all except the 605-NB/210-WB freeway connector). Each metered onramp has a corresponding mainline detector station for traffic-responsive control, and some, but not all, have HOV bypass lanes. There is a median-side HOV lane that spans the entire site, and is separated from the mixed-traffic lanes by an intermittent barrier (shown in Figure 1). The cut-off occupancy for the HOV lane is two or more passengers per vehicle, and is enforced at all times.

Simulation models require a detailed and complete description of the layout of the site in order to produce a realistic output. In VISSIM, the recommended method for entering the geometric data is to construct a scaled map, in bitmap format. This picture can be displayed as a background image in the program, allowing the user to easily trace the links and connectors that constitute the supply side of the model (see Figure 2). The topological features that were considered relevant to the description of I-210 are:

1. For the mainline:
    (a) Width and numbers of lanes
    (b) Locations of onramps and offramps
    (c) Lane drops

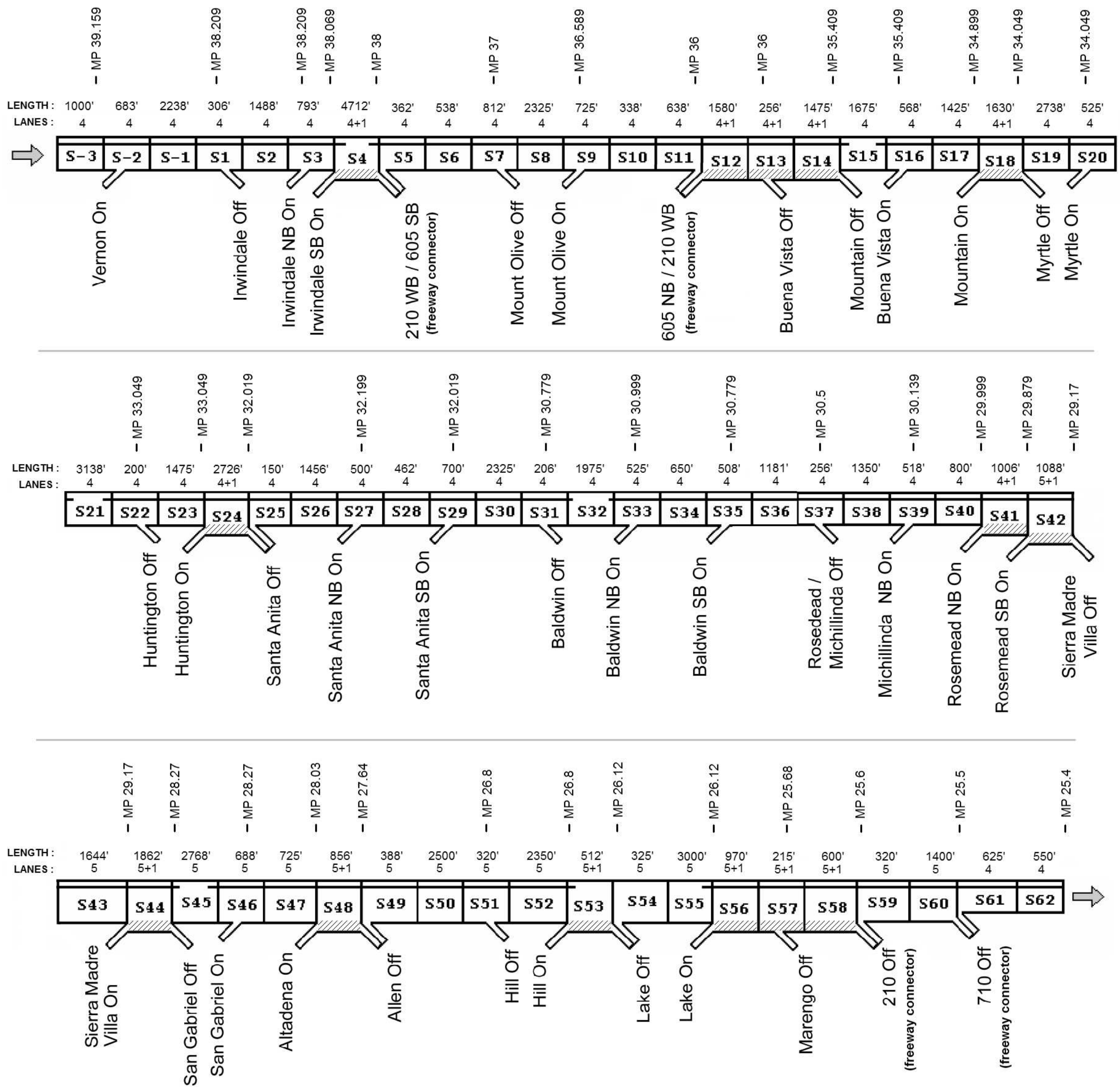

Figure 1: 65 sections in the test site. (MP = Mile Post)

(d) Auxiliary lanes

(e) Lane change zones

(f) Location of the HOV lane and gates

(g) Position of mainline loop-detector stations

2. For onramps and offramps

(a) Number of lanes at the gore of each onramp and offramp

(b) Existence of an HOV bypass lane on onramps

(c) Existence and position of metering lights on onramps

(d) Arrangement of loop-detectors on onramps and offramps. The position of the onramp queue detector with respect to the presence detector is especially important for experiments involving onramp control, since it determines the maximum storage of the onramp.

Three sources of geometric information were used for this study:

1. A set of photocopies of scaled aerial photographs obtained from Caltrans HQ. These photographs are black-and-white and printed on $11'' \times 17''$ paper, with a 1:2400 scale.
2. A set of "as-built" maps indicating the arrangement of loop-detectors on onramps and the mainline. These were provided by the Caltrans District 07 Ramp Metering Group, headed by Mr. Hanh Pham.
3. Un-scaled aerial photographs in bitmap format downloaded from MapQuest (www.mapquest.com)

All of the geometric features were extracted from the aerial photographs (source 1), with the exception of items 1g, 2c, and 2d, which were measured from the as-built maps (source 2). Each of the important features was assigned a section in Figure 1. In total, the site was divided into 65 sections (the first three sections have negative indices because they were appended after the initial numbering). Boundaries were chosen to isolate each of the important topological features. For example, section S29 contains a single lane change zone (item 1e) where traffic from the Santa Anita St. onramp merges with the mainline stream. Figure 1 also provides the lengths (in ft.) and the number of mixed-flow lanes in each section. This highway partition was transferred to the large overhead view compiled from source 3 (Figure 2), and thus encoded into VISSIM.

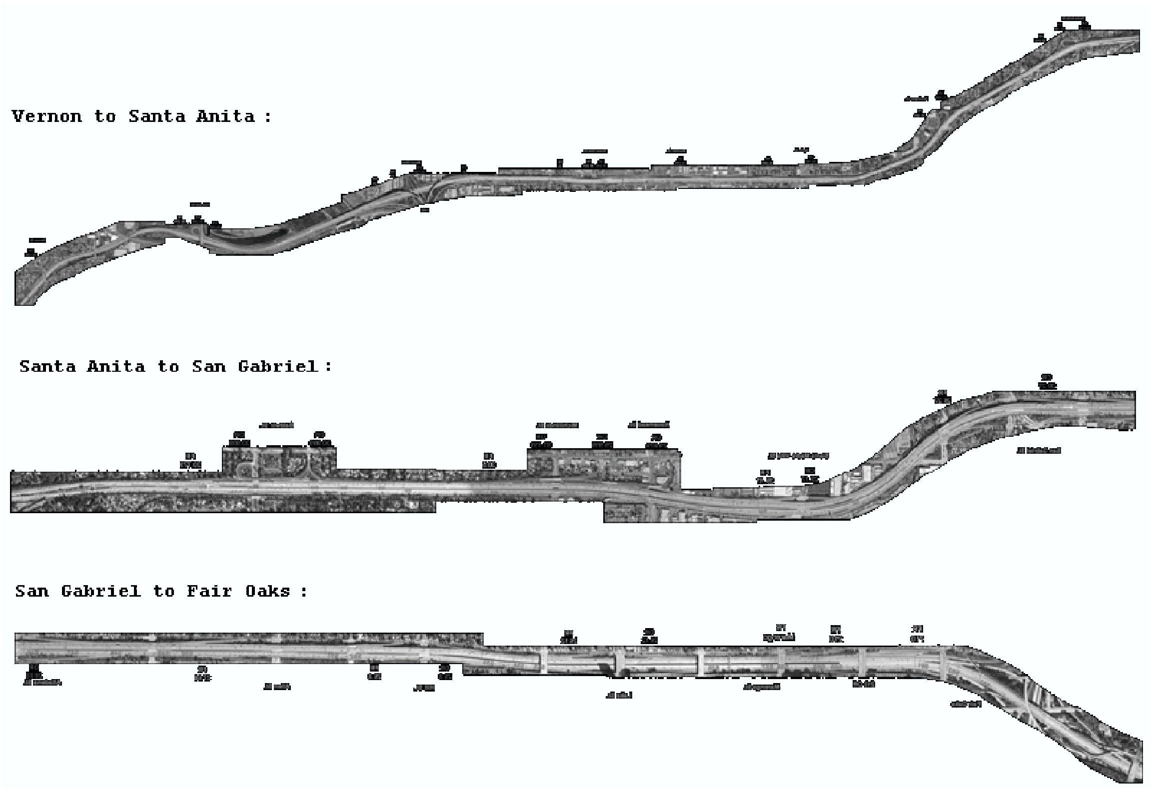

Figure 2: Assembled overhead view of I-210

3 Traffic data sources

The traffic demand can be defined in VISSIM as set of OD matrices, in which are specified the average numbers of vehicles going from every freeway origin to every destination, at 15-minute intervals. (This is one of two available methods. The alternative is to use aggregate vehicle sources, and to direct traffic using turning percentages.) This and the next few sections describe the procedure that was followed to gather and process traffic data for generating the OD matrices. The first step was to compile a complete and representative set of boundary flows, covering every onramp, offramp, and the two mainline boundaries. FREQ was then used to translate the boundary flows into the required set of OD matrices.

Two sources of field data were used:

1. **PeMS**: The PeMS database gathers 30-second and 5-minute data from over 30,000 miles of freeway in California. This database was used to assemble a history of traffic measurements for every loop-detector station in the site. A Matlab-based data processing algorithm was created to filter, aggregate, and correct the PeMS data (Section 4). Three examples of speed contour maps generated from the processed PeMS mainline data can be found in Appendix A. These represent a heavy, a typical, and a light day of congestion on I-210. Speed contour plots such as these were used to characterize the three major bottlenecks in the system (Section 6), and played a significant role in the calibration effort.
2. **Manual counts**: The District 07 Traffic Operations group provided the results of a biennial survey of freeway ramp volumes conducted between 10/2001 and 1/2002. The collected data consists of 15-minute estimates of volumes on most of the onramps and offramps in the test site (all except Marengo St. and the 210 and 710 freeway connectors). The D07 survey did not include any mainline data.

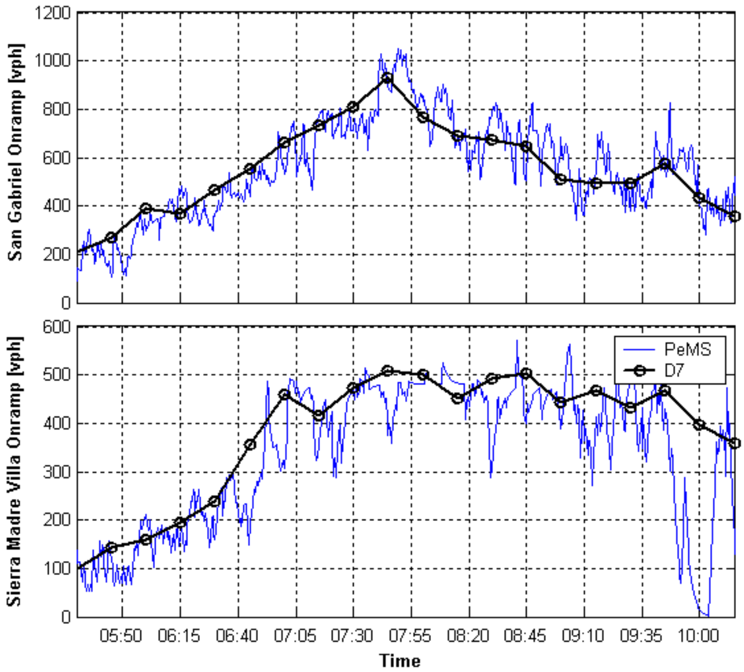

Figure 3: Comparison of PeMS 30-second data with the Caltrans D07 survey

A sample of flow values for the Sierra Madre Villa onramp (MP 29.17) from each of the two data sources is shown in Figure 3. As in this example, there is close agreement between the two sources in most cases. Instances where significant differences were noted were usually attributable to malfunctioning loop-detectors (i.e. errors in PeMS). Manual counts were generally favored over the PeMS loop-detector measurements for the ramps. PeMS data was used primarily where mainline measurements were needed. That is, to determine the upstream and downstream mainline flows (needed to estimate the OD matrices in Section 8) and to construct the contour plots used for model calibration (Section 13).

4 PeMS data processing with Matlab

PeMS - the Performance Measurement System - has as its primary function to gather, analyze, and disseminate real-time traffic information for California highways. Its main user interface is a web page[1], where users can generate a number of plots and traffic performance indices. Additionally, the raw traffic data is stored in a database, and may be provided to interested groups, such as this one. We have used PeMS data in several areas of this project. First, it has served to identify the recurrent trends that characterize the morning commute on I-210. These trends include onramp demands and the normal patterns of congestion on the freeway. Interpretation of PeMS-derived flow and speed contour maps has yielded the critical traffic parameters (e.g. capacity, bottleneck locations) that were used to calibrate the VISSIM model. Secondly, the study of PeMS data has provided insight into the actual availability of reliable real-time data on I-210. Section 5 summarizes the conclusions that were reached in this respect. This section gives a brief overview of the filtering and aggregation algorithms that were applied to the raw PeMS data sources prior to their being used in VISSIM.

The PeMS database stores two levels of data resolution: 30 seconds and 5 minutes. The 5-minute data is generated from the 30-second feed, and is aggregated over time before storage. The traffic variables recorded in PeMS include occupancy, flow, speed, and g-factor (estimated effective vehicle length). These can be combined to compute an estimate of average density. All variables in the PeMS database are *per-loop* quantities. Samples of data sequences from PeMS are shown in Figure 4.

