Congested Freeway Microsimulation Model Using VISSIM

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A procedure for constructing and calibrating a detailed model of a freeway by using VISSIM is presented and applied to a 15-mi stretch of I-210 West in Pasadena, California. This test site provides several challenges for microscopic modeling: a high-occupancy vehicle (HOV) lane with an intermittent barrier, a heavy freeway connector, 20 metered on-ramps with and without HOV bypass lanes, and three interacting bottlenecks. Field data used as input to the model were compiled from two separate sources: loop detectors on the on-ramps and main line (PeMS) and a manual survey of on-ramps and off-ramps. 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 origin–destination matrices from the assembled boundary flows. The model construction procedure consists of (1) identification of important geometric features, (2) collection and processing of traffic data, (3) analysis of the main-line data to identify recurring bottlenecks, (4) VISSIM coding, and (5) calibration based on observations from Step 3. A qualitative set of goals was established for the calibration. These were met with relatively few modifications to VISSIM's driver behavior parameters.

It has long been recognized that simulation modeling is a very useful tool for the design of improvements to urban freeway systems. The simulation model enables the engineer to predict the outcomes of a proposed change to the freeway system before it is implemented, and to evaluate the merits of competing designs. This is a very important consideration, given the impacts that such projects can have on nearby communities and on local economies. For the simulation model to predict the system response correctly, however, it must first be shown to reproduce the existing traffic condition. The procedure by which the parameters of the model are adjusted so that the simulated response agrees with the measured field conditions is what is known as model calibration.

Simulation models are generally classified into macroscopic and microscopic models, depending on their level of modeling detail. Macroscopic models describe the traffic process with aggregate quantities, such as flow and density. Microscopic models describe the behavior of the individual drivers as they react to their perceived environments. The aggregate response in the latter case is the result of interactions among many driver/vehicle entities. A macroscopic model is often sufficient for the purpose of evaluating a proposed modification. These models tend be easier to calibrate, because their parameters can be directly related to field data available from the existing sensor infrastructure. For example, FREQ, a popular macroscopic model, is tuned by direct manipulation of subsection capacities. However, it may sometimes be necessary to use a microscopic model in order to capture the more detailed aspects of the system. In this case, the calibration process may become more difficult, and there is no standard methodology for model calibration. The intent of this paper is not to suggest a general methodology, but to present the steps that were followed in the construction (data collection, coding, and calibration) of a VISSIM-based model of a particular freeway system. Analogous efforts using different microscopic models include PARAMICS (*1*), CORSIM (*2*), and INTRAS (*3, 4*).

This work is part of a larger project (PATH/Caltrans T.O. 4136) that has as its central goal to design and implement an improved on-ramp control system for the Foothill Freeway (I-210 West) in Pasadena, California. The model will be used as a test bed for evaluating different control designs. VISSIM was selected as the environment for constructing the test bed following recommendations from several knowledgeable colleagues. I-210 West is a large and heavily congested test site and presents several complicating features: a high-occupancy vehicle (HOV) lane with an intermittent barrier, several metered on-ramps with and without HOV bypass lanes, an uncontrolled freeway connector, and three interacting bottlenecks.

Although this paper is based on a single test case, practitioners wishing to use microsimulation to study unidirectional freeways may find useful many of the details on how certain features were implemented and how problems related to incomplete data were overcome. The entire process of model construction is covered. The first three sections describe the collection of geometric and traffic data. Next, the paper briefly describes the use of FREQ to translate the boundary flows to origin–destination (O-D) matrices, discusses an analysis of the traffic data that is later used in the model calibration phase, provides details on the coding of VISSIM, describes several important driver behavior parameters, and discusses the parameter adjustment procedure and its results.

DESCRIPTION OF TEST SITE—SOURCES OF GEOMETRIC INFORMATION

The site and time period chosen for the simulation study was the westbound direction of I-210 from Vernon Street to Fair Oaks (on SR-134, just beyond the 210/134 junction), between 5:30 and 10:30 a.m. (Figure 1). This was a 15-mi stretch of freeway that sustained heavy congestion during the morning commute. Congestion usually began around 6:00 a.m., peaked at 7:30 a.m., and finally dissipated at around 10:00 a.m. The site had 21 on-ramps, 20 of which were metered and equipped with a complete set of loop detectors (all except the 605-NB/210-WB freeway connector). Each metered on-ramp had a corresponding main-line detector station for traffic-responsive

