VISSIM CALIBRATION AND VALIDATION

Technical Report

August 28, 2006

Columbia River CROSSING

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ACRONYMS

ATR	Automatic Traffic Recorder
ADC	Automatic Data Collection
FHWA	Federal Highway Administration
GEH	Geoffrey E. Havers Statistic
HOV	High Occupancy Vehicle
I 5	Interstate 5
ODOT	Oregon Department of Transportation
O-D	Origin and destination
SOV	Single Occupant Vehicles
VISSIM	Verkehr in Städten – Simulation, or “traffic in towns – simulation”
VISUM	Verkehr in Städten – Umlegung”, or “traffic in towns – assignment”
VPH	Vehicles per hour
WSDOT	Washington Department of Transportation

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1. Introduction

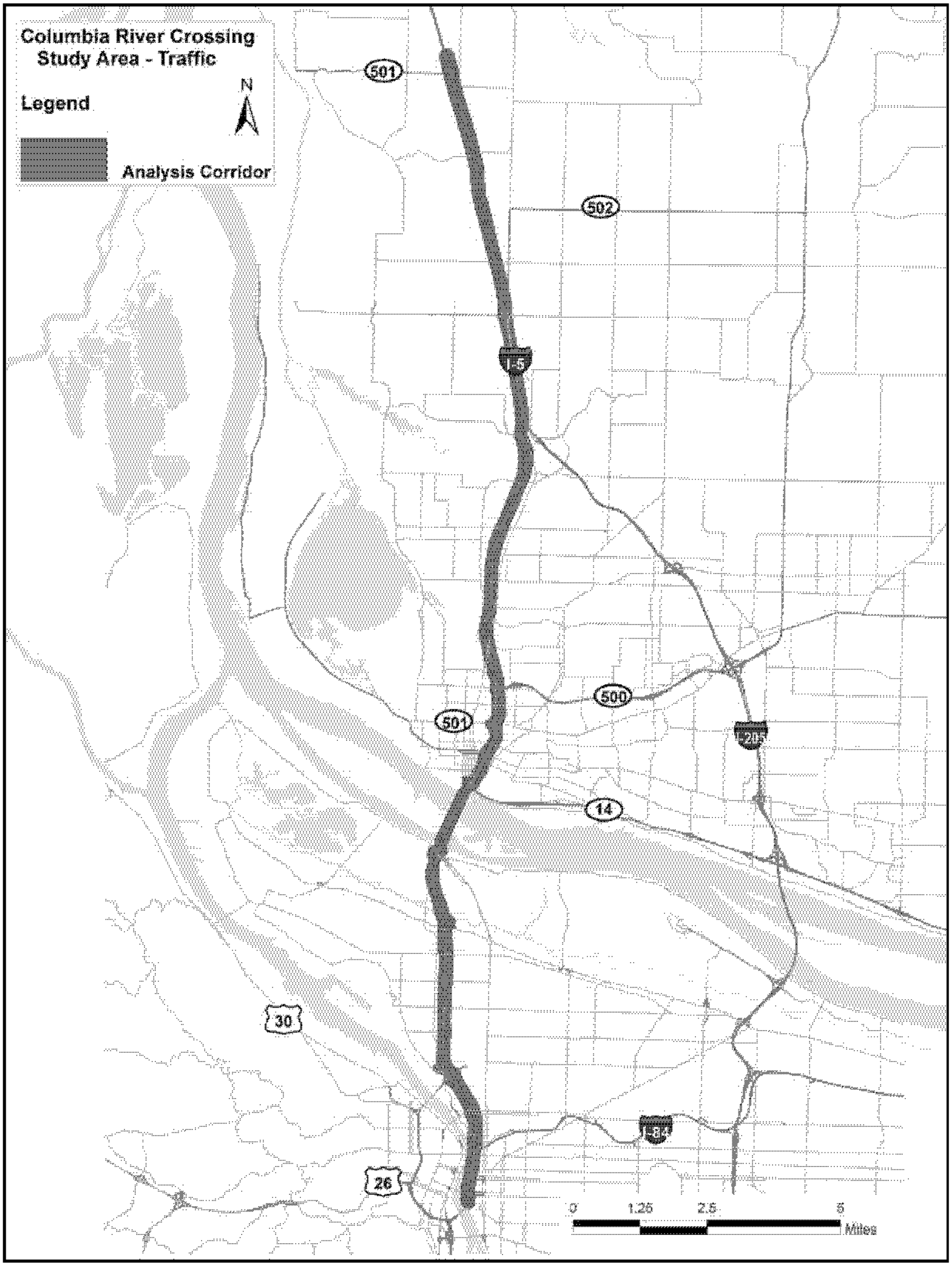
This report documents the components of the VISSIM model development and the calibration process for the Columbia River Crossing (CRC) project and provides a summary of validation results. Two VISSIM models were developed and validated for the 4-hour AM and 4-hour PM peak existing traffic condition (2005). The models were developed to better understand existing travel patterns and issues along the 23-mile study area of Interstate 5 (I-5) and will serve as the basis for modeling year 2030 no-build traffic conditions and future traffic improvements needed to meet mobility needs in this corridor.