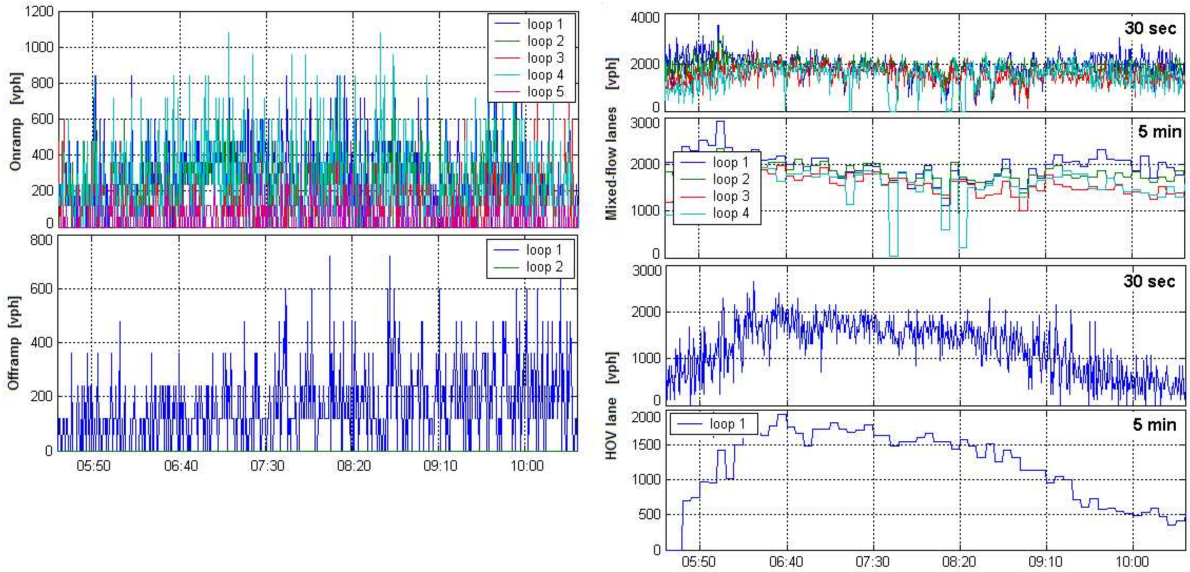

Figure 4: 30-second and 5-minute flows from PeMS (`R30` and `R5`)

Figure 5 illustrates the stages of data processing that were applied to the raw PeMS feeds. All of these were implemented in Matlab. First, the raw 30-second data (`R30`) was put through a first-order low-pass filter, producing output `S30`. The smoothed and raw `per-loop` values (`S30`, `R30` and `R5`) were then aggregated over lanes, to obtain values for cross-sections of the freeway at ramps and mainline locations (`AS30`, `AR30`

[1] http://pems.eecs.Berkeley.edu

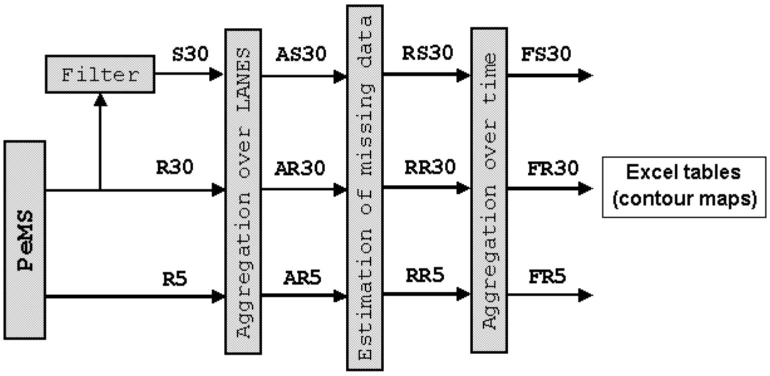

Figure 5: PeMS data processing

and `AR5`). In each case, the aggregation step was performed with:

$$\begin{aligned} occ^{agg}(i,k) &= \sum_j \gamma(i,j)\; occ(i,j,k) \\ flow^{agg}(i,k) &= \sum_j \gamma(i,j)\; flow(i,j,k) \\ speed^{agg}(i,k) &= \sum_j \gamma(i,j)\; speed(i,j,k) \end{aligned} \tag{1}$$

Here, the values on the left-hand-side are aggregated quantities. They are a linear combination of the per-loop values, with coefficients $\gamma(i,j)$. i denotes the detector station, j is an index for each loop-detector within a detector station, and k is the time interval. For onramps, the detector station may include *entrance*, *presence*, *passage*, *hov bypass*, and *queue* detectors. In this case, all $\gamma(i,j)$'s were set to zero, except for the one representing the *entrance* loop, which was set to 1.0. For mainline loop-detector stations, all $\gamma(i,j)$'s were set to 1.0. The $\gamma(i,j)$ coefficients were also used to perform crude data reconstruction for malfunctioning mainline loops. For instance, the detector on lane 2 of the Myrtle St. mainline station (MP 34.049) did not work on 11/6/2001. Its data was replaced with the average of lanes 1 and 3, by setting the γ's on those lanes equal to 1.5.

Next, additional conservation-based data reconstruction methods were applied in cases where more severe data losses could not be compensated with the $\gamma(i,j)$ coefficients. Two examples of this situation that were encountered were the temporary loss of communication with an entire mainline station, and the permanent lack of loop-detectors on several offramps. The current reconstruction method is based on a static balance of flows on a small section of the freeway. Three reconstructed data sets resulted from this step: `RS30`, `RR30`, and `RR5`. These were fed to a time-aggregation block which generated 15-minute tables. The contour plots of Appendix A are examples of the `FR30` stage.

5 Loop-detector reliability

One of the difficulties of using detector data for model input and calibration (as well as for traffic-responsive control) is that in many cases adequate data is not available, due either to an incomplete sensor infrastructure or to failure of the existing system. The availability of large quantities of historical data from the PeMS database allowed us to asses the dependability of the existing loop-detector infrastructure on I-210.

Table 1 provides percentages of time during which each onramp, offramp and mainline station registered signal pulses. The percentage values in the table are the averages over all loops in a given station (onramp, offramp, or mainline/HOV station) of the ratio of the number of non-zero flow measurements to the total number of measurements. These are optimistic estimates since they do not consider whether the non-zero values were reasonable. The statistics were taken over 11 weeks of PeMS data, using weekdays only, and from 5:30 am to 10:30 am. It can be noted in the table that, in general, mainline and onramp detectors are more reliable than offramp detectors. Most remain on-line around 80% of the time. Two exceptions are the Michillinda NB (44%) and Sierra Madre Villa (60%) onramp and mainline stations. The only onramp lacking a set of loop-detectors is the freeway connector from 605 NB (MP 36). Offramps, on the other hand, are more problematic. Many lack sensors, or at least these are not included in the PeMS database (e.g. Buena Vista - MP 36). Others have sensors that appear to be permanently disconnected from the data collection system (e.g. Lake - MP 26.12).

Street Name	MP	% non-zero data		
		offramps	onramps	mainline/HOV
Vernon St On	39.159	-	81.0%	81.0%
Irwindale St. On/Off	38.209	0.0%	81.6%	81.6%
	38.069	-	81.2%	81.2%
605 SB Off	38	n.m.	-	-
Mt. Olive Off	37	n.m.	-	-
Mt. Olive On	36.589	-	81.4%	81.4%
605 NB On	36	-	n.m.	n.m.
Buena Vista Off	36	n.m.	-	-
Mountain Off	35.409	0.0%	-	-
Buena Vista On	35.409	-	72.1%	72.1%
Mountain On	34.899	-	65.9%	65.9%
Myrtle On/Off	34.049	79.1%	79.1%	79.1%
Huntington On/Off	33.049	79.9%	80.4%	80.4%
Santa Anita Off	32.019	76.5%	-	-
Santa Anita NB On	32.199	-	79.4%	79.4%
Santa Anita SB On	32.019	-	80.4%	80.4%
Baldwin Off	30.779	79.1%	-	-
Baldwin NB On	30.999	-	80.5%	80.5%
Baldwin SB On	30.779	-	79.1%	79.1%
Rosemead/Michillinda Off	30.5	n.m.	-	-
Michillinda NB On	30.139	-	44.0%	44.0%
Rosemead NB On	29.999	-	79.9%	79.9%
Rosemead SB On	29.879	-	62.7%	62.7%
Sierra Madre Villa On/Off	29.17	60.2%	60.2%	60.2%
San Gabriel On/Off	28.27	67.2%	81.5%	81.5%
Altadena On	28.03	-	81.5%	81.5%
Allen Off	27.64	74.0%	-	-
Hill On/Off	26.8	80.0%	80.0%	80.0%
Lake On/Off	26.12	0.0%	81.5%	81.5%
Marengo Off	25.68	81.5%	-	81.5%
210 connector Off	25.6	n.m.	-	-
710 connector Off	25.5	n.m	-	-

Table 1: Percent non-zero flow measurements (n.m.=not measured, '-'=does not apply)

6 Ramp flows from the Caltrans D07 survey

The ramp counts collected by the District 07 biennial survey are provided in Appendix B. These measurements were gathered manually, by counting the number of vehicles that used every onramp and offramp, at 15-minute intervals, throughout the day. Each ramp was surveyed over a period of about 14 consecutive days. The surveyed days are highlighted in Tables B.1 and B.2 in Appendix B. This data set constituted a complete picture of the traffic demand entering and exiting the test site using the ramps, but it did not include any mainline data. Conversely, the PeMS database provided mainline measurements that were practically complete, but lacked information from several key ramps, including the heavy freeway connector from 605 NB (MP 36), and several offramps where loop-detectors had either failed or were missing.

The main difficulty encountered with the D07 boundary data was that there was no single day in which all ramps were surveyed simultaneously. This situation is common in real-world settings, since it is rare to find a complete and reliable sensor structure. As a consequence, it was necessary to assemble a single composite day using ramp counts from several different days considered as *typical*. The set of typical days was created by first discarding all Mondays, Fridays, weekends, and days that did not closely follow the normal (i.e. average) pattern. The remaining days are highlighted with bold grey lines in the time series plots of Figures B.3 through B.5. The variances in the counts for the reduced group are plotted in Figure 6. These values were computed as:

$$\text{var}(s) = \frac{1}{K \times D} \sum_{k=1}^{K} \sum_{d=1}^{D} \frac{(f_{s,k,d} - \bar{f}_{s,k})^2}{\bar{f}_{s,k}}$$

$$\text{with} \qquad \bar{f}_{s,k} = \frac{1}{D} \sum_{d=1}^{D} f_{s,k,d}$$

$f_{s,k,d}$ is the kth 15-minute vehicle count in the 5:30 am to 10:30 am period ($K = 20$), on day d, from station s. D is the number of days in the reduced set. From this set, a single day was selected for each onramp and offramp. The selected day is marked with a '+' sign in Tables B.1 and B.2, and also with '+' markers in Figures B.3 through B.5.

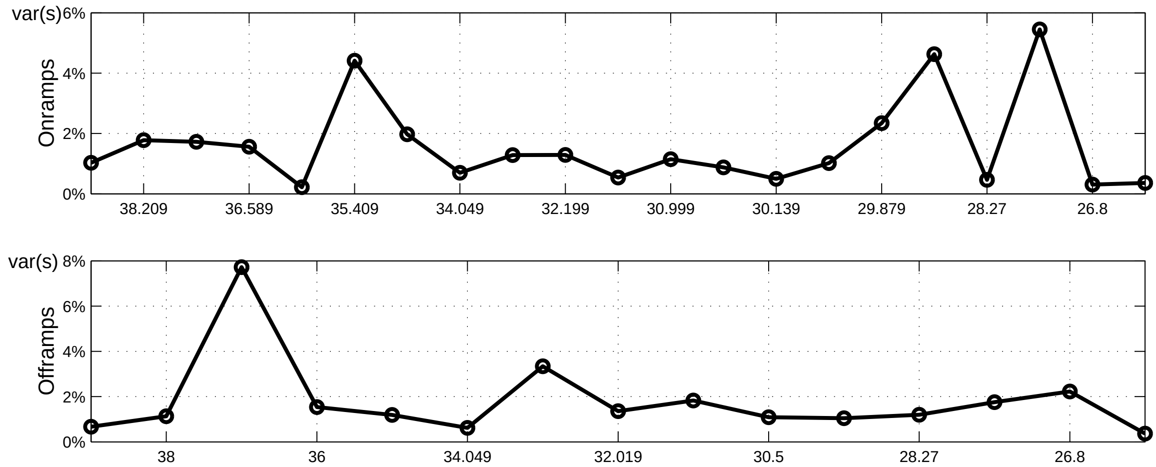

Figure 6: Percent variance in selected ramp counts from the Caltrans D07 survey

7 Mainline flows from PeMS

Measurements for the two mainline boundaries (Vernon and Fair Oaks) were required to complete the specification of traffic demands for FREQ's OD table estimation. These were obtained from PeMS. Figure 7 shows per-lane average flow measurements (AS30) for several days (Tuesdays, Wednesdays and Thursdays only) during the District 7 survey of freeway ramps. Notice that the flow pattern near Vernon St. does not resemble the expected inverted U shape for the morning period. Flows at this location start at an extremely high value, near 2200 vph per lane, and slowly decrease throughout the morning. This tendency is odd, but repeats itself from day to day.

Again, it was necessary to select a single typical day for the mainline boundary flows from a number of days. This selection was based on the following criteria:

1. completeness of the data set,
2. how well the flow data followed the day-to-day trend,
3. resulting "scale factor".

Scale factors are defined as the ratio, for each 15-minute period, of the total number of vehicles entering the system to the total number of vehicles that exit. They are computed in FREQ as a first step to finding the OD matrices (Section 8). They can also be used to identify possible problems in the data set, since they are expected to fall within 10% of 1.00, for a normal (incident-less) traffic scenario, and their average over a 5-hour period should be very close to 1.00. The scale factors resulting from the final selection of ramp and mainline flows are shown in Figure 8. The aggregate scale factor for the 5 hour period is 1.02.

Two tables with the final selection of ramp flows can be found in Appendix C.

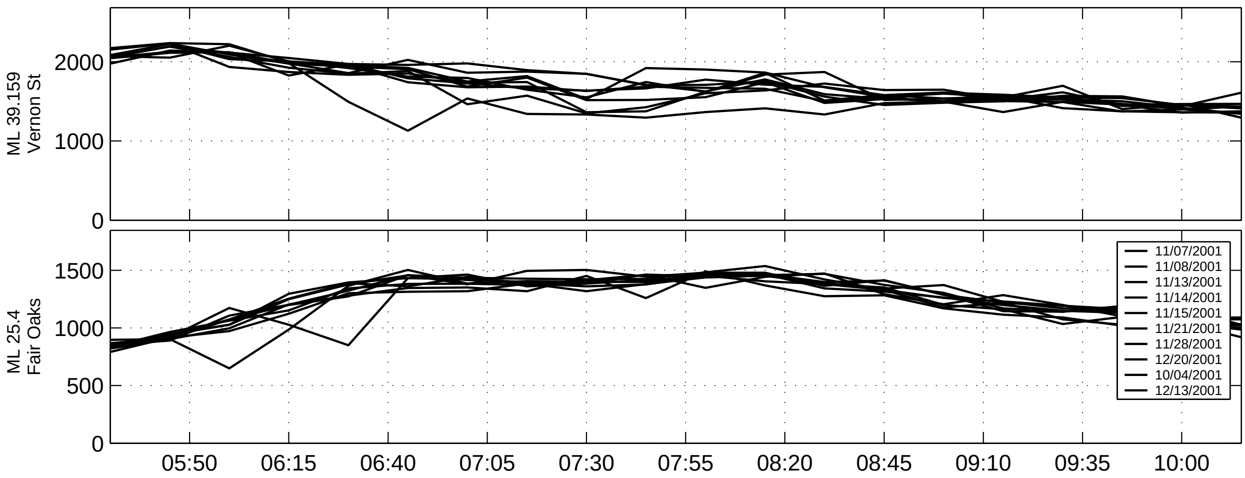

Figure 7: Mainline boundary flows

8 Estimating OD matrices with the FREQ model

The translation of ramp counts to the set of OD matrices required by VISSIM was achieved with FREQ. FREQ is a macroscopic deterministic freeway corridor model for the development and evaluation of freeway operational strategies, developed by Adolf May and his colleagues at U.C. Berkeley (Hall, Bloomberg, Rouphail, Eads, and May 2000). As was mentioned in the previous section, FREQ was first used as a data verification tool. Specifically, it was used to check scale factors ($\alpha[k]$):

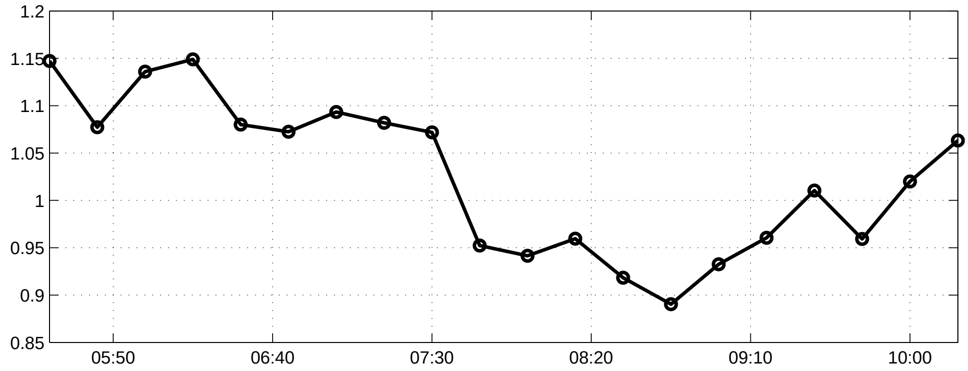

Figure 8: Scale factors with final input flow selection

$$\alpha[k] = \frac{\sum_{\text{origins}} f_i^{in}[k]}{\sum_{\text{destination}} f_i^{out}[k]} \qquad k = \text{ all 15-minute time intervals} \tag{2}$$

The scale factors corresponding to the final selection of flows were shown in Figure 8.