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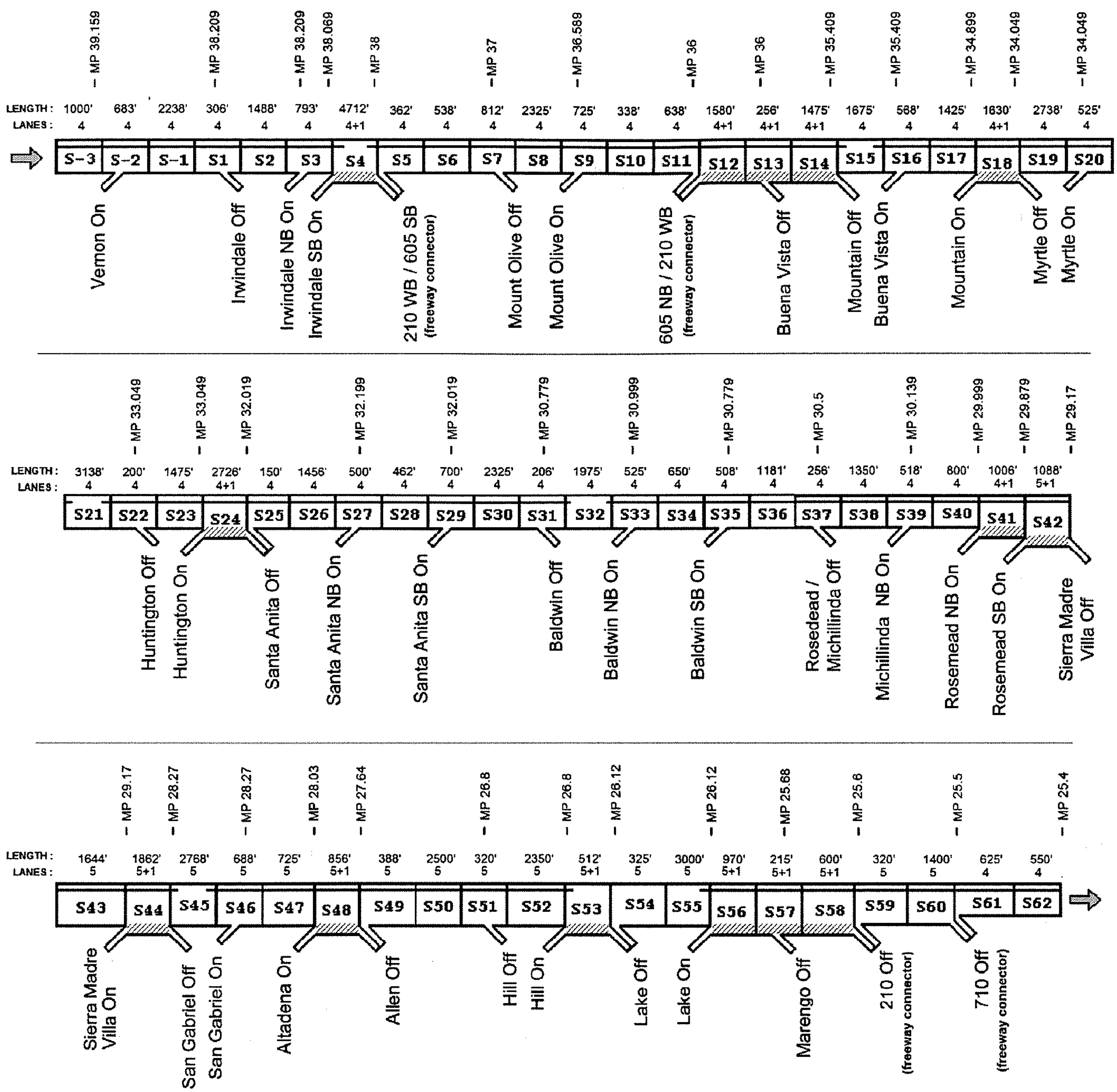


FIGURE 1 Sixty-five sections in test site.

control, and some, but not all, had HOV bypass lanes. There was a median-side HOV lane that spanned the entire site and was separated from the mixed-traffic lanes by an intermittent barrier (Figure 1). The cut-off occupancy for the HOV lane was two or more passengers per vehicle and was 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. The important features that are usually represented include the location of on-ramps and off-ramps, the number of lanes and location of lane drops, freeway curvature, auxiliary lanes, and weaving sections. In the case of I-210, additional features were also considered important, for example, the positions of the HOV gates—the gaps in the intermittent barrier where vehicles entered and exited the HOV lane—and also the arrangement of loop detectors and metering lights on the on-ramp and main line. In particular, the position of the queue detector with respect to the metering light was especially important for control applications because it determined the maximum permitted queue length, when queue length restrictions were enforced.

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 were black-and-white and printed on 11- × 17-in. paper, with a 1:2,400 scale.
2. A set of as-built maps indicating the arrangement of loop detectors on on-ramps and the main line. These were provided by the District 07 Ramp Metering Group.
3. Unscaled aerial photographs in bitmap format downloaded from MapQuest (www.mapquest.com).

All of the desired features were extracted from the aerial photographs (Source 1), with the exception of the arrangement of sensors and metering lights, which was measured from the as-built maps (Source 2). Each of the important features was assigned a single 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). Figure 1 also provides the lengths and number of mixed-flow lanes in each section. The features mentioned above were marked on a large overhead view of the site compiled from Source 3 and thus encoded into VISSIM.

TRAFFIC DATA SOURCES

The traffic demand was defined in VISSIM as a set of O-D matrices, which contain the average numbers of vehicles going from every freeway origin to every destination, at 15-min 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 in order to generate the O-D matrices. The first step was to compile a complete and representative set of boundary flows, covering every on-ramp, off-ramp, and the two main-line boundaries. FREQ was then used to translate the boundary flows into the required set of O-D matrices.

Two sources of traffic data were used:

1. PeMS: The PeMS database gathered 30-s and 5-min data from over 30,000 mi of freeway in California (*5*). This database was used to assemble a history of traffic measurements for every loop-detector station in the site. Three examples of speed contour maps generated from the PeMS main-line data are shown in Figure 2. 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 (see section on identification of recurring bottlenecks) 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 gathered between 10/2001 and 1/2002. The collected data consisted of 15-min estimates of volumes on most of the on-ramps and off-ramps in the test site (all except the Marengo Street off-ramp and the 210 and 710 freeway connectors). The D07 survey did not include any main-line data.

Close agreement between the two sources was found in most cases. Instances in which 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 were primarily used where main-line measurements were needed, that is, to determine the upstream and downstream main-line flows and to construct the contour plots used for model calibration.

BOUNDARY FLOWS FROM CALTRANS D07 SURVEY AND PeMS

The ramp counts collected by the biennial District 07 survey were gathered manually, by a count of the number of vehicles that used every on-ramp and off-ramp, at 15-min intervals, throughout the day. Each ramp was surveyed over a period of about 14 consecutive days. 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 main-line data. Conversely, the PeMS database provided main-line measurements that were practically complete but lacked information from several key ramps, including the heavy freeway connector from 605 NB (MP 36), and several off-ramps where loop detectors had either failed or were missing.