I-5 sustains heavy congestion during the morning and evening commute along several miles upstream and downstream of the Interstate Bridge—one of only two major interstate highway river crossings providing connectivity and mobility between Washington and Oregon. Stop-and-go traffic conditions in the corridor last for 2 to 5 hours in the mornings and afternoons. It is anticipated that by the year 2030, traffic congestion and delay will increase substantially in the I-5 corridor. Increased delays would also impact freight mobility and transit schedules and operations, thus heightening the need for improvements in the I-5 crossing area.

To help the simulation models match reality, extensive data collection was undertaken. The data collection relevant to the VISSIM model is discussed in Section 3 below. The AM and PM calibration effort covered both the peak and off-peak directions of travel along I-5 and involved comparing the model results to the field data that included not only link traffic volumes and the extent of queues, but also measures of effectiveness such as travel times and average speed. The calibration goals and how they were achieved are discussed under Section 3.3 below.

The extent of the study area includes I-5 from the Pioneer Street interchange (Ridgefield, Washington) in the north to the Marquam Bridge (Portland, Oregon) in the south (refer to **Figure 1-1**). Ramp terminals are also included in the study. The analysis time periods include 6 a.m. to 10 a.m. and 3 p.m. to 7 p.m.

Figure 1-1. Study Corridor Modeled in VISSIM



2. Background

Simulation modeling is a very useful tool for designing improvements to the roadway system. Simulation models enable engineers to predict the outcome of a proposed change to the roadway before it is implemented and helps in evaluating the merits and demerits of design options. Models are set up to correctly predict the system response by calibrating to existing traffic conditions. Calibration is a process of adjusting model parameters so that simulated response agrees with the measured field conditions (Ref. 1 and 3).

Traffic simulation may be macroscopic or microscopic in nature. While 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 (Ref. 1). Microscopic models are helpful in capturing the more detailed aspects of the system (e.g., interacting bottlenecks).

For the current study of I-5 operations, VISSIM was selected as the environment for micro-simulation modeling. VISSIM was supplemented by VISUM, a macro-simulation model for providing traffic flow information as mentioned under Section 3.1.2. (VISSIM is an acronym for the German words “Verkehr in Städten – Simulation” which loosely translates to English as “traffic in towns – simulation”. Similarly, VISUM is an acronym for the German words Verkehr in Städten – Umlegung, meaning “traffic in towns – assignment”.)

VISSIM is the stochastic traffic simulator that uses the psycho-physical driver behavior model developed by R. Wiedemann (Ref. 2). VISSIM combines a perceptual model of the driver with a vehicle model. Every driver with his or her specific behavior characteristics is assigned to a specific vehicle. As a result, the driver behavior corresponds to the technical capabilities of his vehicle. The behavior model for the driver involves a classification of reactions in response to the perceived relative speed and distance with respect to the preceding vehicle. Drivers can make the decision to change lanes that can either be forced by a routing requirement, or made by the driver in order to access a faster-moving lane. Four driving modes are defined: free driving, approaching, following, and braking. In each mode, the driver behaves differently, reacting either to his following distance, or trying to match a prescribed target speed (Ref. 1 and 2). More detailed descriptions of the VISSIM model can be found in the VISSIM User Manual – Version 4.10 (Ref. 2).