FREQ's OD estimation capability was then used to convert the onramp and offramp demand data into a sequence of 20 OD matrices – one for each 15-minute time interval in the 5 hour period. Each of these matrices has dimensions (22)×(19) = (21 onramps + 1 mainline origin)×(18 offramps + 1 mainline destination). An intermediate step was performed here to incorporate the information of the percentage of HOV vehicles present in each of the source flows. As is explained in Section 10.3, each OD matrix in VISSIM applies to a specific *traffic composition*. Since the I-210 model includes two traffic compositions (MIX_TC and HOV_TC, defined in Section 10.3), each FREQ OD matrix spawned two VISSIM OD matrices, giving a total of 40 matrices. The following assumptions were made based on available data and on suggestions from Caltrans staff. They were sufficient to make the conversion from 20 to 40 OD matrices.

- The number of vehicles using the HOV lane at the upstream mainline boundary (Vernon St.) is a given time-varying fraction of the total (mixed-lanes plus HOV lane). This fraction, shown in Figure 9, was derived from PeMS data.
- In addition to the HOV vehicles in the HOV lane, 5% of the vehicles in the Vernon St. mixed-flow lanes are also HOV.
- 12% of the vehicles entering the freeway at onramps are HOV.
- Of the total number of HOV vehicles that reach the downstream mainline boundary, at Fair Oaks St., 20% are in mixed-flow lanes, and 80% are in the HOV lane.

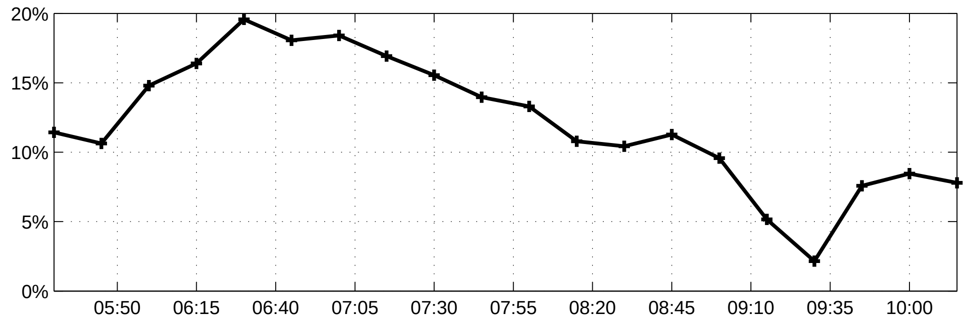

Figure 9: Percentage flow in the HOV lane at Vernon St.

9 Identification of recurring bottlenecks

The first step in the model calibration process was to identify the location and causes of the congestion on I-210. Appendix A contains three speed contour plots showing the congestion patterns for a heavy, a typical, and a light day of traffic. From these and other similar contour plots, three distinct problem areas, or bottlenecks, were identified. They are:

B1: Near Huntington St. (MP 33.049).

B2: Near the Rosemead and Michillinda St. ramps (MP 30.139).

B3: Near Hill St. (MP 26.8).

These three bottlenecks are illustrated in Figure 10. Mainline loop-detector stations are depicted in the figures with a $\times$, $\circ$, or $\otimes$ symbol, depending on whether the station is characterized by heavy congestion (speed is often < 40 mph), by free flow (speed > 55 mph), or by decreased speeds not reaching full congestion (speed is between 40 mph and 55 mph). Distances between ramps are marked on the figure, along with the number of mixed-flow lanes in each section. The number accompanying each onramp and offramp is a representative (approximately average) level of flow on the ramp when congestion begins.

The following conclusions were reached on the probable causes of congestion at each bottleneck:

B1: This bottleneck is not easily explained with a simple comparison of nominal capacities and demands. The Myrtle ramps make no net contribution to the amount of traffic on the freeway (600-600=0). The Huntington ramps supply about 500 vph to the mainline, but this should be easily absorbed by the auxiliary lane between Huntington and Santa Anita. The observed deceleration of the traffic stream must therefore be caused by a reduction in capacity near the Huntington ramps, or somewhere between Huntington and Santa Anita. Localized reductions in capacity have a variety possible causes, including grades, curves, reduced visibility, street signs, and direct oncoming sunlight. In this case, the most probable cause is the series of reverse curves between Myrtle and Huntington (as suggested by Caltrans staff).

B2: Bottleneck B2 is less stable than B1, in the sense that its location and congestion pattern are less predictable. Congestion initiates somewhere near the Rosemead and Michillinda ramps (MPs 30.139 to 29.879), however, complete breakdown, with speeds in the 20's and 30's, only occurs upstream near the Baldwin onramp (MP 30.779). The Rosemead and Michillinda detectors sometimes register speeds decreasing as low as 40 mph, but seldom less than that. Congestion in this region is probably caused by the two heavy onramps from Rosemead and Michillinda, which add approximately 1700 vph to the freeway. These onramp flows should be easily accommodated by the two additional auxiliary lanes. However, it appears that this increased capacity is not being fully utilized, probably due to increased weaving in that area.

B3: Mainline traffic near Hill St. (MP 26.8) is usually slow, and sometimes fully congested. Traffic near Altadena (MP 28.03) almost always becomes completely congested. As with the previous two, bottleneck B3 cannot be easily explained by comparing demands and nominal capacities, since the heavy flow from the Hill onramp is supported by an auxiliary lane. The observed congestion must therefore again be explained by a reduction in capacity. In this case, at least two probable causes exist: the S-shaped bend between Hill and Lake, and the heavy weaving that takes place in the 800-foot auxiliary lane before the Lake offramp.

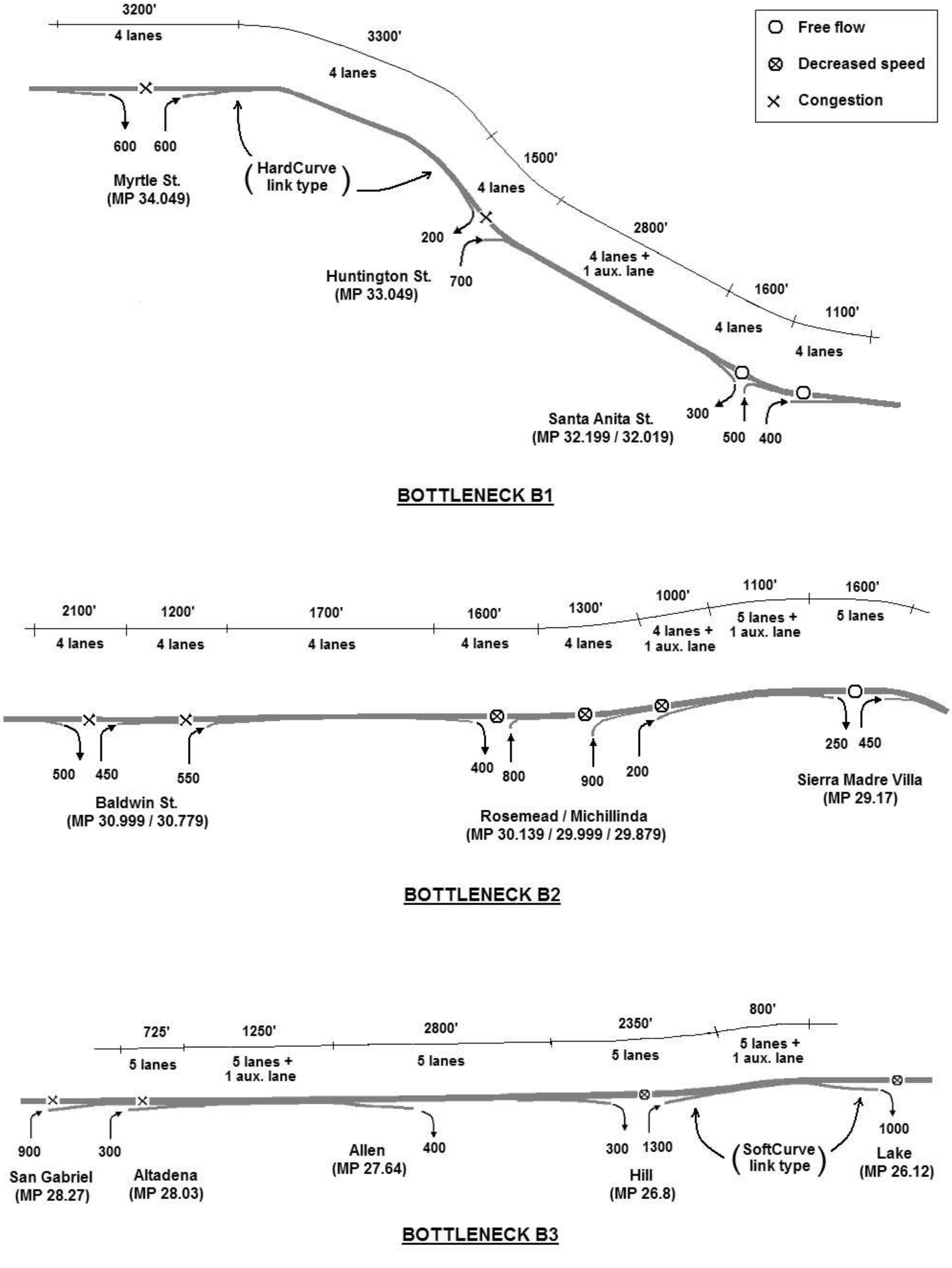

Figure 10: Three major bottlenecks

10 The VISSIM model

10.1 Overview of the program

VISSIM is the microscopic/stochastic traffic simulator that was used to create the detailed model of I-210 West. In the past, it has been used mostly as a tool for the design of urban public transportation systems, but has been shown to be capable of reproducing freeway traffic behaviors as well. Its traffic model is based on the work of R. Wiedemann (Wiedemann 1974; Wiedemann 1991), which combines a perceptual model of the driver with a vehicle model. The behavioral model for the driver involves a classification of reactions in response to the perceived relative speed and distance with respect to the preceding vehicle. Four driving modes are defined, as shown in Figure 11: Free driving, approaching, following, and braking. In each mode the driver behaves differently, reacting either to its following distance, or trying to match a prescribed target speed. These reactions result in a command acceleration given to the vehicle, which is processed according to its capabilities. Drivers can also make the decision to change lanes. This decision can either be forced by a routing requirement, for example when approaching an intersection, or made by the driver in order to access a faster-moving lane.

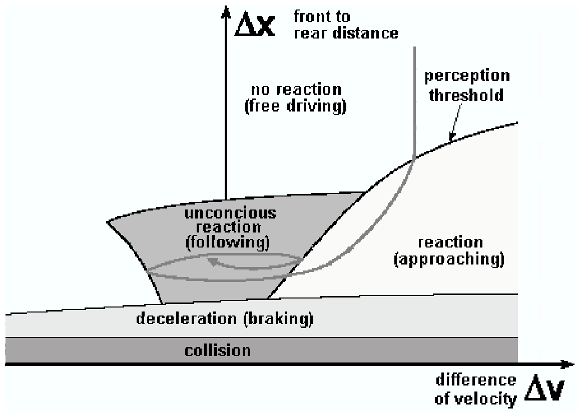

Figure 11: VISSIM's driver behavior model

A useful feature in VISSIM is that it allows stochastic variations of several of its parameters, such as the desired speeds and accelerations. Stochastic sources of boundary flows (rates and compositions) are also supported. Randomness can further be introduced in the ability of the driver population to perceive changes in relative speeds and distances and to determine their mode of driving. More comprehensive descriptions of the VISSIM model and software can be found in (Fellendorf and Vortisch 2001; PTV AG 2003).

Traffic signals can be simulated, and are controlled in VISSIM by the Signal State Generator (SSG), which is a separate module from the traffic simulation module. One important feature of the SSG is that it is programmable – the user is allowed to specify signal control logics with a descriptive language called VAP (Vehicle Actuated Phasing). Through the VAP interface, the user can access loop-detector measurements, and use them to generate commands for the traffic signals. A trace file can be exported from the VAP process to record loop-detector and signal related variables. These traffic signaling features can be used, for example, on freeway onramps to simulate onramp metering control.

10.2 Coding of the network geometry

As was described in Section 2, the relevant features of the I-210 test site were marked on a composite aerial photograph, which was downloaded from MapQuest (Figure 2). Scale was established on this image by matching landmarks with the scaled aerial photographs obtained from Caltrans HQ. Links and link connectors were then traced on this background image in VISSIM. A screenshot of VISSIM is shown in Figure 12.

Figure 12: Snapshot of VISSIM

Control Hardware

In addition to the freeway geometry, coding of the supply side of the model also entailed the placement of the control hardware elements: loop-detectors and signal heads. In VISSIM, each signal head is associated with a signal group. All signal heads in the same group display the same signal status at all times. For I-210, a separate signal group was created for each signal head, in order to allow every onramp, and even different signal heads on the same onramp, to act independently. Every signal group, in turn, is associated with a signal controlled junction (SCJ). An SCJ can contain several signal groups. The control logic (i.e. VAP code) corresponding to a particular SCJ determines the signal status of all signal groups and signal heads within that SCJ. A single SCJ was used to control all of the signals in the I-210 model.

All signal heads were held on green for the calibration runs of this document. It should be mentioned that this is not the current situation on I-210. District 07 uses a combination of local traffic-responsive and fixed-time onramp metering for this freeway. However, as was shown in Figure 3, the survey counts used as input to the VISSIM model closely follow the measurements from the *entrance* loop recorded in PeMS. This loop-detector is placed at the gore of the onramp, beyond the metering light. It was therefore inferred that the survey counts represent the actual number of vehicles entering the freeway, not the demand entering the back of the onramp queue. It should also be pointed out that all freeway offramps, including the two bifurcating freeway connectors, were left uncontrolled, based on information received from Caltrans D07 that none of the offramps in the test site are affected by external queues (e.g. emanating from surface street traffic lights).

HOV lanes

Another important aspect of the network coding is the implementation of HOV lanes. VISSIM allows particular lanes of a link to be closed to certain vehicle types (vehicle types are defined in the next section). HOV-only restrictions were enforced by creating a separate vehicle type for the HOV vehicles, and by closing the HOV-only lanes to all non-HOV types. This method was used to create the HOV lanes on the mainline and HOV bypass lanes on the onramps.

Freeway connector

Almost all of the onramp merges were modeled following the method recommended in (PTV AG 2003), where vehicles entering from the onramp join the mainline stream by changing lanes within a merge section. It was found however, that this approach only worked well for onramps with small or moderate flows. It failed for the heavy freeway connector from 605 NB (MP36), where it produced a large queue on the onramp. An alternative configuration was designed to shift some of the burden of the merge away from the onramp and onto the mainline, by forcing a percentage of the mainline vehicles to evacuate the right-most lane upstream of the ramp junction, thereby opening space for the flow from 605 NB. This was accomplished using VISSIM's *partial routing decisions* (see (PTV AG 2003) for further details).

10.3 Coding of traffic demands

Vehicle Types and Traffic Compositions

The vehicle population in VISSIM is categorized into *vehicles types.* A single type gathers vehicles that share common vehicle performance attributes. These attributes include model, minimum and maximum acceleration, minimum and maximum deceleration, weight, power, and length. All of these, except for model and length, are defined in VISSIM with probabilistic distributions (as opposed to scalars). Four vehicle types were created to model I-210: LOV, HOV, HGV_MED, and HGV_LARGE. The LOV type represents passenger vehicles with a single occupant. HOV vehicles have 2 or more occupants and are allowed to use the HOV and bypass lanes. The vehicle specifications for these two types are identical to those of the default CAR type in VISSIM (PTV AG 2003). The HGV_MED and HGV_LARGE types represent, respectively, medium and large size trucks. Parameter values for each of the four vehicle types are provided in Appendix D. *Traffic compositions* are the proportions of each vehicle type present in each of the source flows. Two traffic compositions were defined: MIX_TC for mixed-flow lane sources (93% LOV, 3.5% HGV_MED, 3.5% HGV_LARGE) and HOV_TC for HOV lane sources (100% HOV type).