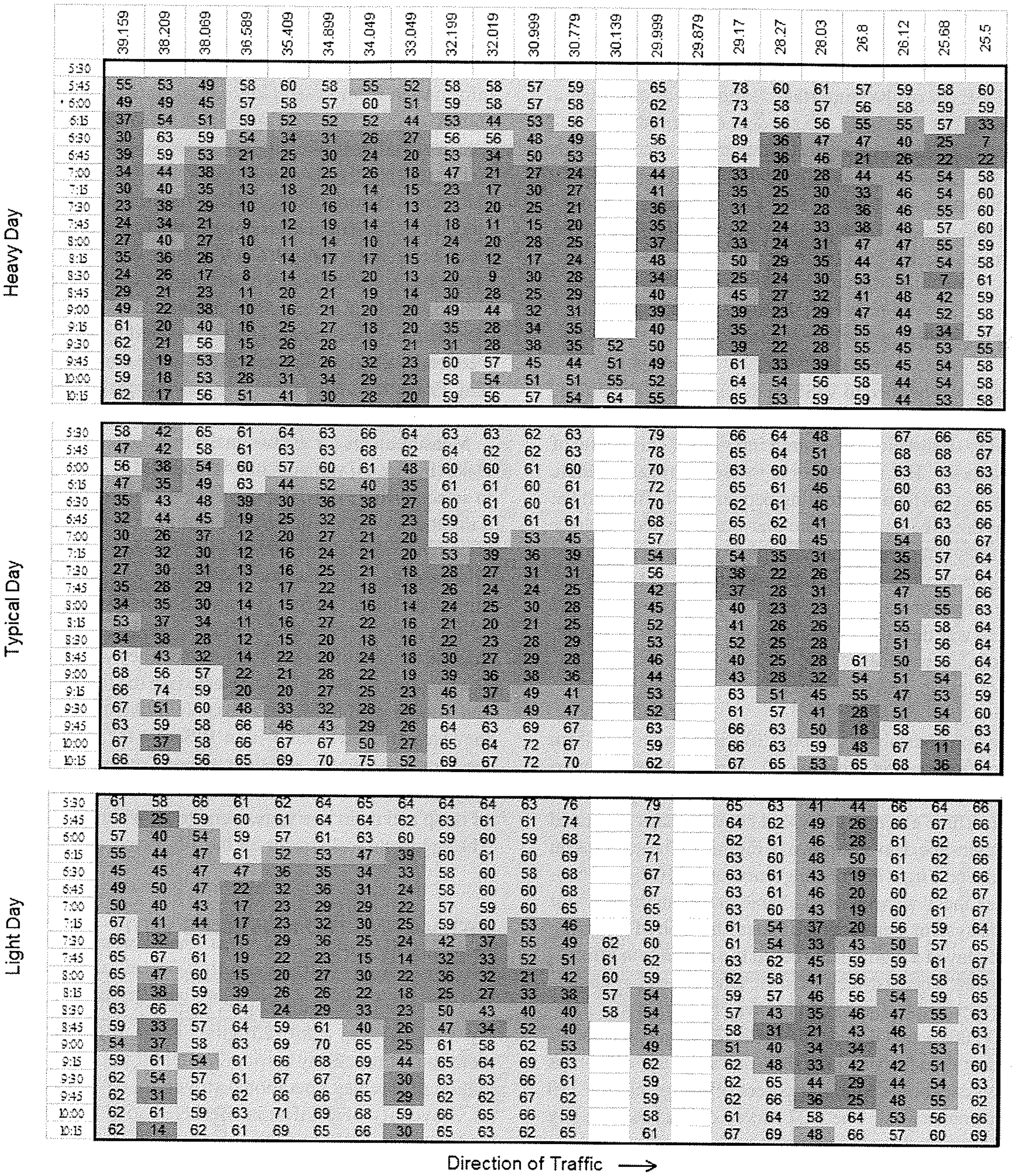
The main difficulty encountered with the D07 boundary data was that there was no single day in which all ramps were surveyed simultaneously. This situation is common in real-world settings, because it is rare to find a complete and reliable sensor structure. As a consequence, it was necessary to assemble 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 strayed from the normal (i.e., average) pattern. From this set, a single day was selected for each on-ramp and off-ramp.

Measurements for the two main-line boundaries [Vernon and Fair Oaks (Figure 1)] were obtained from PeMS. Again, it was necessary to select a single typical day for the main-line boundary flows from a number of days. The selection of typical days for the main-line boundaries was based on three criteria: completeness of the data set, how well the flow data followed the day-to-day trend, and the resulting "scale factor." Scale factors were defined as the ratio, for each 15-min period, of the total number of vehicles entering the system to the total number of vehicles that exited. They were computed in FREQ as a first step to finding an O-D table (see the following section). 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 (incidentless) traffic scenario, and their average over a 5-h period should be very close to 1.00. The scale factors resulting from the final selection of ramp and main line were found to be within the acceptable range. The aggregate scale factor for the 5-h period was 1.02.

ESTIMATING O-D MATRICES WITH THE FREQ MODEL

The translation of ramp counts to the set of O-D 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 at University of California, Berkeley (*6*). The O-D matrices are computed in FREQ as the solution to a steady-state optimization problem. In our case, the FREQ optimization generated a sequence of 20 O-D matrices—one for each 15-min time interval—each with dimensions 22 × 19 = (21 on-ramps + 1 main-line origin) × (18 off-ramps + 1 main-line 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 the section on coding of traffic demands, each O-D 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 the aforementioned section), each FREQ O-D matrix spawned two VISSIM O-D matrices, for a total of 40 matrices. The following assumptions were made on the basis of available data and on suggestions from Caltrans staff. They were sufficient to make the conversion from 20 to 40 O-D matrices.