VISSIM was selected for analysis due to its powerful multi-model modeling capabilities that may include cars, trucks, and buses. Another benefit of using VISSIM is that it can simulate unique operational conditions, high occupancy vehicle (HOV) lanes, toll lanes, exclusive lanes, merging/diverging, and weaving areas. It also has 3D visualization capabilities—which makes it easier to visualize design options—and is helpful during non-technical presentations. Also, the Oregon Department of Transportation’s (ODOT) I-5/Delta Park Project had already developed a VISSIM model for the southern part of the study area (Ref. 3). Elements from that model were used and expanded to develop the entire study corridor for the CRC project, which helped in saving time and energy in setting up the base year model for the current project.

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3. Data

The model setup required the input of geometric, traffic control, and traffic flow data for the freeway and ramp intersections. Highlights from the data collection and field observations relevant to the VISSIM model development are discussed below.

3.1. Geometric Data

The features that were included are the location of on-ramps and off-ramps, the number of lanes, lane additions, lane drops, auxiliary lanes, highway curvature, and weaving sections. In addition, start and end locations of the northbound I-5 HOV lane and the position of ramp meters were defined in the model. Five sources of geometric information were used for this study: (1) scaled aerial photographs which were obtained in 2005 for the CRC study, (2) unscaled aerial photographs in bitmap format downloaded from GoogleMaps (http://maps.google.com/), (3) I-5/Delta Park study aerials and graphics, (4) roadway maps, and (5) field observations.

Lane configurations were initially taken from the aerial photographs. The lane configurations and location of ramp meters were confirmed or revised based on field observations.

3.2. Traffic Control Data

Traffic signal timing sheets for the signalized ramp intersections, along with ramp meter rates, were obtained from ODOT and the City of Portland for the Oregon section of I-5, while the Washington Department of Transportation (WSDOT) directed that an optimized signal timing plan be used for the Washington section of I-5. The signal timing information was fed into VISSIM with the objective of analyzing any off-ramp queues or spillovers on the I-5 mainline. Additionally, the location of intersection control was identified using aerials and confirmed during field observations. The posted speed limits for the study area roadways were also collected during field observations.

3.3. Traffic Flow Data

Traffic flow data relevant to micro-simulation model development includes the following:

- Turning movement counts collected at 84 ramps and ramp terminal intersections. Hourly counts for the analysis time periods were converted to demand flow rates before entering the data into the model to reflect the appropriate congestion on I-5.
- Vehicle classification counts for both northbound and southbound I-5 mainline at 10 locations.
- Northbound and southbound lane utilization and speed counts by lane at 10 locations.
- Travel time runs northbound and southbound along I-5.

- Origin and destination (O-D) surveys to determine the amount of traffic originating and leaving I-5 between Columbia Boulevard and SR 500/39th Street ramps. The O-D surveys were done for the peak period-peak direction only.

  For I-5 traffic O-D's outside of the Columbia Boulevard to SR 500/39th Street section, macro-simulation (VISUM) outputs were utilized. VISUM O-D outputs included data for the whole corridor which was post-processed to match surveyed O-Ds for the section of I-5 between Columbia Boulevard and SR 500/39th Street. Detailed discussion on the process utilized for calibrating O-Ds is outside the scope of this report.

- Automatic Traffic Recorder (ATR) and Automatic Data Collection (ADC) data available from ODOT's and WSDOT's Web sites respectively:

  http://www.oregon.gov/ODOT/TD/TDATA/tsm/trendspage.shtml#2005_Monthly_Trends

  http://www.wsdot.wa.gov/mapsdata/tdo/atdc_report_2005.htm

  The data were available at four mainline locations along I-5 within the study area and included the Interstate Bridge.

- Occupancy counts for the HOV lane.
- Capacity data at known bottleneck/congested locations for I-5 mainline. This data was collected as part of the current study and verified against the I-5/Delta Park project observations and the ATR monthly average data for the relevant sections of I-5.
- Queue length observations at bottleneck locations and ramps. This was obtained using video recorded data and web cams on I-5 and accessible through ODOT's and WSDOT's Web sites respectively:

  http://www.tripcheck.com/

  http://www.wsdot.wa.gov/traffic/vancouver/VancouverTraffic/

4. VISSIM Model Development

The VISSIM model was constructed by tracing the roadway network over the aerial photographs which served as a background. Scale was established on the aerials by matching landmarks with the scaled aerials from the I-5/Delta Park study, and was also verified from field measurements.