Dynamic Assignment

VISSIM supports two different forms of input for the traffic demands. We chose to use its *dynamic assignment* module, which automatically determines inlet flows and routing information based on a user-supplied set of OD matrices. Each OD matrix is related to a single traffic composition, and to a 15-minute period of the simulation. The demand specification for the I-210 model consists of 40 OD matrices - 2 traffic compositions (MIX_TC and HOV_TC) times 20 time intervals. Each OD matrix has entries in the ij^{th} position indicating the average flow of a given traffic composition entering the network at the i^{th} onramp, with destination at the j^{th} offramp, during a particular 15-minute period. Routes, or traffic assignments, are generated by the dynamic assignment module by assigning a cost to every route available to each OD pair, and then choosing the route with minimum cost. The cost function in VISSIM includes terms penalizing the total distance, total travel time, and a link cost. This last term serves to model factors not covered by the first two, such as tolls. The link cost was used here, as explained below, to encourage the use of the HOV lanes by HOV vehicles.

HOV lanes and link costs

The idea behind dynamic assignment is that repeated simulations using this method for generating routes, and updating the travel time cost between iterations, should eventually converge to an equilibrium solution, in the sense that traffic assignments and travel times will eventually stop changing between iterations. In the case of I-210, the only routing decision to be made is whether and where the HOV vehicles will access the HOV lane. The simulation runs presented in this document are based on a single iteration of dynamic assignment. Travel time was therefore not a consideration in the selection of routes for HOV vehicles (this is because travel time is only known after the first iteration). Instead, the HOV lane was given a favorable cost by using the link cost coefficient. A separate link cost coefficient can be assigned to each vehicle type. The LOV vehicle type's link cost coefficient was set to 0.0, whereas the HOV type was given a value of 1.0. In computing a cost for each route, the program multiplies this coefficient by a link cost associated with each link in a given route, and adds them up. HOV lanes were given a preferred status by attaching a lesser link cost to HOV lanes, as compared to mixed traffic lanes. Thus, the minimum-cost route available to HOV-type vehicles was always to enter the HOV lane at the gate nearest to its origin, and to exit it at the gate nearest to its destination. Non-HOV vehicles were declined the use of HOV lanes with type-specific lane closures (described in Section 10.2).

10.4 VISSIM output

Two output files were used to generate the contour and time-series plots included in this document. First, the VAP process (Section 10.1) produced a trace file that contains 5-minute averages of flow and occupancy measurements for all of the loop-detectors in the model. Second, VISSIM's *link evaluation* was used to export space-aggregated traffic variables, such as link flow, density, and speed, also at 5-minute intervals. A MATLAB-based interpreter was created to read these output files and to generate the Excel tables and Matlab plots used to evaluate the simulation outcome.

11 Changeable model parameters - default values

Section 10.3 listed the model parameters related to the physical attributes of the *vehicle*. These were assigned separately for each vehicle type. Fixing the vehicle population, we now look at the parameters of the *driver* model. We have assumed that driver behavior is not correlated with vehicle type, but instead with the position of the driver/vehicle unit in the freeway. For example, drivers might behave differently on curved sections, as compared to straight sections. Thus, the parameters described in this section apply equally to all vehicle types, but were adjusted for each *link type*. Link types are analogous to vehicle types. They gather links with similar driver behavior parameters. Six link types were created to model I-210. These are described in Section 12. The driver behavior parameters that were changed from their default values to define each link type are described below. This is a subset of the total number of adjustable driver behavior parameters available in VISSIM. A complete list can be found in (PTV AG 2003).

Necessary lane change

The dynamic assignment module provides to each driver a sequence of links to follow that will take it from its origin to its destination. The parameters related to necessary lane changes dictate how far in advance each driver will be able to anticipate the next bifurcation (i.e. offramp) or lane drop on its list, and how aggressively that driver will change lanes to reach it. The first two items below – *look-back distance* and *emergency stop distance* – are the only driver behavior parameters that are not grouped into link types, but must be specified for each link connector separately (in VISSIM the *link connector* is the boundary between two links).

- Look-back distance: Distance in anticipation of a bifurcation that the driver will begin maneuvering towards the desired lane. Range=$(0,\infty)$. Default=200 m.
- Emergency stop distance: Distance before the bifurcation where the driver will stop if it has not reached its desired lane. Range=$(0,\infty)$. Default=5 m.
- Waiting time before diffusion: A driver/vehicle that has come to a halt at the emergency stop position will wait at most this amount of time for a gap to appear in the adjacent lane. After the waiting time has elapsed, it is removed from the simulation. Range=$(0,\infty)$. Default=60 seconds.

Vehicle following behavior

VISSIM includes two versions of the Wiedemann model: urban driver and freeway driver. Only the freeway driver type was used. The car-following mode of the freeway driver model involves 10 tunable parameters: CC0 through CC9. Below are described only those CC-parameters that were modified from their default values.

- CC0 and CC1: Coefficients used in the calculation of the safe bumper-to-bumper distance (in [m]): $dx\_safe = CC0 + v \cdot CC1$, where v (in [m/s]) is the speed of the trailing vehicle. According to (PTV AG 2003), CC1 is the parameter with the strongest influence on freeway capacity. In fact, it can be related almost directly to capacity by noting that (dx_safe+vehicle length)*capacity = freeflow speed. With reasonable values of capacity, dx_safe, and freeflow speed, and default CC0, this calculation gives CC1=1.5 seconds. The range for both CC0 and CC1 is $(0,\infty)$. Default values are CC0=1.5 m and CC1=0.90 s.

- CC4 and CC5: These are dimensionless parameters influencing the coupling between leader and follower accelerations. Smaller absolute values result in driver behaviors that are more sensitive to changes in the speed of the preceding vehicle. It is recommended in (PTV AG 2003) that these two parameters have opposite signs and equal absolute values. Default values are CC4=-0.35 and CC5=0.35. The absolute value of CC4 (or CC5) can be understood as the inverse of a stiffness coefficient between consecutive vehicles.

These three CC-parameters (CC0, CC1, and the CC4/CC5 pair) were used to model the curvature-induced capacity drops that are the supposed culprits of bottlenecks B1 and B3. We can infer from their definitions that increments in CC0, CC1, or in the absolute value of CC4/CC5 will lead to reductions in freeway capacity.

12 Variations of selected driver behavior parameters

With model inputs (network supply and traffic demand) fixed as described in Section 10, an initial simulation experiment was run using default driver behavior parameters. The resulting speed contour plot is shown in Figure 13. The immediate observation here is that there is a severe blockage near the downstream end of the freeway that produces a queue which quickly overruns the entire site. This problem was caused by the large number of vehicles attempting to exit through the last two offramps (the 210 and 710 freeway connectors), but were unable to complete the necessary lane changes before reaching and stopping at the emergency stop position. Several adjustments to the routing-imposed lane change parameters were made to correct this problem.

time ↓	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	34	24	62	61	63	62	63	63	63	62	64	62	63	63	63	62	63	64	63	30	61
5:45	12	6	7	62	58	63	62	63	63	63	62	63	63	64	64	63	62	64	64	62	8	61
6:00	6	5	6	62	59	63	62	63	63	63	62	63	60	62	62	62	59	62	51	6	5	61
6:15	5	6	8	62	46	61	62	62	62	63	59	61	59	63	63	62	60	63	5	4	4	62
6:30	7	7	8	63	41	61	60	61	60	62	52	58	51	54	59	47	14	4	3	4	4	63
6:45	7	7	9	61	41	59	60	59	57	59	45	40	24	21	11	3	4	3	3	3	4	63
7:00	6	7	8	61	51	62	62	62	29	23	3	2	2	3	2	2	3	3	3	4	5	62
7:15	5	5	6	62	53	60	61	9	2	2	4	3	3	3	2	3	4	3	3	4	5	63
7:30	5	7	8	61	50	45	5	2	2	2	3	2	3	3	3	3	4	3	4	5	6	61
7:45	7	6	8	61	14	2	2	2	2	2	3	3	3	4	3	4	5	5	6	6	5	62
8:00	7	7	8	43	2	2	2	2	3	3	4	4	4	5	4	4	4	3	3	5	6	61
8:15	7	7	8	3	3	2	3	3	3	3	3	3	3	4	3	3	5	5	5	5	5	61
8:30	4	3	3	3	3	2	2	2	3	3	4	4	4	4	4	4	5	4	5	6	6	61
8:45	3	3	3	2	3	2	3	3	3	3	3	4	4	5	4	5	5	4	4	5	5	63
9:00	3	3	3	3	3	2	2	3	3	3	4	3	4	5	4	4	5	4	5	5	6	62
9:15	4	3	3	2	3	3	3	2	3	3	4	4	4	5	4	4	5	4	4	5	5	63
9:30	3	3	4	3	3	2	2	3	3	3	4	3	4	5	4	4	5	5	5	6	6	61
9:45	3	3	3	2	3	3	3	3	3	4	5	4	5	5	4	4	5	5	4	5	6	61
10:00	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	5	4	5	6	6	56
10:15	3	3	3	3	3	3	3	3	3	4	4	5	5	5	4	4	6	5	6	7	7	61

Direction of traffic →

Figure 13: Speed contour plot with default driver behavior parameters (in [mph])

<u>Adjustments to the look-back distance</u>

It was determined that the default look-back distance of 200 m was too small for large numbers of vehicles crossing over several lanes of traffic to reach their exits. On the other hand, increasing this value too much had the unrealistic effect of bunching up all of the exiting vehicles in the right-most lane, far upstream of their intended offramp. These vehicles then obstructed other upstream offramps and onramps. It was therefore necessary to tune the look-back distances individually for each offramp, in a way that allowed vehicles sufficient weaving space while ensuring that these lane-change regions did not overlap. The list of tuned look-back distances is given in Table 2. Figure E.1 in Appendix E shows the contour plot resulting from this adjustment. Note that the offramp blockage problem was corrected almost completely by tuning the look-back distances.

MP	Street Name	Mainline look-back	Offramp look-back
38.209	Irwindale	800’	800’
38	605-SB	1450’	1450’
37	Mount Olive	800’	800’
36	Buena Vista	400’	400’
35.409	Mountain	200’	400’
34.049	Myrtle	800’	800’
33.049	Huntington	800’	800’
32.019	Santa Anita	200’	800’
30.779	Baldwin	800’	800’
30.5	Rosemead	800’	800’
29.17	Sierra Madre Villa	800’	800’
28.27	San Gabriel	800’	800’
27.64	Allen	800’	800’
26.8	Hill	800’	800’
26.12	Lake	800’	800’
25.68	Marengo	600’	700’
25.6	210 connector	250’	700’
25.5	710 connector	200’	700’

Table 2: Adjusted look-back distances for mainline/offramp bifurcations

Adjustments to the Waiting time before diffusion

Another modification that was found useful for eliminating the offramp blockages was to decrease the *waiting time before diffusion* parameter, from its default 60 seconds to 1 second. With this setting, vehicles that stopped at the emergency stop position on the mainline (at the offramp bifurcation) were immediately removed from the simulation, thereby minimizing the obstruction to the freeway. Eliminating these vehicles has little impact on the total travel time, since they are few and very close to their exit anyway. However, this adjustment is only recommended after the number of affected vehicles has been minimized by tuning the look-back distances. Also, one should be careful not to affect other bifurcations and/or lane drops within the network where larger waiting times are desired. For example, in the case of I-210, vehicles attempting to enter the freeway also frequently reached the emergency stop position at the end of the onramp/mainline merge sections (which contain a lane drop). To avoid these vehicles from being evaporated, a set of *merge* link types was created. These match their non-merge counterparts in all features except for the waiting time, which was set to 60 seconds for the merge types (see Table 4). Merge link types were used on all onramps and onramp merge sections.

Link types - Variations of following behavior (CC-) parameters

The remainder of the calibration effort focused on finding a suitable set of values for the CC-parameters defined in Section 11. Three separate sets of CC-parameter values were defined: Freeway, HardCurve, and SoftCurve. Each was accompanied by a merge link type (with a 60 second diffusion time), giving a total of 6 link types. The Freeway and Freeway Merge types were used almost everywhere. The HardCurve and SoftCurve link types were applied only to the curved sections that affect bottlenecks B1 and B3 respectively (see Figure 10). As is described in the next section, one of the findings of this study is that only modest adjustments to the CC-parameters were required to produce the desired simulation response. Also, that capacity drops due to curvature can be reproduced with changes to the CC1 parameter alone.

13 Calibration goals - Final parameter selection

Having assembled the onramp and offramp flow inputs using data from several different days, it is not immediately obvious how the simulation results should be evaluated. The usual method of computing an error norm with respect to the measured data, and tuning the model parameters to minimize that norm is not applicable in this case due to the composite nature of the input data. The question arises, should a single typical day be used, or a composite day, as was done with the boundary flows? Added to this difficulty is the fact that none of the data sets considered as typical had a complete set of mainline measurements. Furthermore, there seems to be more variability in the mainline measurements than appears in the onramp flows, suggesting the influence of unseen factors, such as weather, day-to-day variations in driver behavior, traffic incidents, etc.

Instead, the goal for the calibration was to match more qualitative aspects of the freeway operation. These were:

1. location of the three identified bottlenecks,
2. initial and final times for each of the three mainline queues,
3. extent of the queues,
4. utilization of the HOV lane,
5. onramp performance.

The first three items on this list pertain to the simulated response of the mixed-flow lanes. Target values for these characteristics were extracted from contour plots similar to those in Appendix A, and are listed in Table 3. The goal for the HOV lane was to approximately match the flow values from PeMS. For the onramps, the only objective was to avoid large onramp queues that might obstruct the vehicle sources.

The parameter selection methodology consisted of iterated runs, visual evaluation of the results using speed contour plots (e.g. Figure 15), and manual adjustments of the parameters. These adjustments were limited to the CC-parameters described in Section 11, and were aided by the bottleneck analysis of Section 9 and by the physical interpretation of the parameters of Section 11. The iterative procedure was stopped when all of the qualitative calibration goals were met (see Sections 13.1, 13.2, and 13.3). This approach was favored over a more exhaustive automated search method because of the potentially huge number of parameter variations, as well as the approximately 3 hour running time (PC/Windows XP, 2.6 GHz, 500 Mb RAM), and the advantage that it leads to a more sensible result.

The final selection of driver behavior parameters is shown in Table 4. This parameter set is the most parsimonious among those sets that also met the calibration goals. Notice that the CC4/CC5 parameter was increased (in absolute value), but was kept uniform throughout the freeway. It was found that this parameter, in addition to CC1, also has an important influence on capacity. Its default value of -0.35/0.35 produced almost no congestion. The CC0 parameter was also increased globally from 1.5 to 1.7. As expected from its definition, this parameter was more influential at low speeds (i.e. within the mainline queues), and was used to regulate the queue lengths. The CC1 parameter on the other hand, was changed only locally, at two locations. The HardCurve link type was used on the reverse curve near Huntington St. and the SoftCurve type was used on the curved section between Hill and Lake St. (see Figure 10). CC1 was adjusted in both cases to achieve the correct activation times for bottlenecks B1 and B3 respectively. Interestingly, bottleneck B2 did not require a separate CC1 value. This result supports the interpretations provided in Section 9 for the causes of the three bottlenecks; that B1 and B3 are probably caused by curvature, whereas B2 is probably due to weaving.

13.1 Onramp response

One of the qualitative goals for the CC-parameter calibration was to avoid unrealistic queues on the onramps that might obstruct the vehicle sources. The only onramp queuing problem that arose was on the freeway

	Bottleneck	Location	Start time	End time	Queue length
Measured	B1	MP 33.049	6:00 - 6:30	10:00 - 10:30	To MP 39.159
	B2	MP 30.779 / 30.139	6:45 - 7:15	9:00 - 9:45	Into B1
	B3	MP 28.03 / 26.8	7:00 - 7:30	9:15 - 9:45	To MP 29.17
Simulated	B1	MP 33.049	6:00	10:15	To MP 39.159
	B2	MP 30.779	7:00	9:45	Into B1
	B3	MP 26.8	7:15	9:30	To MP 29.17

Table 3: Measured and Model predicted congestion pattern

Link type	CC0	CC1	CC4 / CC5	Waiting time
Freeway	1.7	0.9	-2.0 / 2.0	1
SoftCurve	1.7	1.1	-2.0 / 2.0	1
HardCurve	1.7	1.4	-2.0 / 2.0	1
Freeway Merge	1.7	0.9	-2.0 / 2.0	60
SoftCurve Merge	1.7	1.1	-2.0 / 2.0	60
HardCurve Merge	1.7	1.4	-2.0 / 2.0	60

Table 4: Calibrated CC values. (Defaults: CC0=1.5, CC1=0.9, CC4/CC5=-0.35/0.35, Waiting time=60)

connector from 605 NB (MP 36). As was mentioned in Section 12, this was corrected at an earlier stage with partial routing decisions and was not a factor in tuning CC-parameters. All other onramps were checked by comparing the supplied onramp flows with the simulated onramp flows. These were a close match in all cases (see Appendix F), indicating that none of the vehicles sources were obstructed by overflowing onramp queues.