- The number of vehicles using the HOV lane at the upstream main-line boundary (Vernon Street) was a given time-varying fraction of the total (mixed-lanes plus HOV lane). This fraction was derived from PeMS data.



	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
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10:15	62	17	56	51	41	30	28	20	59	56	57	54	64	55		65	53	59	59	44	53	58

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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
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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 2 Processed PeMS contour plots.

- In addition to the HOV vehicles in the HOV lane, 5% of the vehicles in the Vernon Street mixed-flow lanes were also HOV.
- Twelve percent of the vehicles entering the freeway through on-ramps were HOV.
- Of the total number of HOV vehicles that reach the downstream main-line boundary, 20% were in mixed-flow lanes, and 80% were in the HOV lane.

IDENTIFICATION OF RECURRING BOTTLENECKS

The first step in the model calibration process was to identify the location and causes of congestion on I-210. This information was later used as a guide in the parameter tuning phase (see section on calibration goals). Figure 2 shows 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:

B1: Near Huntington Street (MP 33.049),
B2: Near the Rosemead and Michillinda Street ramps (MP 30.139), and
B3: Near Hill Street (MP 26.8).

These three bottlenecks are illustrated in Figure 3. Main-line stations are depicted in the figure with a ×, ○, or ⊗, depending on whether the station is characterized by heavy congestion (speeds often under 40 mph), by free flow (speeds exceeding 55 mph) or by decreased

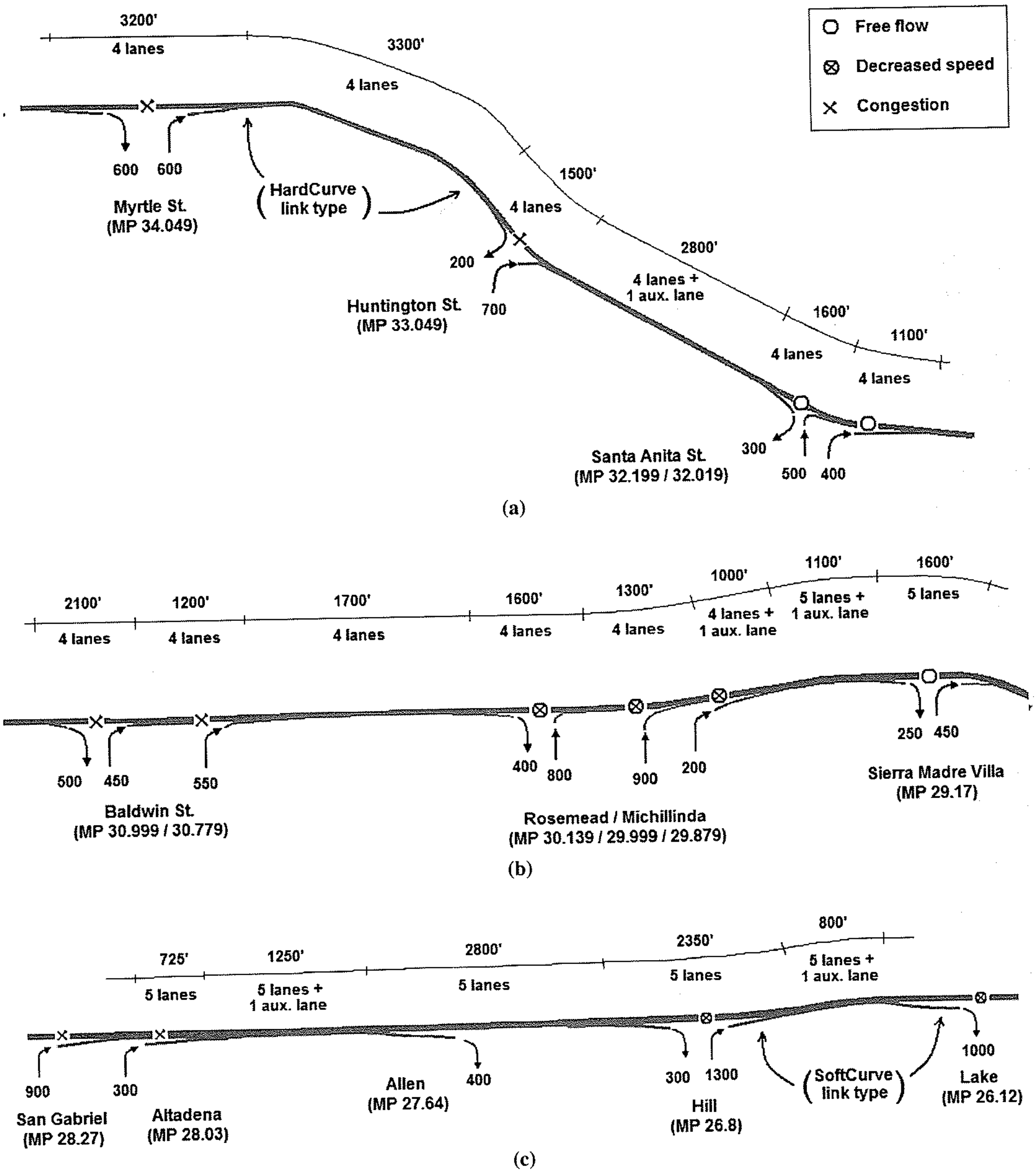


FIGURE 3 Three major bottlenecks: *(a)* B1, *(b)* B2, and *(c)* B3.

speeds not reaching full congestion (speeds between 40 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 on-ramp and off-ramp 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 was not easily explained with a simple comparison of nominal capacities and demands. The Myrtle ramps made no net contribution to the amount of traffic on the freeway (600 – 600 = 0). The Huntington ramps supplied about 500 vehicles per hour (vph) to the main line, but this should easily have been absorbed by the auxiliary lane between Huntington and Santa Anita. The observed deceleration of the traffic stream must therefore have been due to a reduction in capacity near the Huntington ramps or somewhere between Huntington and Santa Anita. Localized reductions in capacity had a variety possible causes, including grades, curves, reduced visibility, street signs, and direct oncoming sunlight. In this case, the most probable cause was the series of reverse curves between Myrtle and Huntington (as suggested by Caltrans staff).