The number of lanes, location of lane additions and drops, and other roadway geometry were confirmed by field visits. Additional detail was incorporated into VISSIM network (posted speed limits, grades, etc.) to better reflect field conditions. Ramp meter rates and signal timings for the off-ramps were specified. In addition, driver behavior parameters (such as driver aggressiveness) and saturation flow rates were calibrated based on field observations.

It was found that not all default VISSIM input parameters represented study area conditions and needed to be adjusted to replicate reality. The distribution of vehicle types was also calibrated to local conditions so that the percentage of cars (single occupant vehicles (SOV) and HOVs), heavy trucks, and buses matched the traffic counts. While the network coding, with the exception of the northbound HOV lane implementation, remained the same for both the models, different driver behavior parameters were used in the two peak periods to achieve realistic queuing and congested traffic conditions.

Detailed discussion on network and traffic coding for the models and driver behavior parameters is provided in **Appendix A**.

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5. Calibration Goals and Results

The objective of model calibration was to obtain the best match possible between model performance estimates and the field measurements of performance. It may be noted that there are no universally accepted procedures for conducting calibration and validation for complex transportation networks. The responsibility lies with the modeler to implement a suitable procedure which provides an acceptable level of confidence in the model results. During VISSIM calibration, model outputs were compared against field data to determine if the output was within acceptable levels. Validation criteria used for the present study were based on the suggestions by the Federal Highway Administration (FHWA) (Ref. 4) and by similar studies conducted in the past (Ref. 1 and 5).

The calibration goals included:

Goal 1: Identification of AM and PM peak period recurring bottlenecks and queuing

Goal 2: Modeled capacity to be within 10 percent of field measurements

Goal 3: Model link versus observed flows and travel time to meet the following criteria:

- Link volumes for more than 85 percent of cases to be:
    - Within 100 vph, for volumes less than 700 vph
    - Within 15 percent, for volumes between 700 vph and 2,700 vph
    - Within 400 vph, for volumes greater than 2,700 vph
- Link volumes for more than 85 percent of cases to have a GEH statistic less than five
- Sum of link volumes to be within 5 percent
- Sum of link volumes to have a GEH statistic less than four
- Average travel time to be within 15 percent (or one minute, if higher) for the selected I-5 mainline segments

Goal 4: Visually acceptable on- and off-ramp queuing

Goal 5: Modeled average speeds to be within the acceptable range of observed speeds on the mainline links. (Mainline links for data analysis were defined as sections between consecutive on and off ramps)

Goal 6: Visually acceptable utilization of the lanes at the lane drop locations and the HOV lane

The results of model calibration are presented below.

Goal 1: Identification of AM and PM Peak Period Recurring Bottlenecks and Queuing

The first step in the model calibration process was to identify locations and causes of congestion on I-5. Bottleneck locations, activation and dissipation times, and queue extents were studied using traffic video recordings collected for the project along with several days of Portland's inductive loop-detector data and ODOT's and WSDOT's live traffic webcam images and speed maps. Examples of loop-detector data plots and webcams showing times of bottleneck activation, queuing, and dissipation of queue are shown in **Figures 5-1**, **5-2**, and **5-3**. Results from the I-5/Delta Park study were also used to verify the results.

During the AM peak period, four distinct problem areas/bottlenecks were identified in the southbound direction and one in the northbound direction. Bottleneck locations along southbound I-5 include the Interstate Bridge (SR 14 on-ramp merge area), Delta Park at the lane drop, Alberta/I-405 area, and the Rose Quarter section. With the exception of the Rose Quarter bottleneck, which acts independently on typical days, the other three bottlenecks interact among themselves during some portion of the AM peak period. Among these, the Delta Park lane drop is the most severe bottleneck that emerges first each morning and affects upstream portions of I-5 into Vancouver. In the northbound direction during the AM peak, I-5 between the Morrison on-ramp to the I-405 off-ramp also shows significant slowing.