13.2 HOV lane response

The goal of matching the utilization of the HOV lane was verified by checking the simulated HOV lane flows. Samples of simulated and field-measured HOV lane flows are shown in Figure 14. Recall that the upstream boundary flows (at Vernon) are an input to the model. The differences at other locations may reflect modeling errors, such as errors in the provided percentage of HOV vehicles at onramps, and/or errors in the modeling of route choice by HOV drivers (Section 8). In general, the result is considered a sufficiently good match for the control purposes of this model. However, this aspect of the model can be improved with a refinement of the HOV input percentages (Section 5), and/or more iterations of VISSIM's dynamic assignment routine.

13.3 Mixed-flow lane response

The bulk of the calibration effort was dedicated to matching the response of the mixed flow lanes, in terms of the start time, end time, and extent of the queue generated by each of the three major bottlenecks. The iterative procedure was stopped when all of the 9 indicators for the mixed-flow response fell within their target ranges. Target and simulated values for these 9 indicators are given in Table 3. The resulting speed contour plot, shown in Figure 15, is compared to the typical PeMS contour of Figure A.2. Notice that the model has approximately matched the period of activation and queue length for the three bottlenecks. This was accomplished with a few global changes to the default parameter values, and with a couple local changes that were based on the analysis of field data and freeway geometry.

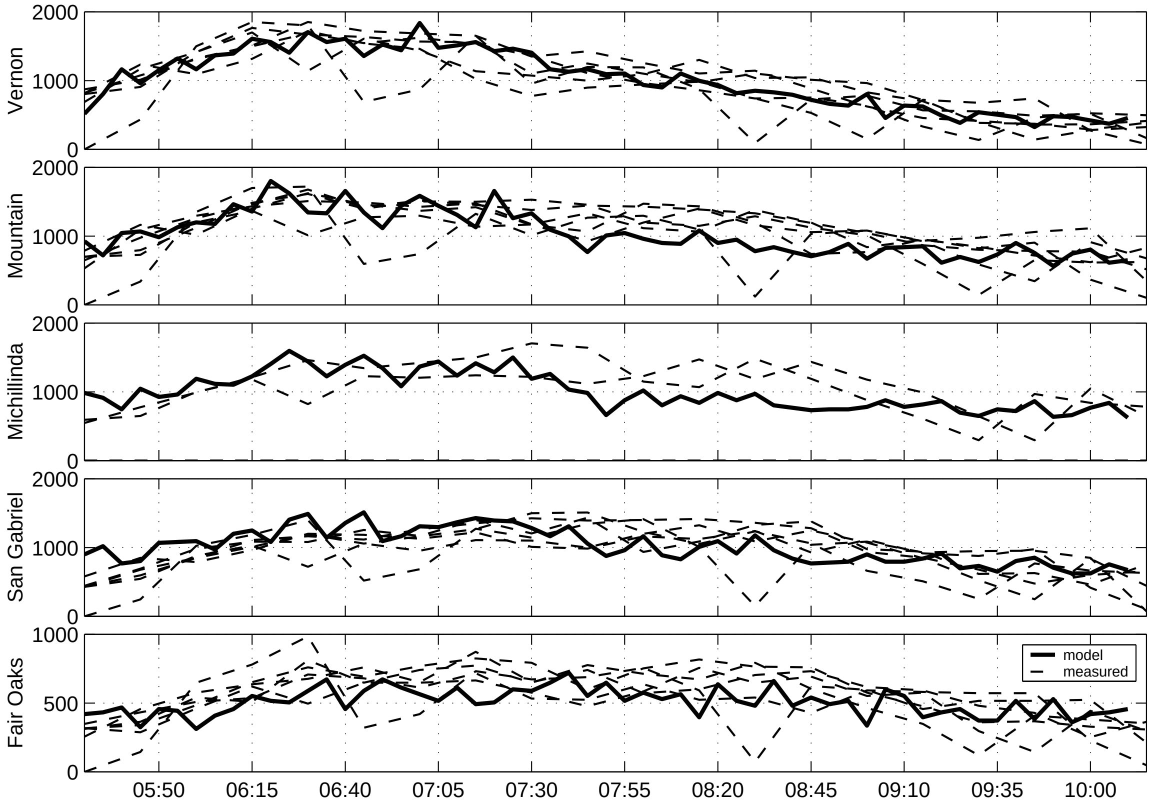

Figure 14: Measured and simulated HOV flows (in [vph])

time ↓	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	63	60	64	63	63	64	62	64	63	63	63	64	63	64	64	64	64	63	64	63	64
5:45	63	63	60	64	61	62	63	57	63	63	63	63	63	63	64	64	64	64	63	63	63	64
6:00	49	59	58	63	61	62	54	53	63	63	63	61	62	62	63	63	63	63	63	63	61	64
6:15	63	58	51	63	61	49	19	53	63	62	62	63	63	62	63	64	63	63	62	61	60	64
6:30	63	61	55	62	20	16	15	51	62	62	62	61	63	59	61	63	62	57	61	62	61	63
6:45	63	62	61	38	15	15	14	53	60	60	62	59	61	60	62	63	63	61	59	58	57	63
7:00	63	62	61	11	17	16	15	51	62	59	62	37	55	52	59	61	63	59	56	57	58	62
7:15	63	61	48	11	17	16	15	52	62	59	37	28	29	41	54	60	62	55	44	50	55	62
7:30	61	20	19	10	16	16	15	53	43	28	21	25	24	39	54	60	61	44	33	41	54	63
7:45	18	17	21	11	16	17	15	44	15	18	20	23	26	38	52	60	27	26	26	35	54	62
8:00	33	16	21	12	16	16	14	20	16	20	21	24	26	38	53	33	20	25	29	44	55	62
8:15	63	32	31	12	16	15	12	22	18	23	20	22	24	34	30	20	21	28	34	49	53	63
8:30	63	64	60	11	16	15	14	21	18	22	21	24	23	35	40	23	24	29	36	55	55	62
8:45	63	63	60	14	14	14	15	25	18	23	23	28	35	43	56	22	24	37	40	55	60	63
9:00	63	64	62	57	17	18	16	35	24	29	27	31	44	44	56	28	25	32	39	60	60	63
9:15	64	64	63	64	18	18	17	52	24	30	41	38	58	56	60	51	29	41	38	60	60	64
9:30	64	64	63	64	36	17	15	53	53	51	35	33	57	56	61	63	50	43	41	60	58	63
9:45	64	64	62	64	62	19	16	53	62	61	63	54	59	59	61	63	63	62	58	62	60	64
10:00	64	64	63	64	63	54	15	52	62	62	63	62	63	63	64	64	64	62	63	63	62	64
10:15	64	64	62	64	63	62	17	53	63	62	63	62	64	63	64	64	64	63	63	64	63	64

Direction of traffic →

Figure 15: Contour plot with final parameters selection

13.4 Random seed variations

Finally, the calibrated parameter set was run with 10 different *random seeds*. The random seed affects the realization of the stochastic quantities in VISSIM, such as inlet flows and vehicle capabilities. Contour plots for three examples are shown in Appendix G. Average percent variations in several simulation inputs and outputs resulting from random seed variations are shown in Table 5.

Quantity	Average Value	% Variation
Onramp flow	e.g. Figure 16	12.20%
Offramp flow	e.g. Figure 16	14.04%
Average speed	Figure 16	2.26%
Average volume	Figure 16	1.05%
Total Passenger Hours	22,482 veh.hr	1.56%
Total Passenger Kilometers	1,539,700 veh.km	0.09%

Table 5: Variation in model output due to changes in the random seed

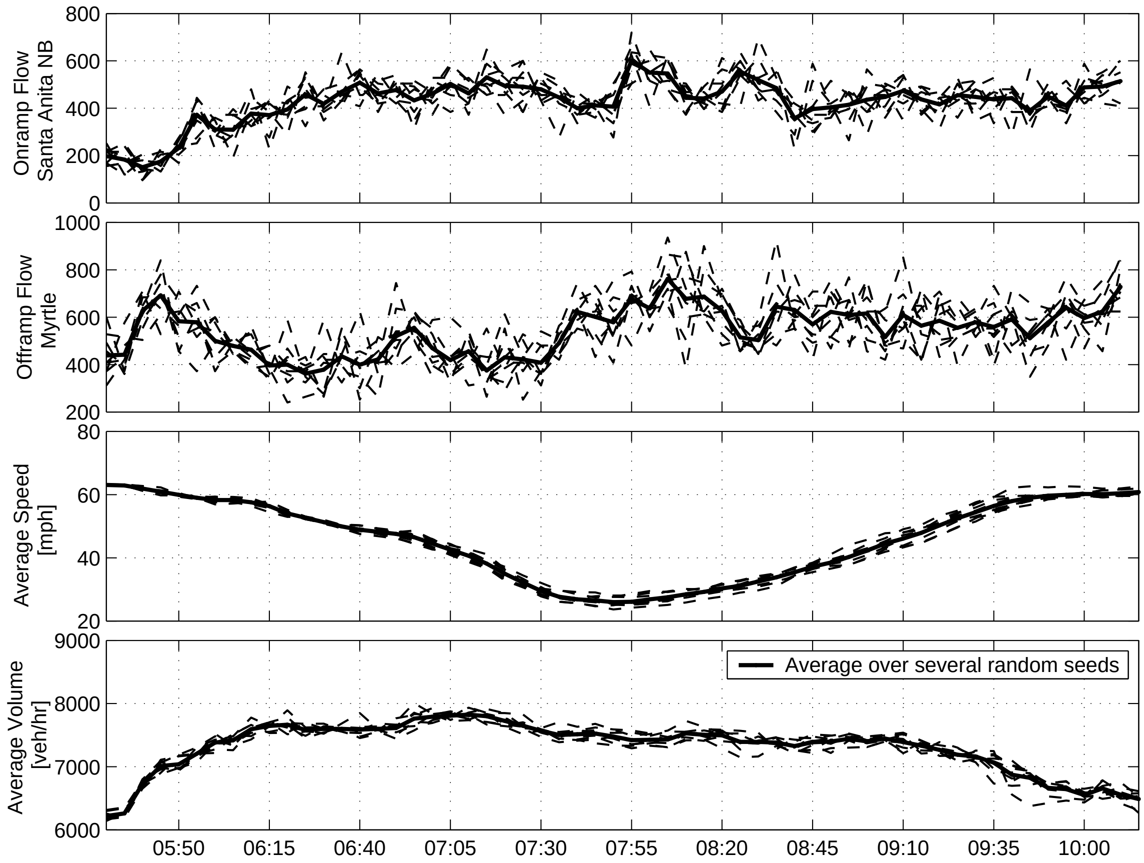

Figure 16: Mainline speed and flow measurements with several random seeds

14 Summary and Conclusions

This document has outlined a complete methodology for constructing and calibrating a simulation model of a unidirectional freeway with onramp control. The procedure included gathering and processing of field data from the PeMS database, estimation of OD matrices with FREQ, and microscopic simulation with VISSIM. Deficiencies in the field data were dealt with by assembling a composite typical day using data from several different days. The procedure was applied to I-210 West, a freeway that presents several challenging features: 20 metered onramps, with and without HOV bypass lanes, an HOV lane with an intermittent barrier, an uncontrolled freeway connector, and several interacting bottlenecks. All of these features were included in the model. Analysis of the supply and demand characteristics of the freeway lead to the conclusion that two of these bottlenecks were geometry-induced, while another was caused by weaving. A successful calibration of the VISSIM model was carried out based on this observation. As a conclusion, this study has shown that the VISSIM simulation environment is well-suited for such freeway studies involving complex interactions. With few and well reasoned modifications to its driver behavior parameters, the simulation model is capable of reproducing the field-measured response on the onramps, HOV lanes, and mixed-flow lanes.

Research will now continue using the calibrated VISSIM model to investigate a wide variety of ramp control strategies for the westbound I-210 freeway during the morning peak period. Ramp control strategies will include local and system-wide alternatives. Caltrans will consider implementing improved ramp control strategies based on their assessment of the predicted results.

A PeMS speed contours

	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30																						
5:45	55	53	49	58	60	58	55	52	58	58	57	59		65		78	60	61	57	59	58	60
6:00	49	49	45	57	58	57	60	51	59	58	57	58		62		73	58	57	56	58	59	59
6:15	37	54	51	59	52	52	52	44	53	44	53	56		61		74	56	56	55	55	57	33
6:30	30	63	59	54	34	31	26	27	56	56	48	49		56		89	36	47	47	40	25	7
6:45	39	59	53	21	25	30	24	20	53	34	50	53		63		64	36	46	21	26	22	22
7:00	34	44	38	13	20	25	26	18	47	21	27	24		44		33	20	28	44	45	54	58
7:15	30	40	35	13	18	20	14	15	23	17	30	27		41		35	25	30	33	46	54	60
7:30	23	38	29	10	10	16	14	13	23	20	25	21		36		31	22	28	36	46	55	60
7:45	24	34	21	9	12	19	14	14	18	11	15	20		35		32	24	33	38	48	57	60
8:00	27	40	27	10	11	14	10	14	24	20	28	25		37		33	24	31	47	47	55	59
8:15	35	36	26	9	14	17	17	15	16	12	17	24		48		50	29	35	44	47	54	58
8:30	24	26	17	8	14	15	20	13	20	9	30	28		34		25	24	30	53	51	7	61
8:45	29	21	23	11	20	21	19	14	30	28	25	29		40		45	27	32	41	48	42	59
9:00	49	22	38	10	16	21	20	20	49	44	32	31		39		39	23	29	47	44	52	58
9:15	61	20	40	16	25	27	18	20	35	28	34	35		40		35	21	26	55	49	34	57
9:30	62	21	56	15	26	28	19	21	31	28	38	35	52	50		39	22	28	55	45	53	55
9:45	59	19	53	12	22	26	32	23	60	57	45	44	51	49		61	33	39	55	45	54	58
10:00	59	18	53	28	31	34	29	23	58	54	51	51	55	52		64	54	56	58	44	54	58
10:15	62	17	56	51	41	30	28	20	59	56	57	54	64	55		65	53	59	59	44	53	58

Figure A.1: A heavy day (11/8/2001)

	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	58	42	65	61	64	63	66	64	63	63	62	63		79		66	64	48		67	66	65
5:45	47	42	58	61	63	63	68	62	64	62	62	63		78		65	64	51		68	68	67
6:00	56	38	54	60	57	60	61	48	60	60	61	60		70		63	60	50		63	63	63
6:15	47	35	49	63	44	52	40	35	61	61	60	61		72		65	61	46		60	63	66
6:30	35	43	48	39	30	36	38	27	60	61	60	61		70		62	61	46		60	62	65
6:45	32	44	45	19	25	32	28	23	59	61	61	61		68		65	62	41		61	63	66
7:00	30	26	37	12	20	27	21	20	58	59	53	45		57		60	60	45		54	60	67
7:15	27	32	30	12	16	24	21	20	53	39	36	39		54		54	35	31		35	57	64
7:30	27	30	31	13	16	25	21	18	28	27	31	31		56		38	22	26		25	57	64
7:45	35	28	29	12	17	22	18	18	26	24	24	25		42		37	28	31		47	55	66
8:00	34	35	30	14	15	24	16	14	24	25	30	28		45		40	23	23		51	55	63
8:15	53	37	34	11	16	27	22	16	21	20	21	25		52		41	26	26		55	58	64
8:30	34	38	28	12	15	20	18	16	22	23	28	29		53		52	25	28		51	56	64
8:45	61	43	32	14	22	20	24	18	30	27	29	28		46		40	25	28	61	50	56	64
9:00	68	56	57	22	21	28	22	19	39	36	38	36		44		43	28	32	54	51	54	62
9:15	66	74	59	20	20	27	25	23	46	37	49	41		53		63	51	45	55	47	53	59
9:30	67	51	60	48	33	32	28	26	51	43	49	47		52		61	57	41	28	51	54	60
9:45	63	59	58	66	46	43	29	26	64	63	69	67		63		66	63	50	18	58	56	63
10:00	67	37	58	66	67	67	50	27	65	64	72	67		59		66	63	59	48	67	11	64
10:15	66	69	56	65	69	70	75	52	69	67	72	70		62		67	65	53	65	68	36	64