B2: Bottleneck B2 was less stable than B1, in the sense that its location and congestion pattern were less predictable. Congestion initiated somewhere near the Rosemead and Michillinda ramps (MPs 30.139 to 29.879); however, complete breakdown, with speeds in the 20s and 30s, only occurred upstream near the Baldwin on-ramp (MP 30.779). The Rosemead and Michillinda detectors sometimes registered speeds decreasing as low as 40 mph, but seldom less than that. Congestion in this region was probably caused by the two heavy on-ramps from Rosemead and Michillinda, which added approximately 1,700 vph to the freeway. These on-ramp flows should have been easily accommodated by the two additional auxiliary lanes. However, this increased capacity was apparently not fully utilized, probably because of increased weaving in that area.

B3: Main-line traffic near Hill Street (MP 26.8) was usually slow and sometimes fully congested. Traffic near Altadena (MP 28.03) almost always became completely congested. As with the previous two, bottleneck B3 could not easily be explained by comparing demands and nominal capacities, since the heavy flow from the Hill on-ramp was 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 existed: the S-shaped bend between Hill and Lake, and the heavy weaving that took place in the 800-ft auxiliary lane before the Lake off-ramp.

THE VISSIM MODEL

Overview of Program

VISSIM was the microscopic or stochastic traffic simulator that was used to create the detailed model of I-210 West. In the past, it has been used primarily 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 Wiedemann (*7, 8*), 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: free driving, approaching, following, and braking. In each mode the driver behaves differently, either reacting to his or her 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 (e.g., when approaching an intersection) or made by the driver in order to access a faster-moving lane.

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 on-ramps to simulate on-ramp metering control. Further descriptions of the VISSIM model and software can be found in Fellendorf and Vortisch (*9*) and PTV (*10*).

Coding of Network Geometry

As was described previously, the relevant features of the I-210 test site were marked on a composite aerial photograph, which was downloaded from MapQuest. 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.

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

HOV Lanes

Another important aspect of the network coding was 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 main line as well as the HOV bypass lanes on the on-ramps.

Freeway Connector

Almost all of the on-ramp merges were modeled following the method recommended in PTV (*10*), where vehicles entering from the on-ramp join the main-line stream by changing lanes within a merge section. It was found, however, that this approach only worked well for on-ramps with small or moderate flows. It failed for the heavy freeway connector from 605 NB (MP 36), where it produced a large queue on the on-ramp. An alternative configuration was designed to shift some of the burden of the merge away from the on-ramp and onto the main line by forcing a percentage of the main-line vehicles to evacuate the rightmost lane upstream of the ramp junction and thereby open space for the flow from 605 NB. This was accomplished by using VISSIM's partial routing decisions [see PTV (*10*) for further details].

Coding of Traffic Demands

Vehicle Types and Traffic Compositions

The vehicle population in VISSIM is categorized into vehicle 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: low-occupancy vehicle (LOV), HOV, HGV_MED, and HGV_LARGE. The

LOV type represented passenger vehicles with a single occupant. HOV vehicles had two or more occupants and are allowed to use the HOV and bypass lanes. The vehicle specifications for these two types were identical to those of the default CAR type in VISSIM (*10*). The HGV_MED and HGV_LARGE types represent, respectively, medium and large size trucks. 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. The authors chose to use its dynamic assignment module, which automatically determines inlet flows and routing information based on a user-supplied set of O-D matrices. Routes, or traffic assignments, were generated by the dynamic assignment module by assigning a cost to every route available to each O-D pair and then choosing the route with minimum cost. The cost function in VISSIM included terms penalizing the total distance, total travel time, and a link cost. This last term served to model other 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 Cost

The idea behind dynamic assignment is that repeated simulations using this method for generating routes and for 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 was whether and where the HOV vehicles would access the HOV lane. The simulation runs presented in this document were 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 could 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 with 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 the section on coding of the network geometry).

CHANGEABLE MODEL PARAMETERS: DEFAULT VALUES

The previous section on coding of traffic demands listed the model parameters related to the physical attributes of the vehicle. These were assigned separately for each vehicle type. Fixing the vehicle population, the authors now look at the parameters of the driver model. Driver behavior was assumed to be correlated not with vehicle type, but instead with the position of the driver or vehicle in the network. For example, drivers might behave differently on curved sections, as compared to straight sections. Thus the parameters described in this section applied equally to all vehicle types but were adjusted for each link type. Link types were analogous to vehicle types. They gathered links with similar driver behavior parameters. Six link types were created to model I-210. These are described in a later section. 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 PVT (*10*).

Necessary Lane Change (Weaving Behavior)

The dynamic assignment module provides to each vehicle 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 vehicle will be able to anticipate the next bifurcation (i.e., off-ramp) or lane drop on its list and how aggressively that vehicle 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 toward the desired lane. Range = (0, ∞). Default = 200 m.
- Emergency stop distance: Distance before the bifurcation where the driver will stop if he or she has not reached his or her desired lane. Range = (0, ∞). Default = 5 m.
- Waiting time before diffusion: A 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, the vehicle is removed from the simulation. Range = (0, ∞). Default = 60 s.