During the PM peak, I-5 at the Interstate Bridge (Hayden Island on-ramp merge area) acts as a bottleneck in the northbound direction. There is also slowing of traffic in the southbound direction between the Alberta ramps and the I-405 off-ramp and Greeley Avenue on-ramp to the I-84 off ramp.

The possible causes of bottleneck activations at the identified locations, times of bottlenecks activation, and the extent of queues are discussed in **Appendix B**.

Figure 5-1. Loop-Detector Data - Speed Plot

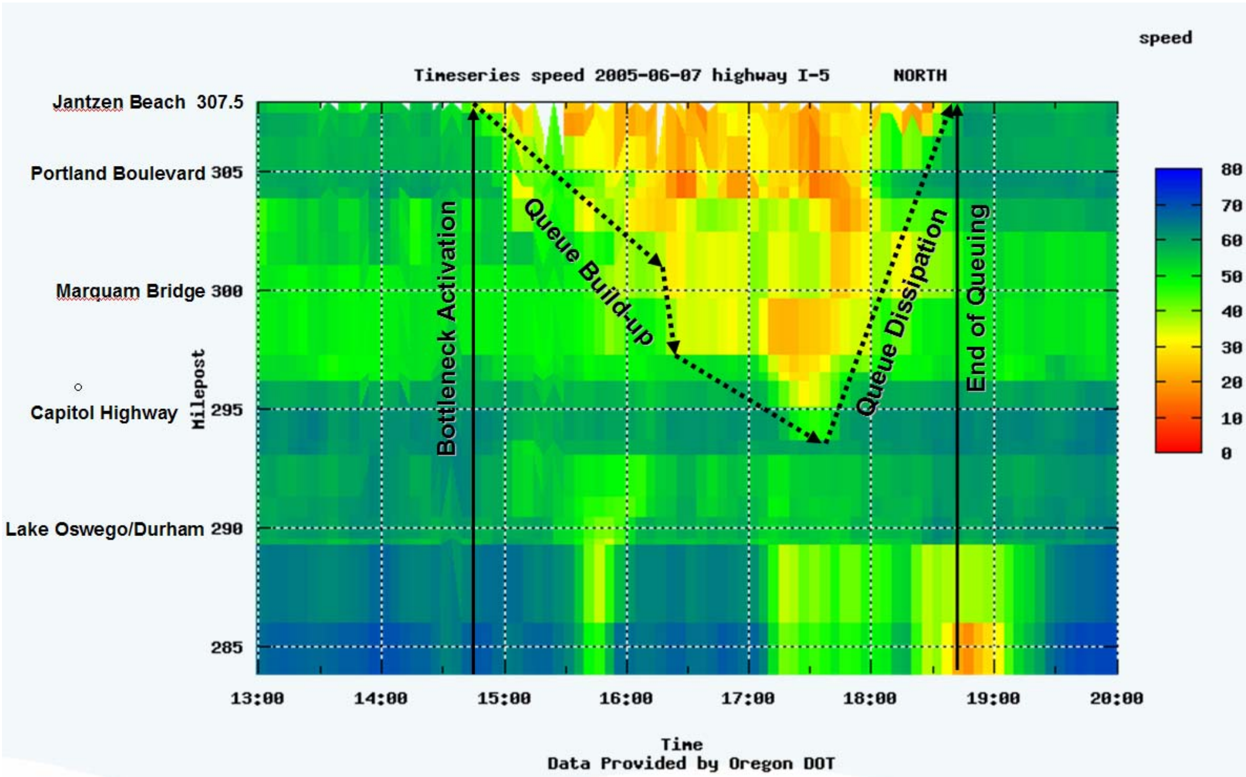


Figure 5-2. Web Based Real Time Speed Maps

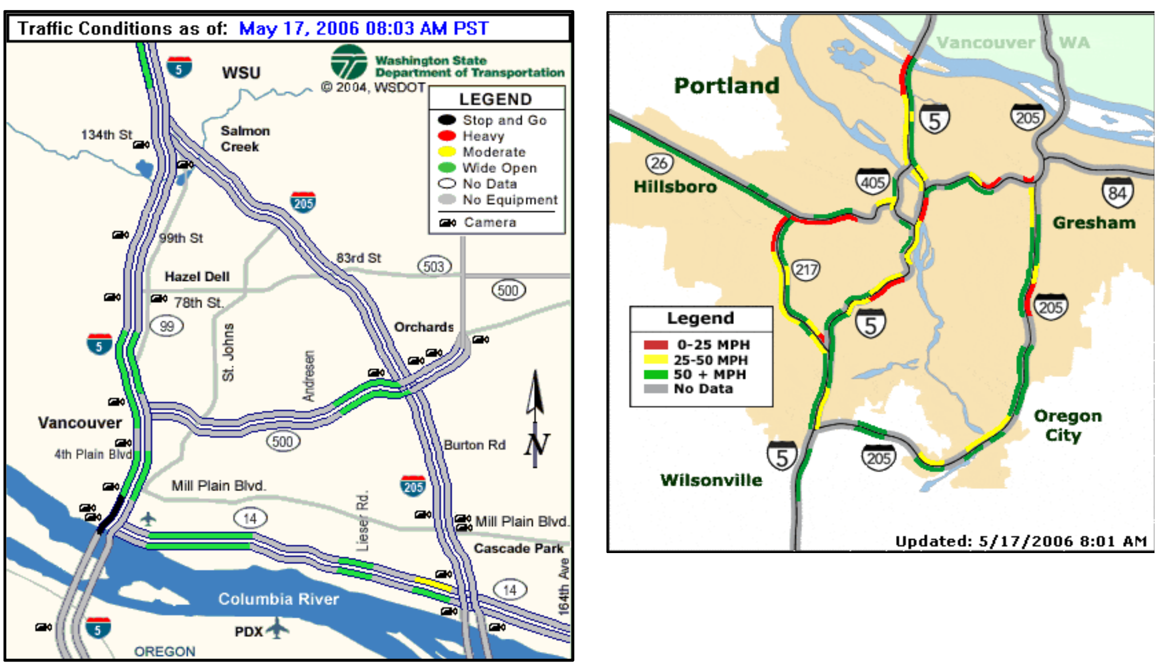
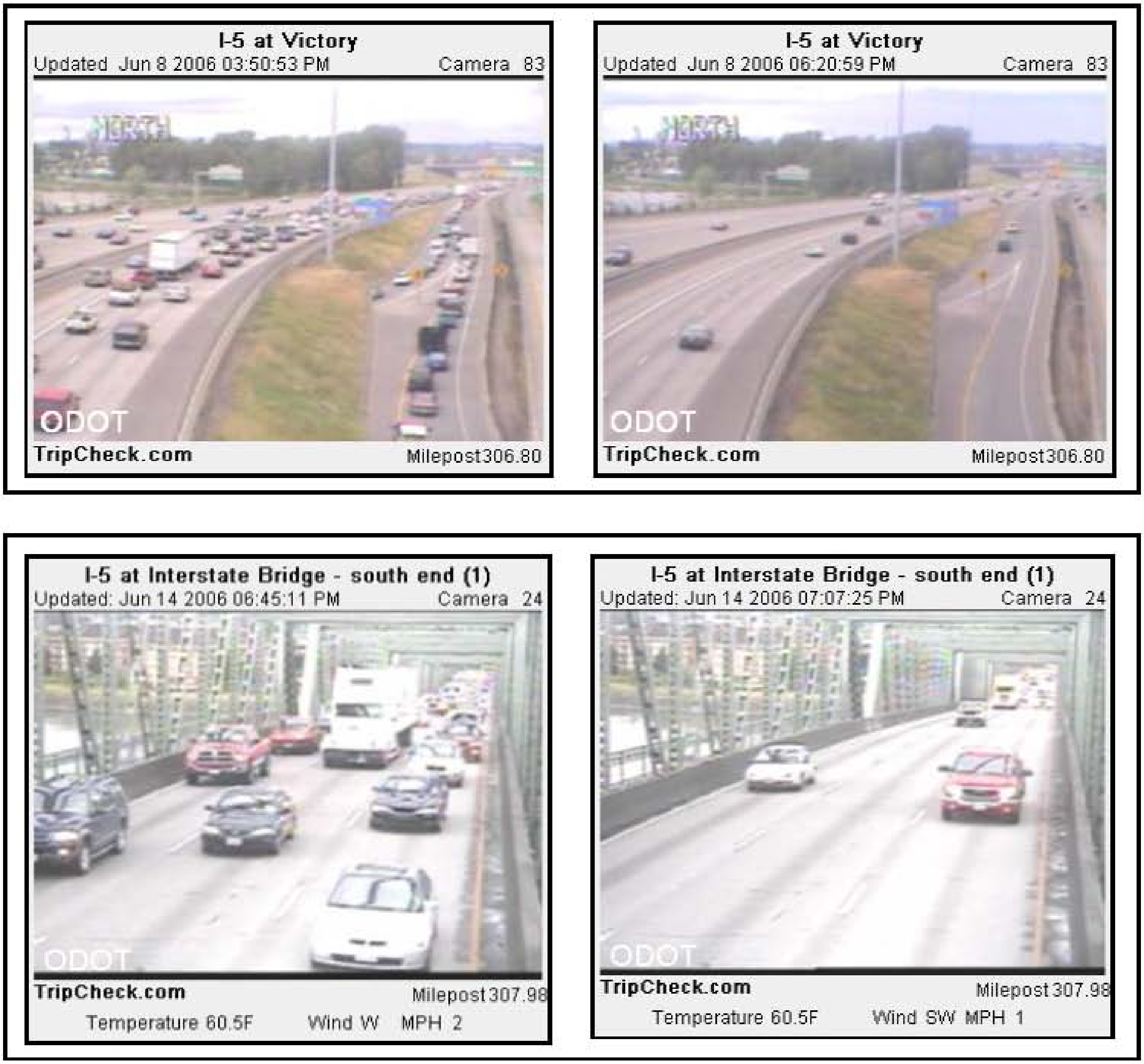