Figure A.2: A typical day (11/28/2001)

	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	61	58	66	61	62	64	65	64	64	64	63	76		79		65	63	41	44	66	64	66
5:45	58	25	59	60	61	64	64	62	63	61	61	74		77		64	62	49	26	66	67	66
6:00	57	40	54	59	57	61	63	60	59	60	59	68		72		62	61	46	28	61	62	65
6:15	55	44	47	61	52	53	47	39	60	61	60	69		71		63	60	48	50	61	62	66
6:30	45	45	47	47	36	35	34	33	58	60	58	68		67		63	61	43	19	61	62	66
6:45	49	50	47	22	32	36	31	24	58	60	60	68		67		63	61	46	20	60	62	67
7:00	50	40	43	17	23	29	29	22	57	59	60	65		65		63	60	43	19	60	61	67
7:15	67	41	44	17	23	32	30	25	59	60	53	46		59		61	54	37	20	56	59	64
7:30	66	32	61	15	29	36	25	24	42	37	55	49	62	60		61	54	33	43	50	57	65
7:45	65	67	61	19	22	23	15	14	32	33	52	51	61	62		63	62	45	59	59	61	67
8:00	65	47	60	15	20	27	30	22	36	32	21	42	60	59		62	58	41	56	58	58	65
8:15	66	38	59	39	26	26	22	18	25	27	33	38	57	54		59	57	46	56	54	59	65
8:30	63	66	62	64	24	29	33	23	50	43	40	40	58	54		57	43	35	46	47	55	63
8:45	59	33	57	64	59	61	40	26	47	34	52	40		54		58	31	21	43	46	56	63
9:00	54	37	58	63	69	70	65	25	61	58	62	53		49		51	40	34	34	41	53	61
9:15	59	61	54	61	66	68	69	44	65	64	69	63		62		62	48	33	42	42	51	60
9:30	62	54	57	61	67	67	67	30	63	63	66	61		59		62	65	44	29	44	54	63
9:45	62	31	56	62	66	66	65	29	62	62	67	62		59		62	66	36	25	48	55	62
10:00	62	61	59	63	71	69	68	59	66	65	66	59		58		61	64	58	64	53	56	66
10:15	62	14	62	61	69	65	66	30	65	63	62	65		61		67	69	48	66	57	60	69

Figure A.3: A light day (11/21/2001)

B Counts from the District 7 ramp survey

Onramps:				39.159	38.209	38.069	36.589	36	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12
October	2	2001	Tu																					
October	3	2001	We																					
October	4	2001	Th																	+	+			
October	5	2001	Fr																					
October	6	2001	Sa																					
October	7	2001	Su																					
October	8	2001	Mo																					
October	9	2001	Tu																					
October	10	2001	We																					
October	11	2001	Th																					
October	12	2001	Fr																					
October	13	2001	Sa																					
October	14	2001	Su																					
October	15	2001	Mo																					
October	31	2001	We																					
November	1	2001	Th															+						
November	2	2001	Fr																					
November	3	2001	Sa																					
November	4	2001	Su																					
November	5	2001	Mo																					
November	6	2001	Tu																					
November	7	2001	We																+					
November	8	2001	Th								+	+	+		+	+	+					+		
November	9	2001	Fr																					
November	10	2001	Sa																					
November	11	2001	Su																					
November	12	2001	Mo																					
November	13	2001	Tu											+										
November	14	2001	We																					
November	15	2001	Th				+																	
November	16	2001	Fr																					
November	17	2001	Sa																					
November	18	2001	Su																					
November	19	2001	Mo																					
November	20	2001	Tu																					
November	21	2001	We						+	+														
November	22	2001	Th																					
November	23	2001	Fr																					
November	24	2001	Sa																					
November	25	2001	Su																					
November	26	2001	Mo																					
November	27	2001	Tu																					
November	28	2001	We		+			+																
November	29	2001	Th	+		+																		
November	30	2001	Fr																					
December	1	2001	Sa																					
December	2	2001	Su																					
December	3	2001	Mo																					
December	4	2001	Tu																					
December	5	2001	We																					
December	6	2001	Th																					
December	12	2001	We																					
December	13	2001	Th																				+	
December	14	2001	Fr																					
December	15	2001	Sa																					
December	16	2001	Su																					
December	17	2001	Mo																					
December	18	2001	Tu																					
December	19	2001	We																					
December	20	2001	Th																					
January	7	2002	Mo																					
January	8	2002	Tu																					
January	9	2002	We																					+
January	10	2002	Th																					
January	11	2002	Fr																					
January	12	2002	Sa																					
January	13	2002	Su																					
January	14	2002	Mo																					
January	15	2002	Tu																					

Figure B.1: Onramp days

Offramps :

				38.209	38	37	36	35.409	34.049	33.049	32.019	30.779	30.5	29.17	28.27	27.64	26.8	26.12
October	2	2001	Tu															
October	3	2001	We															
October	4	2001	Th												+			
October	5	2001	Fr															
October	6	2001	Sa															
October	7	2001	Su															
October	8	2001	Mo															
October	9	2001	Tu															
October	10	2001	We															
October	11	2001	Th															
October	12	2001	Fr															
October	13	2001	Sa															
October	14	2001	Su															
October	15	2001	Mo															
October	31	2001	We															
November	1	2001	Th										+					
November	2	2001	Fr															
November	3	2001	Sa															
November	4	2001	Su															
November	5	2001	Mo															
November	6	2001	Tu											+				
November	7	2001	We															
November	8	2001	Th						+	+	+	+						
November	9	2001	Fr															
November	10	2001	Sa															
November	11	2001	Su															
November	12	2001	Mo															
November	13	2001	Tu			+												
November	14	2001	We		+													
November	15	2001	Th															
November	16	2001	Fr															
November	17	2001	Sa															
November	18	2001	Su															
November	19	2001	Mo															
November	20	2001	Tu															
November	21	2001	We				+	+										
November	22	2001	Th															
November	23	2001	Fr															
November	24	2001	Sa															
November	25	2001	Su															
November	26	2001	Mo															
November	27	2001	Tu															
November	28	2001	We	+														
November	29	2001	Th															
November	30	2001	Fr															
December	1	2001	Sa															
December	2	2001	Su															
December	3	2001	Mo															
December	4	2001	Tu															
December	12	2001	We															
December	13	2001	Th														+	
December	14	2001	Fr															
December	15	2001	Sa															
December	16	2001	Su															
December	17	2001	Mo															
December	18	2001	Tu													+		
December	19	2001	We															
December	20	2001	Th															
January	7	2002	Mo															
January	8	2002	Tu															
January	9	2002	We															+
January	10	2002	Th															
January	11	2002	Fr															
January	12	2002	Sa															
January	13	2002	Su															
January	14	2002	Mo															
January	15	2002	Tu															

Figure B.2: Offramp days

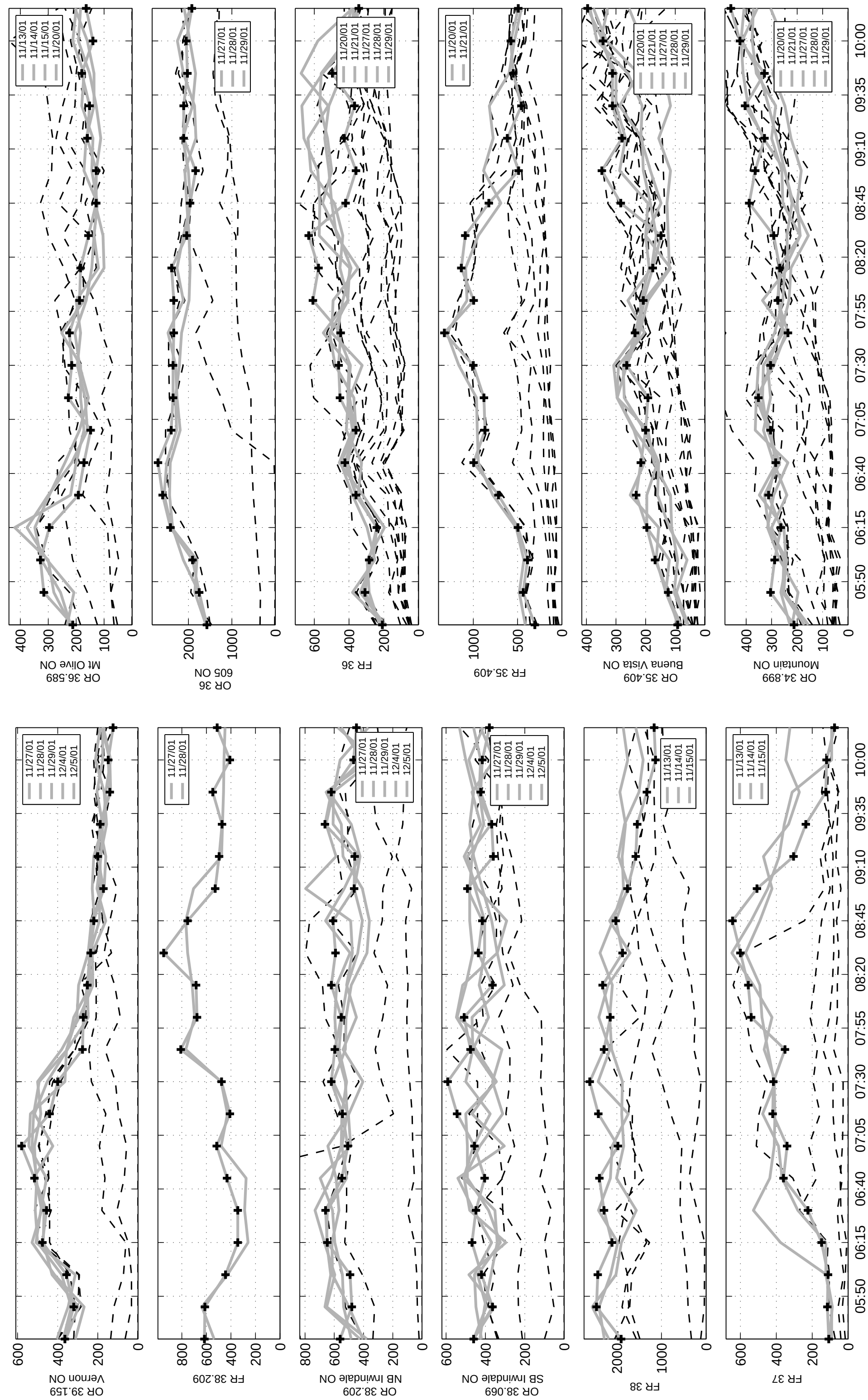

Figure B.3: District 07 ramp survey (OR=onramp, FR=offramp)

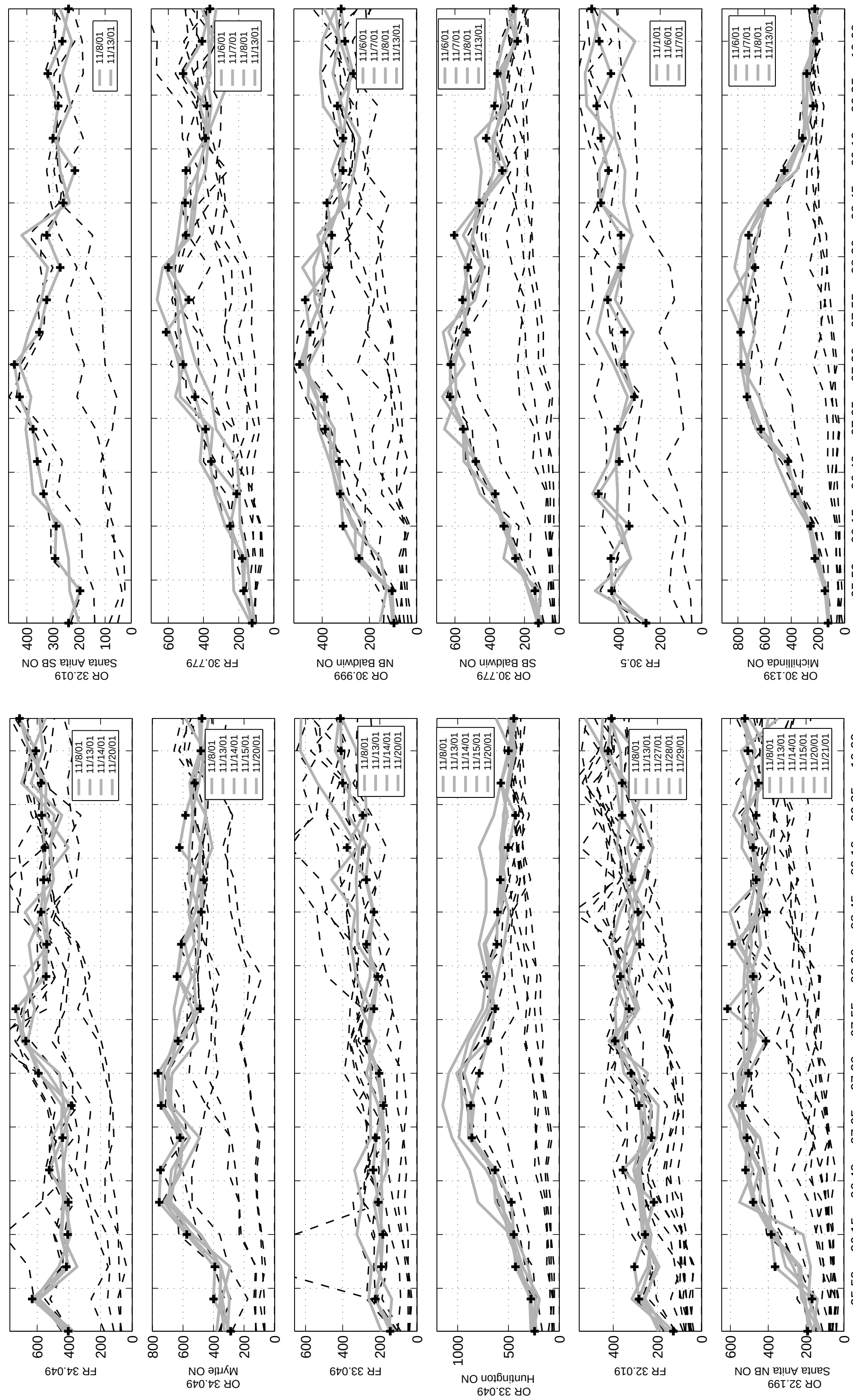

Figure B.4: District 07 ramp survey (OR=onramp, FR=offramp)