Vehicle-Following Behavior

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

- CC0 and CC1: Coefficients used in the calculation of the safe bumper-to-bumper distance (in meters): dx_safe = CC0 + $v \cdot$ CC1, where v (in m/s) is the speed of the trailing vehicle. According to PTV (*10*), 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 = free-flow speed. With reasonable values of capacity, dx_safe, and free-flow speed, and default CC0, this calculation gives CC1 = 1.5 s. The range for both CC0 and CC1 is (0, ∞). 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 (*10*) 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 reproduce the curvature-induced capacity drops that are the supposed culprits of bottlenecks B1 and B3. It can be inferred from their definitions that increments in CC0, CC1, or in the absolute values of CC4 and CC5 will lead to reductions in freeway capacity.

VARIATIONS OF SELECTED DRIVER BEHAVIOR PARAMETERS

With model inputs (network supply and traffic demand) fixed as described, an initial simulation experiment was run with default driver behavior parameters. The resulting speed contour plot is shown in Figure 4. A severe blockage near the downstream end of the freeway produced a queue that quickly overran the entire site. This problem was caused by a large number of vehicles attempting to exit through the last two off-ramps (the 210 and 710 freeway connectors) but 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.

Adjustments to the Look-Back Distance

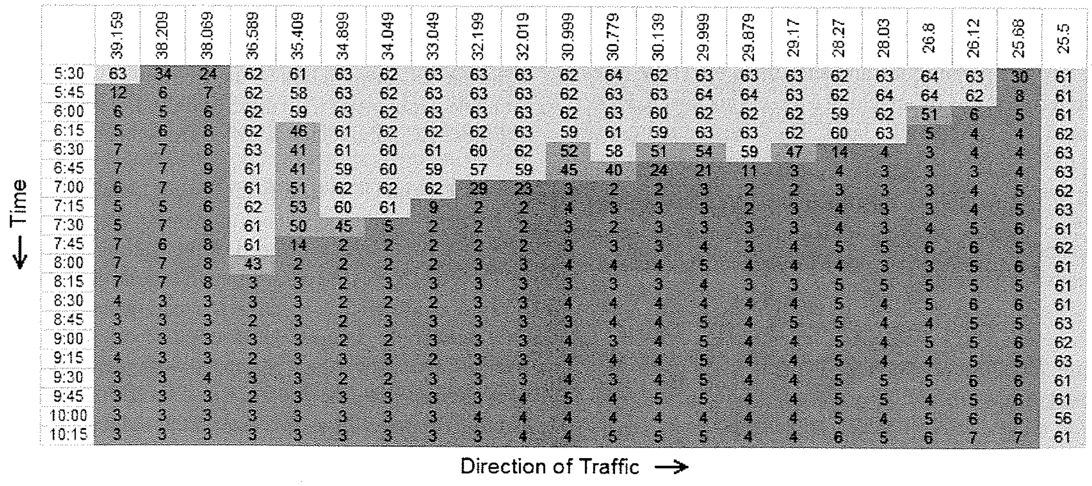
It was determined that the default look-back distance of 200 m was too small for large numbers of vehicles crossing over several lanes of traffic to reach their exits. But, increasing this value too much had the unrealistic effect of bunching up all of the exiting vehicles in the rightmost lane, far upstream of their intended off-ramp. These vehicles then obstructed other upstream off-ramps and on-ramps. It was therefore necessary to tune the look-back distances individually for each off-ramp in a way that allowed vehicles sufficient weaving space while ensuring that these lane-change regions did not overlap.

Adjustments to Waiting Time Before Diffusion

Another modification that was found useful for eliminating the off-ramp blockages was to decrease the waiting time before diffusion parameter from its default 60 s to 1 s. With this setting, vehicles that stopped at the emergency stop position on the main line (at the off-ramp bifurcation) were immediately removed from the simulation and thereby the obstruction to the freeway was minimized. Eliminating these vehicles had little impact on the total travel time, because they were few and very close to their exit anyway. However, this adjustment was only recommended after the number of affected vehicles had been minimized by tuning the look-back distances. Also, one should be careful not to affect other bifurcations and 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 on-ramp/main-line merge sections (which contain a lane drop). To avoid these vehicles from being evaporated, a set of merge link types was created. These matched their nonmerge counterparts in all features except for the waiting time, which was set to 60 s for the merge types (see Table 1). Merge link types were used on all on-ramps and on-ramp 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 mentioned previously. Three separate sets of CC parameters were defined: Freeway, HardCurve, and SoftCurve. Each was paired with a merge link type (with a 60-s diffusion time), giving a total of six 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 affected bottlenecks B1 and B3, respectively (see Figure 3). As 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, the finding that capacity drops as a result of curvature can be reproduced with changes to the CC1 parameter alone.



	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
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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

FIGURE 4 Speed contour plot with default driver behavior parameters (mph).

TABLE 1 Calibrated CC Values

Link Type	CC0	CC1	CC4 / CC5	Waiting Time before Diffusion
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

Defaults: CC0 = 1.5, CC1 = 0.9, CC4/CC5 = –0.35/.035; waiting time = 60 s.

CALIBRATION GOALS: CC PARAMETER SELECTION

With the on-ramp and off-ramp flow inputs assembled with data from several different days, it was not immediately obvious how the simulation results should have been evaluated. The usual method of computing an error norm with respect to the measured data and tuning the model parameters to minimize that norm was not applicable in this case because of the composite nature of the input data. The question arose, Should a single typical day have been used, or a composite day, as with the boundary flows? Added to this difficulty was the fact that none of the data sets considered as typical had a complete set of main-line measurements. Furthermore, the additional variability in the main-line measurements over what appeared in the on-ramp flows suggested the influence of unseen factors, such as weather, day-to-day variations in driver behavior, traffic incidents, and so forth.