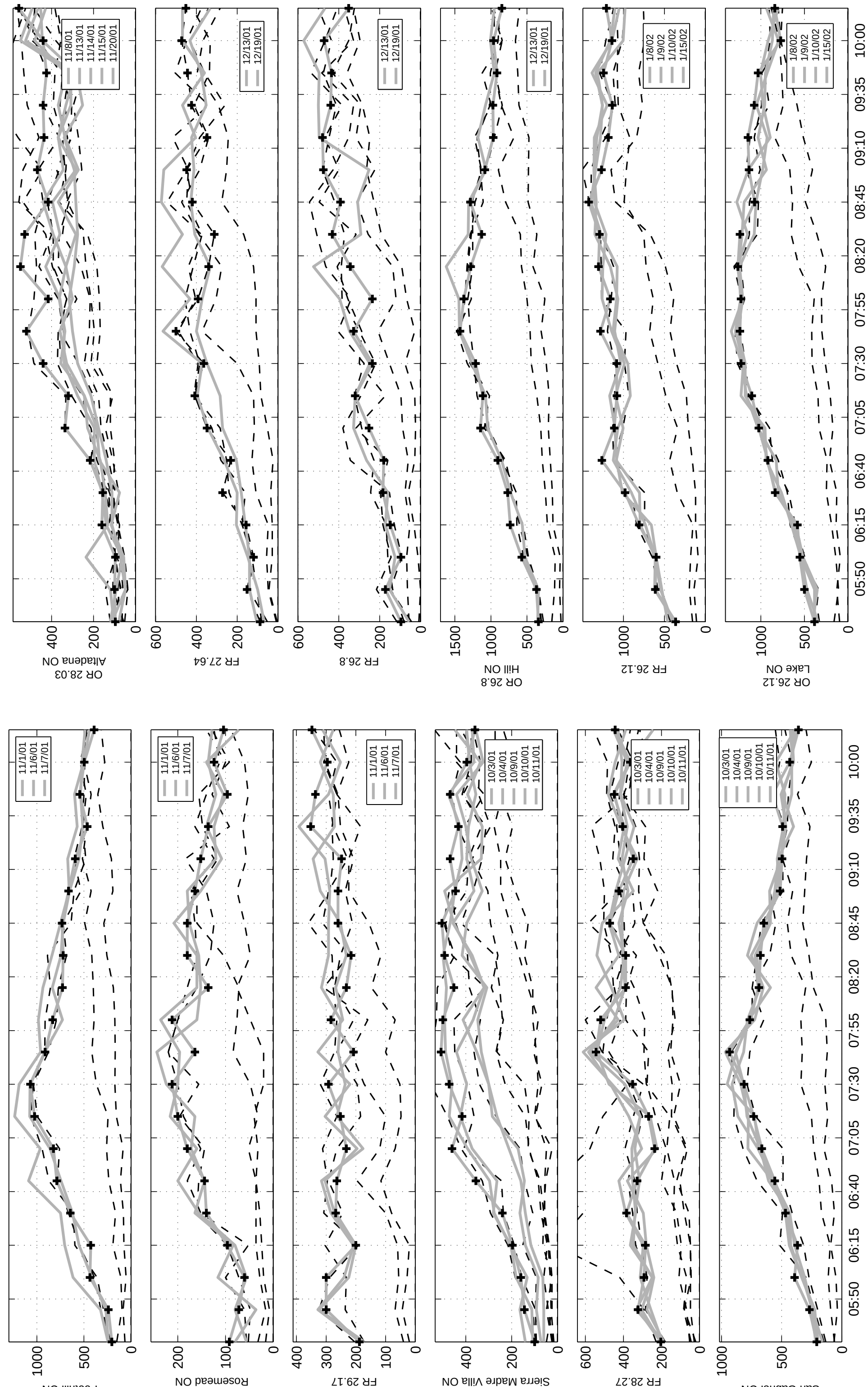

Figure B.5: District 07 ramp survey (OR=onramp, FR=offramp)

C Final selection of boundary flows

Onramps (vph)	39.159	39.159	38.209	38.069	36.589	36	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12
5:30	7632	364	560	460	212	1576	92	212	288	244	192	240	96	120	124	204	92	100	208	96	340	384
5:45	9521	320	480	364	316	1752	124	304	400	280	168	196	104	140	148	240	72	144	268	100	368	500
6:00	8948	356	492	420	328	1908	168	288	392	432	364	292	244	252	224	436	60	160	392	96	572	552
6:15	9152	476	648	468	296	2416	196	264	576	448	384	288	312	320	256	428	96	196	368	160	732	580
6:30	8608	456	660	448	192	2596	232	312	756	472	480	336	324	368	372	644	140	240	468	156	768	836
6:45	8552	516	548	404	172	2704	216	284	748	632	520	360	328	480	424	788	144	356	556	216	904	920
7:00	8820	580	508	456	148	2400	200	304	620	860	512	376	388	552	628	824	180	460	664	336	1144	1024
7:15	9028	440	544	544	228	2356	192	352	744	872	536	428	392	628	732	1024	200	416	732	320	1112	1104
7:30	8744	400	620	592	216	2356	264	304	764	788	504	448	496	624	776	1068	212	472	812	440	1212	1228
7:45	7936	276	596	476	224	2340	236	236	632	704	412	352	452	532	780	912	164	508	932	520	1428	1240
8:00	7252	272	552	508	188	2340	208	276	488	632	616	324	472	556	732	832	212	500	764	416	1376	1228
8:15	7968	252	620	364	184	2388	176	268	640	716	480	272	372	524	672	728	136	452	688	548	1280	1264
8:30	7100	236	592	436	156	2040	148	292	612	616	592	324	360	604	720	720	180	492	676	528	1128	1240
8:45	6672	220	608	416	128	1964	284	388	480	608	408	260	380	460	576	732	180	504	648	416	1284	1072
9:00	6648	172	464	492	128	1836	348	364	464	580	464	216	312	328	452	664	164	444	512	468	1084	1136
9:15	6432	200	460	360	160	2112	280	328	624	504	480	300	312	420	316	592	152	468	496	436	968	1148
9:30	6298	188	664	368	152	2112	312	404	584	432	464	280	336	372	236	464	136	432	492	440	972	1076
9:45	6072	140	620	424	180	2024	312	328	524	576	452	320	268	356	284	544	96	468	576	424	916	1032
10:00	6192	148	468	416	140	2052	344	424	484	500	508	264	304	240	212	496	124	396	432	440	964	772
10:30	6368	124	448	380	164	1924	396	460	476	448	524	240	320	264	224	392	104	360	360	556	848	840

Figure C.1: Onramp flows (first column is upstream mainline)

Offramps (vph)	38.209	38	37	36	35.409	34.049	33.049	32.019	30.779	30.5	29.17	28.27	27.64	26.8	26.12	25.68	25.6	25.5	25.4
5:30	616	2200	108	208	304	404	144	128	124	268	188	204	88	96	364	304	1372	1372	3568
5:45	612	2456	116	308	436	632	224	284	172	432	300	324	152	172	612	436	1692	1692	4088
6:00	444	2428	112	284	388	416	192	304	180	436	300	292	120	96	600	300	1974	1974	4456
6:15	344	2108	148	240	496	408	184	256	248	348	200	284	156	148	808	432	2202	2202	5376
6:30	344	2288	224	360	716	404	208	216	212	496	268	384	272	184	980	440	2176	2176	6044
6:45	432	2392	360	424	996	524	236	356	356	396	264	328	232	180	1264	592	1930	1930	6176
7:00	516	1976	340	360	868	440	220	228	388	404	232	236	348	252	1112	648	2534	2534	6472
7:15	408	2416	420	452	880	384	180	284	448	324	252	268	408	320	1080	600	2752	2752	6560
7:30	476	2608	416	460	1000	592	204	320	516	372	292	352	364	236	1084	656	2636	2636	6556
7:45	808	2288	352	448	1328	672	272	392	612	372	208	544	500	328	1280	764	2584	2584	6648
8:00	676	2148	540	608	996	736	232	328	484	452	284	520	392	236	1160	776	2372	2372	6720
8:15	684	2320	556	576	1136	544	212	368	600	388	232	388	340	344	1304	748	2358	2358	6420
8:30	948	1872	600	632	1092	540	272	280	500	388	216	388	312	432	1292	640	2304	2304	6540
8:45	752	2024	644	420	824	576	232	288	504	484	260	472	420	392	1424	776	2222	2222	6052
9:00	528	1764	508	360	488	560	272	316	500	448	260	424	448	476	1268	628	2120	2120	5536
9:15	496	1576	304	428	616	552	376	276	388	484	248	348	348	480	1184	640	2122	2122	5280
9:30	472	1544	236	368	456	572	292	360	380	504	352	404	424	440	1136	512	1926	1926	4732
9:45	548	1328	124	496	548	576	400	360	516	436	336	448	444	436	1244	672	2040	2040	4664
10:00	408	1132	120	380	576	608	408	424	408	492	296	364	472	472	1140	472	1806	1806	4216
10:30	512	1164	76	344	492	712	412	408	364	528	348	444	452	352	1208	456	1588	1588	3808

Figure C.2: Offramp flows (last column is downstream mainline)

D Vehicle types

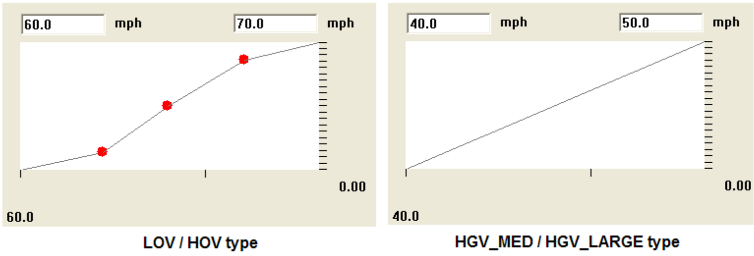

Figure D.1: Desired velocity

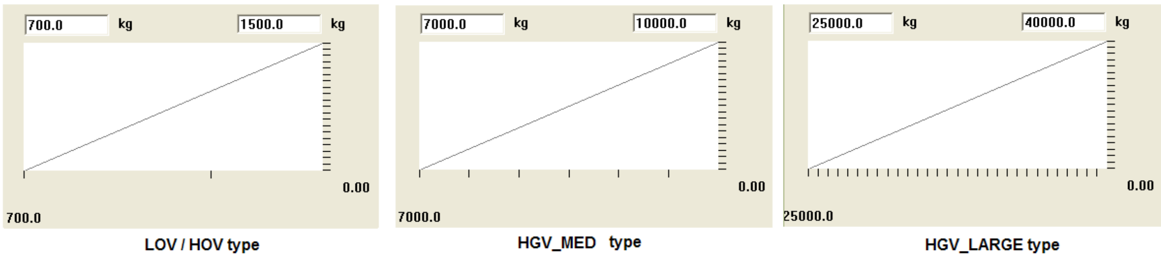

Figure D.2: Weight

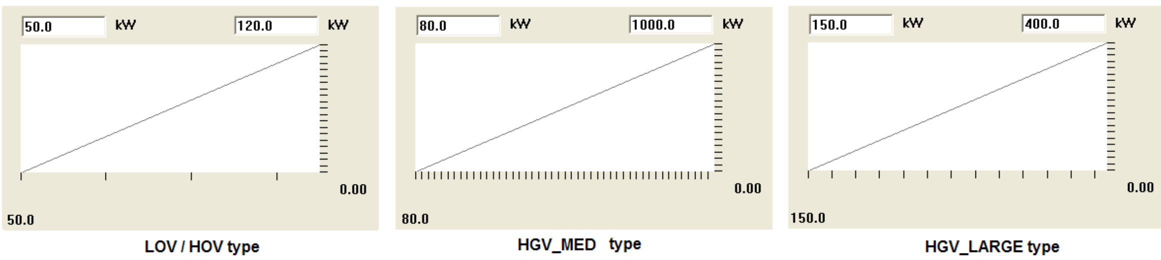

Figure D.3: Power

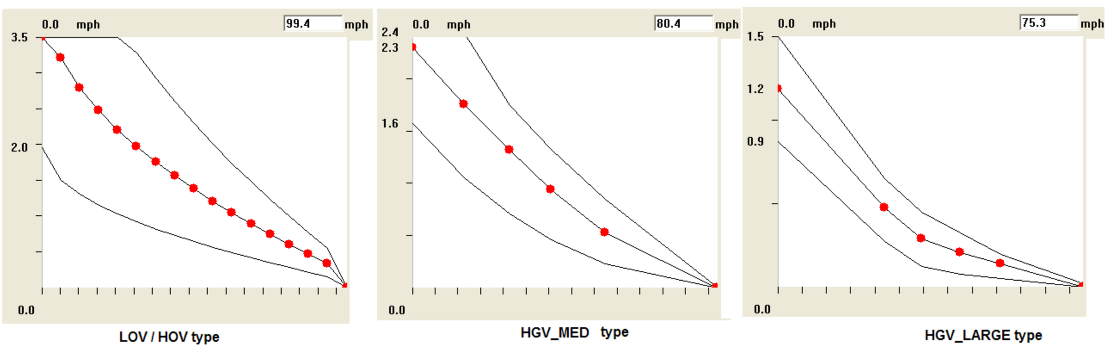

Figure D.4: Maximum acceleration

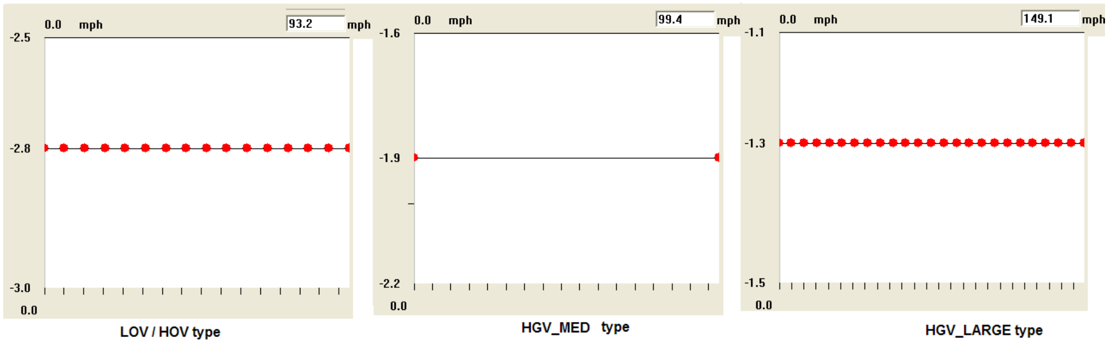

Figure D.5: Desired acceleration

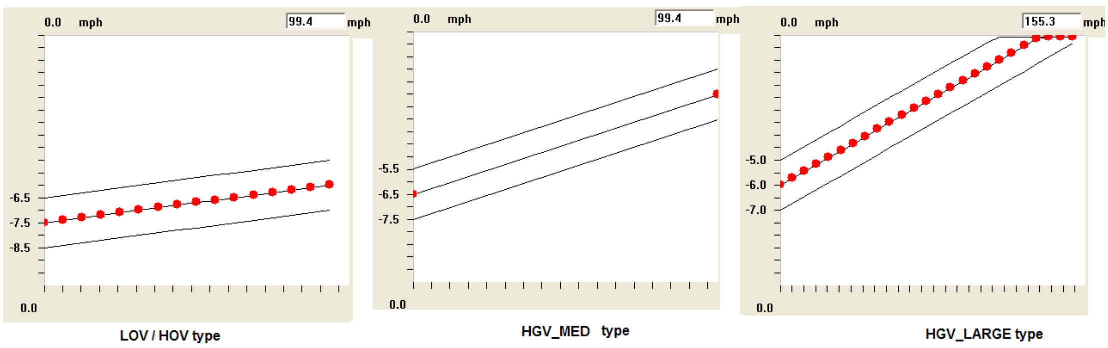

Figure D.6: Maximum deceleration

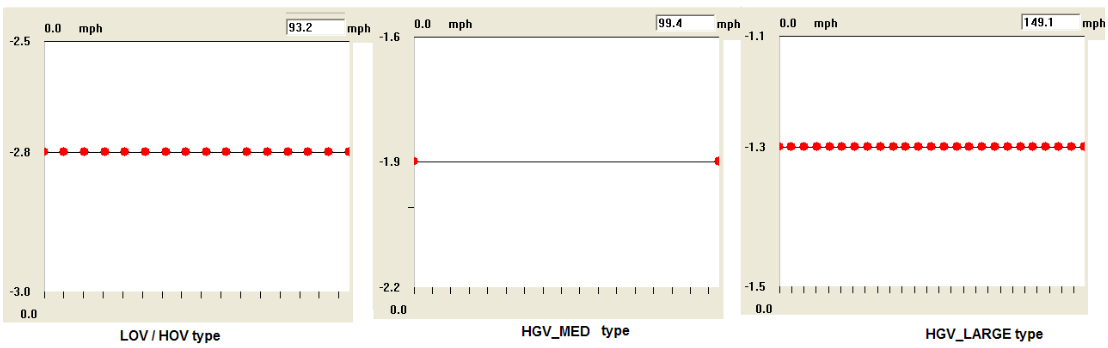

Figure D.7: Desired deceleration

E Intermediate VISSIM results

	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	63	62	63	62	63	63	64	63	63	63	62	63	62	63	63	64	63	64	63	63	64
5:45	63	62	61	63	61	62	63	63	63	63	63	63	63	63	63	64	63	64	64	64	61	64
6:00	63	62	60	63	62	62	63	63	63	62	63	62	62	61	62	63	63	63	63	63	60	64
6:15	63	61	57	63	57	60	62	61	61	60	61	60	62	62	62	63	62	61	63	63	58	63
6:30	63	63	57	63	49	57	60	61	59	57	47	38	57	54	58	61	61	61	62	61	54	62
6:45	63	62	60	63	57	58	61	60	48	37	29	26	56	55	58	61	62	59	61	61	55	62
7:00	63	60	58	63	60	61	62	63	33	24	26	25	56	50	56	61	60	56	60	58	54	62
7:15	63	63	57	63	61	62	63	62	22	28	27	27	47	44	54	59	58	50	61	38	40	62
7:30	63	62	61	63	59	61	62	62	21	23	25	27	29	40	54	60	60	43	29	22	40	61
7:45	63	63	61	64	59	62	63	63	25	26	22	25	36	38	52	58	26	23	21	25	40	62
8:00	63	63	62	64	63	63	64	63	63	52	40	32	26	41	54	33	19	28	27	29	42	61
8:15	63	63	62	64	63	63	64	64	63	63	63	61	58	53	58	43	37	41	35	36	45	61
8:30	63	63	61	64	63	63	64	63	63	61	63	62	63	60	62	63	63	62	59	44	42	61
8:45	63	64	61	64	64	63	64	63	63	63	63	63	63	60	62	63	63	62	63	62	61	64
9:00	64	64	63	64	62	63	63	64	63	62	63	62	63	62	63	63	63	63	63	63	62	64
9:15	63	64	63	64	62	63	63	63	63	63	63	62	63	63	62	63	63	62	63	63	58	64
9:30	64	64	62	64	63	62	63	63	63	63	63	63	62	62	62	63	63	63	63	63	61	63
9:45	64	64	62	64	63	63	64	64	63	63	63	63	62	62	63	64	63	62	63	63	58	64
10:00	63	64	63	64	63	63	63	63	63	63	63	63	64	63	63	64	64	63	63	63	60	64
10:15	63	64	62	64	62	61	63	62	62	61	63	62	63	62	63	63	64	63	63	63	61	64