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 main-line queues,
3. Extent of the queues,
4. Utilization of the HOV lane, and
5. On-ramp performance.

The first three items pertain to the simulated response of the mixed-flow lanes. Target values for these (Table 2) were extracted from contour plots similar to those shown in Figure 2. The goal for the HOV lane was to approximate the flow values from PeMS. For the on-ramps, the only objective was to avoid large on-ramp 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 5), and manual adjustments of the parameters. These adjustments were limited to the CC parameters described previously and were aided by the bottleneck analysis and by the physical interpretation of the parameters. The iterative procedure was stopped when all of the qualitative calibration goals were met (see the following subsections). This approach was favored over a more automatic and exhaustive search method because of the potentially huge number of parameter variations, as well as the approximately 3-h running time (PC/Windows XP, 2.6 GHz, 500 Mb RAM) and the advantage that it led to a more sensible result.

The final selection of driver behavior parameters is shown in Table 1. This parameter set was the most parsimonious among those sets that also met the calibration goals. 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 had 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 main-line queues) and was used to regulate the queue lengths. But the CC1 parameter was changed only locally, at two locations. The HardCurve link type was used on the reverse curve near Huntington Street, and the SoftCurve type was used on the curved section between Hill and Lake Street (Figure 3). CC1 was adjusted in both cases to achieve the correct activation times for bottlenecks B1 and B3, respectively. Bottleneck B2 did not require a separate CC1 value. This result supports the interpretations provided in a previous section for the causes of the three bottlenecks: B1 and B3 were probably caused by curvature, whereas B2 was probably due to weaving.

On-Ramp Response

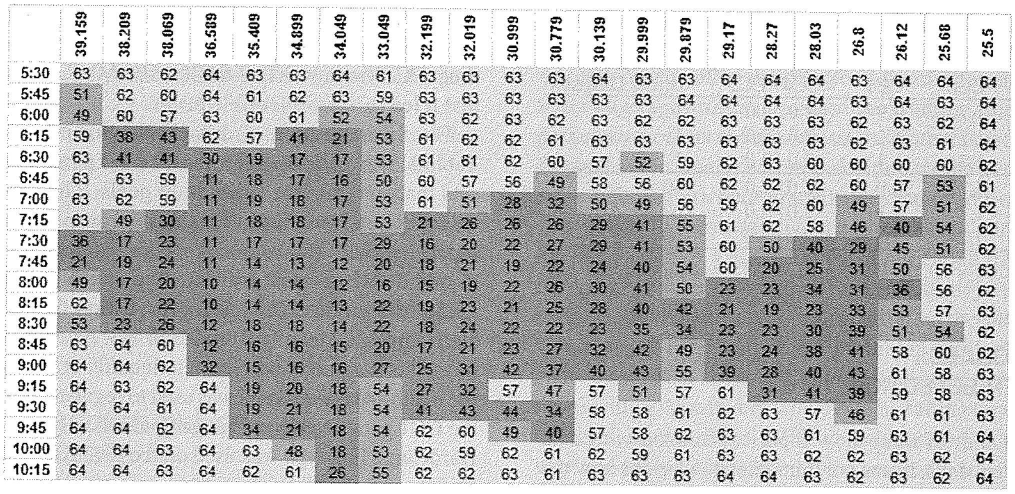
One of the qualitative goals for the CC parameter calibration was to avoid unrealistic queues on the on-ramps that might have obstructed the vehicle sources. The only on-ramp queuing problem that arose was on the freeway connector from 605 NB (MP 36). As mentioned in the section on coding of the network geometry, this was corrected at an earlier stage with partial routing decisions and was not a factor in tuning CC parameters. All other on-ramps were checked by a comparison of the supplied on-ramp flows with the simulated on-ramp flows. These close matches in all cases indicated that none of the vehicles sources were obstructed by excessive on-ramp queues.

HOV Lane Response

The goal of matching the utilization of the HOV lane was verified by a check of the simulated HOV lane flows. Samples of simulated and field-measured HOV lane flows are shown in Figure 6. Recall that the upstream boundary flows (at Vernon) were an input to the model. The differences at other locations might have reflected modeling errors, such as errors in the provided percentage of HOV vehicles at on-ramps (see section on estimating O-D matrices) and errors in the modeling of route choice by HOV drivers (see section on coding of traffic demands). In general, the result was considered a sufficiently good match for the control purposes of this model. However, this aspect of the model could be improved with a refinement of the

TABLE 2 Measured and Predicted Congestion Patterns

	Bottleneck	Location	Start Time (a.m.)	End Time (a.m.)	Queue Length
Target	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



	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	64	61	63	63	63	63	64	63	63	64	64	64	63	64	64	64
5:45	51	62	60	64	61	62	63	59	63	63	63	63	63	63	64	64	64	64	63	64	63	64
6:00	49	60	57	63	60	61	52	54	63	62	63	62	63	62	62	63	63	63	62	63	62	64
6:15	59	38	43	62	57	41	21	53	61	62	62	61	63	63	63	63	63	63	62	63	61	64
6:30	63	41	41	30	19	17	17	53	61	61	62	60	57	52	59	62	63	60	60	60	60	62
6:45	63	63	59	11	18	17	16	50	60	57	56	49	58	56	60	62	62	62	60	57	53	61
7:00	63	62	59	11	19	18	17	53	61	51	28	32	50	49	56	59	62	60	49	57	51	62
7:15	63	49	30	11	18	18	17	53	21	26	26	26	29	41	55	61	62	58	46	40	54	62
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9:15	64	63	62	64	19	20	18	54	27	32	57	47	57	51	57	61	31	41	39	59	58	63
9:30	64	64	61	64	19	21	18	54	41	43	44	34	58	58	61	62	63	57	46	61	61	63
9:45	64	64	62	64	34	21	18	54	62	60	49	40	57	58	62	63	63	61	59	63	61	64
10:00	64	64	63	64	63	48	18	53	62	59	62	61	62	59	61	63	63	62	62	63	62	64
10:15	64	64	63	64	62	61	26	55	62	62	63	61	63	63	63	64	64	63	62	63	62	64

FIGURE 5 Contour plot with final parameter selection.

HOV input percentages and more iterations of VISSIM's dynamic assignment routine.

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 nine indicators for the mixed-flow response fell within their target ranges. Target and simulated values for these nine indicators are given in Table 2. The resulting speed contour plot, shown in Figure 5, is compared with the typical PeMS contour of Figure 2. The model had 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 some local changes that were based on the analysis of field data and freeway geometry.

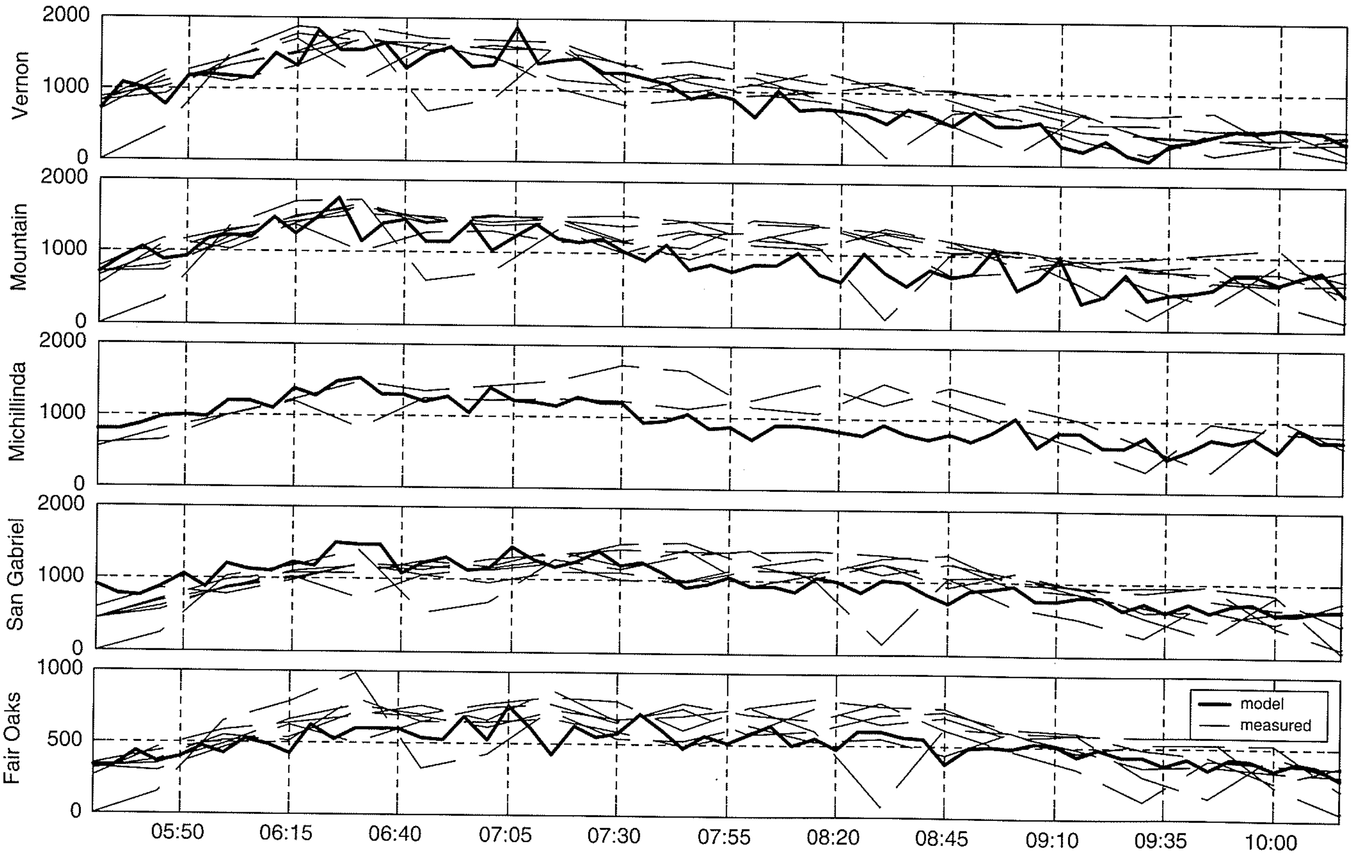

FIGURE 6 Measured and simulated HOV lane flows (vph).

SUMMARY AND CONCLUSIONS

This document has outlined a complete methodology for constructing and calibrating a simulation model of a unidirectional freeway with on-ramp control. The procedure included gathering and processing of field data from the PeMS database, estimation of O-D 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 presented several challenging features: 20 metered on-ramps, 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 led 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 on the basis of this observation. In conclusion, this study has shown that the VISSIM simulation environment was 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 on-ramps, HOV lanes, and mixed-flow lanes.

Research will now continue with 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 systemwide alternatives. Caltrans will consider implementing improved ramp control strategies based on their assessment of the predicted results.

ACKNOWLEDGMENTS

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