Figure E.1: Contour plot after adjusting the look back distances

	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	63	62	64	63	63	63	63	63	63	63	63	63	62	63	64	64	63	64	64	63	64
5:45	63	63	62	63	61	62	63	63	63	63	63	63	63	63	63	64	64	64	64	64	62	64
6:00	63	63	61	64	62	63	63	63	62	62	63	62	61	61	61	63	63	63	63	63	60	64
6:15	63	61	59	63	58	60	62	62	61	62	60	58	62	62	62	63	63	63	63	63	60	64
6:30	63	63	60	63	56	60	61	61	55	50	49	48	48	47	56	61	62	60	61	61	58	63
6:45	63	63	60	63	60	61	62	61	27	33	27	30	55	53	57	61	61	58	62	62	58	63
7:00	63	63	61	63	61	61	62	63	31	26	28	28	55	44	55	60	62	59	60	61	57	63
7:15	63	63	59	63	60	61	63	59	20	33	23	24	22	41	53	59	61	59	62	52	45	62
7:30	63	63	62	63	61	61	62	31	15	19	19	23	23	41	55	60	61	57	47	23	43	62
7:45	63	63	61	64	63	63	64	16	20	27	23	26	26	41	54	60	58	46	25	28	49	62
8:00	63	63	63	64	63	63	64	52	18	29	23	29	26	42	55	59	58	50	26	29	55	62
8:15	63	63	62	64	63	63	64	64	63	55	45	36	23	42	53	58	61	60	35	30	53	61
8:30	63	63	62	64	63	64	64	63	63	62	63	63	54	55	60	62	62	61	61	37	50	62
8:45	63	64	62	64	63	63	64	64	63	63	63	63	63	61	62	63	63	61	63	62	60	63
9:00	64	64	63	64	63	63	63	64	63	62	63	63	63	62	63	63	63	62	63	63	62	64
9:15	63	64	63	64	63	63	63	63	63	62	63	63	63	62	62	63	63	62	63	63	59	63
9:30	64	64	62	64	63	63	63	63	63	63	63	63	63	62	63	63	63	63	63	63	61	64
9:45	64	64	62	64	63	63	64	64	63	62	63	63	63	62	63	64	63	62	63	63	62	64
10:00	63	64	63	64	63	63	63	63	63	63	63	63	63	63	63	64	64	63	63	63	61	64
10:15	63	64	62	64	63	62	63	63	63	63	63	63	61	61	63	63	63	62	63	63	62	64

Figure E.2: Contour plot after adjusting the waiting time

F Onramp response

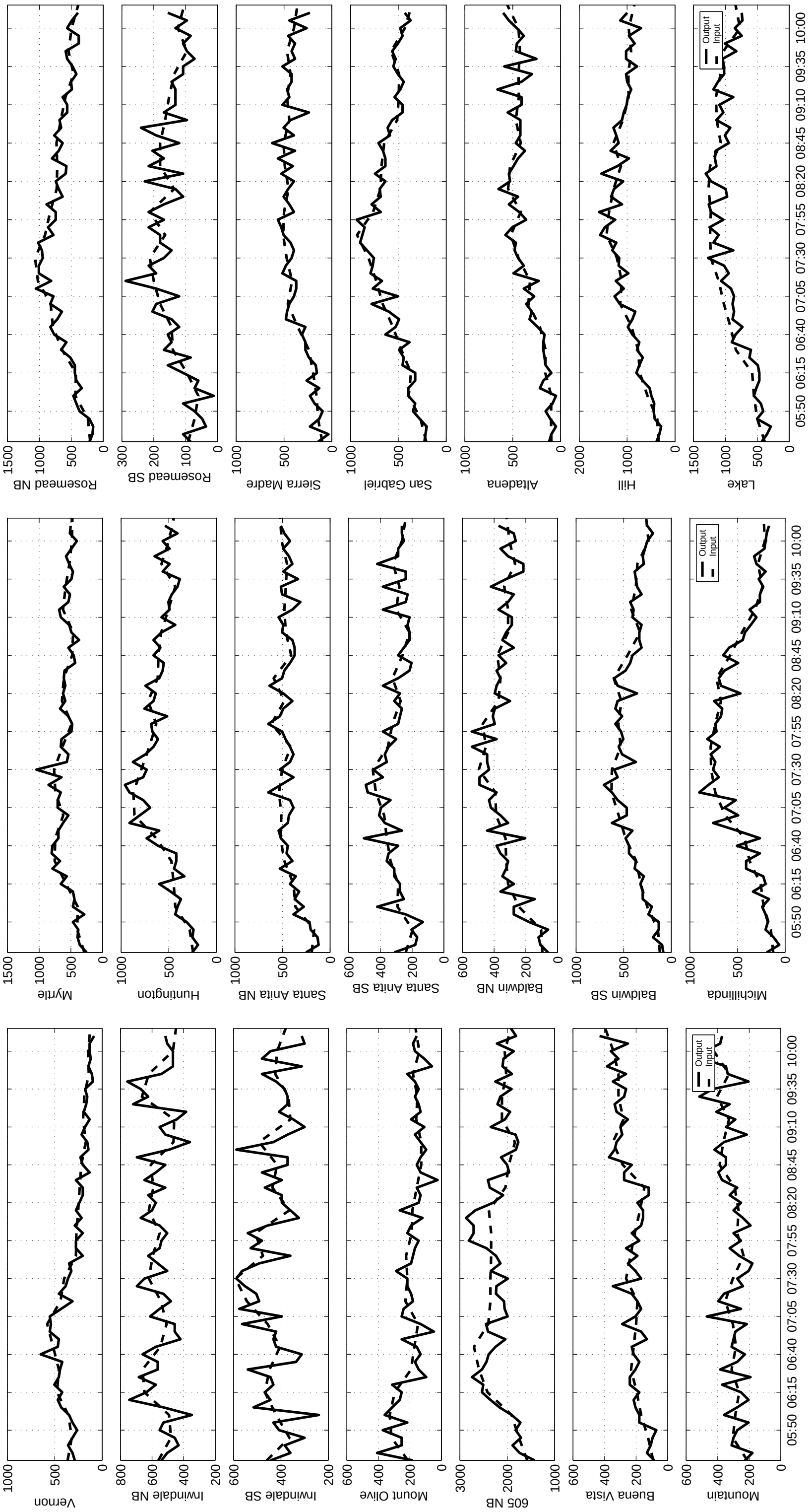

Figure F.1: VISSIM onramp inputs and outputs

G Random seed variations

time ↓	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	63	60	64	63	63	64	59	63	63	63	63	63	63	64	64	64	64	63	64	63	64
5:45	62	62	58	64	62	62	63	57	63	63	63	63	64	63	64	64	64	64	63	64	63	64
6:00	63	60	58	63	61	60	53	52	63	63	63	62	63	62	63	64	63	63	63	63	63	64
6:15	63	62	56	63	60	49	18	51	62	61	62	60	63	62	63	64	63	63	63	62	61	63
6:30	63	63	60	63	19	17	15	52	62	62	61	59	60	58	62	63	63	62	61	61	58	63
6:45	63	62	60	33	16	15	14	51	61	59	61	60	60	49	57	62	62	61	61	60	56	63
7:00	63	63	60	11	17	17	15	52	61	60	61	35	58	57	60	63	61	57	57	56	57	62
7:15	63	63	60	10	17	15	15	52	62	60	50	33	58	54	59	62	62	54	44	53	57	63
7:30	63	30	24	11	16	15	15	52	55	37	23	24	31	41	54	60	53	37	30	40	54	62
7:45	49	18	22	11	17	18	15	51	17	20	20	23	25	41	54	54	18	23	28	45	55	62
8:00	63	33	27	11	18	18	15	32	15	19	19	21	23	40	50	19	20	26	26	31	54	62
8:15	64	64	62	12	17	16	12	19	17	20	19	21	24	34	25	18	19	23	30	41	56	62
8:30	63	64	62	14	14	14	13	19	14	18	19	22	21	30	29	21	23	32	36	56	58	62
8:45	64	64	62	56	12	12	12	22	19	22	24	28	34	39	30	23	23	32	40	58	58	63
9:00	63	64	63	64	15	17	16	33	25	31	26	29	30	37	37	24	27	42	40	58	61	63
9:15	64	64	63	64	19	18	16	53	24	30	29	31	43	41	54	48	29	42	39	59	61	64
9:30	64	64	62	64	55	20	16	52	48	36	28	32	59	59	61	63	46	42	38	60	58	63
9:45	64	64	62	64	63	45	16	52	62	61	51	37	57	57	60	63	63	62	51	61	58	64
10:00	64	64	63	64	63	63	16	53	62	61	63	61	63	62	63	63	63	61	62	63	62	64
10:15	64	64	62	64	62	62	23	54	62	57	63	61	63	63	64	64	63	63	62	63	62	64

Direction of traffic →

Figure G.1: Random seed = 28

time ↓	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	62	61	64	63	63	64	60	63	63	63	63	63	63	64	64	64	64	63	64	63	64
5:45	56	55	47	63	62	63	63	58	63	63	63	63	64	63	64	64	64	64	63	64	63	64
6:00	35	56	47	63	61	61	60	52	62	61	62	62	62	61	63	63	64	63	63	63	62	64
6:15	59	61	47	63	58	54	23	51	62	60	61	61	62	61	63	63	63	62	62	63	60	64
6:30	63	62	59	63	23	16	15	52	62	61	62	62	60	59	61	63	62	62	61	59	61	63
6:45	63	63	62	56	16	16	15	50	62	60	62	59	56	52	59	61	62	62	60	60	57	63
7:00	63	63	60	19	16	15	15	52	61	61	62	37	59	50	57	61	61	52	56	59	59	62
7:15	63	63	57	10	17	16	15	51	61	59	40	29	38	40	54	61	62	57	39	47	51	62
7:30	63	34	26	10	16	15	14	50	37	27	20	23	26	42	55	60	61	43	32	53	50	62
7:45	55	19	26	11	17	17	15	45	15	17	19	21	24	39	54	61	25	28	26	37	53	62
8:00	63	40	27	11	17	16	13	17	15	18	19	22	25	40	54	39	20	25	27	33	53	62
8:15	63	63	62	11	14	14	12	19	17	21	21	24	29	36	40	20	20	26	34	49	52	62
8:30	63	64	61	11	15	14	13	24	19	24	22	24	24	38	48	24	24	34	37	51	57	62
8:45	64	64	61	41	16	16	16	27	20	24	22	26	27	39	54	45	24	32	41	58	58	61
9:00	64	64	63	64	17	18	16	31	21	28	26	33	35	41	55	61	26	34	38	58	59	63
9:15	64	64	63	64	18	17	16	55	24	31	27	32	36	42	55	61	48	43	38	60	59	63
9:30	64	64	62	64	59	19	16	52	39	35	28	32	57	55	61	62	63	60	48	59	58	63
9:45	64	64	62	64	63	46	16	53	63	61	51	42	58	56	60	63	63	61	61	62	61	63
10:00	64	64	62	64	63	63	20	53	62	61	63	62	63	63	64	64	64	62	62	63	62	64
10:15	63	64	62	64	63	61	33	52	62	61	63	63	63	63	63	64	63	62	61	63	62	64

Direction of traffic →

Figure G.2: Random seed = 35

time ↓	39.159	38.209	38.069	36.589	35.409	34.899	34.049	33.049	32.199	32.019	30.999	30.779	30.139	29.999	29.879	29.17	28.27	28.03	26.8	26.12	25.68	25.5
5:30	63	63	61	64	63	63	64	61	63	63	63	63	63	63	64	64	64	64	63	64	63	64
5:45	57	61	48	63	62	63	63	61	64	63	63	63	63	63	64	64	64	64	63	63	63	64
6:00	51	56	52	63	61	62	52	52	62	61	62	62	63	62	63	64	63	63	63	63	62	64
6:15	63	60	50	62	58	51	20	51	61	61	62	61	61	62	63	64	63	63	62	63	61	64
6:30	63	63	58	63	19	15	15	51	62	61	62	61	62	55	60	63	63	62	61	62	59	64
6:45	63	62	58	29	16	15	14	51	61	60	59	47	58	59	61	60	62	61	60	61	56	63
7:00	63	63	62	10	17	16	15	51	60	60	37	29	56	54	60	62	62	59	57	58	56	62
7:15	63	56	48	10	17	15	15	51	62	56	25	28	53	44	55	61	61	58	38	51	54	62
7:30	49	16	19	11	16	16	14	51	23	21	24	25	26	41	54	59	61	41	30	52	52	61
7:45	20	18	21	10	18	18	16	43	15	17	19	22	27	40	54	59	27	28	35	48	54	62
8:00	36	20	25	12	16	16	13	20	17	22	22	24	26	39	54	38	22	32	33	50	54	63
8:15	63	51	46	10	16	16	13	21	18	21	21	26	29	40	55	31	23	32	37	40	56	63
8:30	64	64	61	12	16	16	14	22	19	24	24	25	27	39	54	56	23	34	39	56	55	62
8:45	64	64	63	28	15	16	15	30	19	24	24	30	36	40	55	57	26	42	39	60	59	63
9:00	64	64	62	64	18	18	17	41	23	29	31	30	38	44	55	60	25	35	41	60	61	63
9:15	64	64	63	64	46	27	16	52	31	35	50	43	50	48	57	61	34	38	38	57	59	63
9:30	64	64	62	64	63	60	16	52	61	58	62	42	57	52	58	62	63	58	40	57	59	63
9:45	64	64	62	64	63	63	24	52	63	61	63	62	63	62	63	64	64	62	61	62	60	64
10:00	64	64	63	64	62	63	58	53	63	61	63	62	63	63	63	64	64	62	62	63	62	64
10:15	64	64	63	64	63	62	63	56	62	62	63	62	63	63	63	64	63	62	62	63	61	64

Direction of traffic →

Figure G.3: Random seed = 66

References

Fellendorf, M. and P. Vortisch (Washington, D.C., January, 2001.). Validation of the microscopic traffic flow model vissim in different real-world situations. *National Research Council. 80th Meeting of the Transportation Research Board*.

Hall, F., L. Bloomberg, N. Rouphail, B. Eads, and A. May (2000). Validation results for four models of oversaturated freeway facilities. *Transportation Research Record No.1710, National Research Council*.

PTV AG (2003). Vissim user manual - v.3.70.

Wiedemann, R. (1974). Simulation des straßenverkehrsflusses. *Schtiftenreihe des Instituts fur Verkehrswesen der Universitat Karlsruhe, Heft 8*.

Wiedemann, R. (1991). Modelling of rti-elements on multi-lane roads. *Advanced Telematics in Road Transport*.