Figure 5-3. Web Camera Images at Two Locations on I-5 – PM Peak Period

Early Time Period | **Later Time Period**



Goal 2: Modeled Capacity to be within 10 percent of Field Measurements

The average of field capacity measurements for the congested hours at the bottleneck locations were compared with the outputs from VISSIM. The results are shown below:

I-5 SB AM Peak Period

- Delta Park lane drop: measured around 3,300 – 3,400 vehicles per hour (vph); achieved 3,400 vph (0 percent)
- Columbia River Interstate Bridge: measured around 5,200 – 5,500 vph; achieved 5,100 vph (2 – 8 percent)

I-5 NB PM Peak Period

- Columbia River Interstate Bridge: measured around 5,200 – 5,500 vph; achieved 5,100 vph (2 – 8 percent)
- For both the AM and PM models, the capacity results were within the 10 percent threshold of the field observations.

Goal 3: Model Link versus Observed Flows and Travel Time Criteria

Tables 5-1 through **5-4** present the volume thresholds and results by flow for the overall 4-hour analysis time periods and also for the individual hours. Travel time results are also included. The analysis includes all the on- and off-ramp links and the mainline links for which the ATR data were available.

As shown in **Tables 5-1** through **5-4**, a comparison between modeled and observed volumes was also made using modified Chi-Squared statistic test called the GEH statistic. The GEH statistic is a formula used in traffic engineering, traffic forecasting, and traffic modeling to compare two sets of traffic volumes. The GEH statistic gets its name from Geoffrey E. Havers, who invented it in the 1970s while working as a transport planner in London, England. GEH statistic is not a true statistical test. Rather, it is an empirical formula that has proven useful for a variety of traffic analysis purposes.

The formula for the GEH statistic is:

$$GEH = \sqrt{(M-C)^2 / (0.5 \times (M+C))}$$

Where M is the traffic volume from the traffic model (or new count) and C is the real-world traffic count (or the old count).

Various GEH values give an indication of a goodness of fit as outlined below:

GEH<5	Flows can be considered a good fit
5<GEH<10	Flows may require further investigation
10<GEH	Flows cannot be considered to be a good fit

The results from **Tables 5-1** through **5-4** show that threshold criteria were met for both the AM and PM peak periods for the individual hours, as well as for the overall 4-hour analysis time periods.

Table 5-1 Validation Criteria Thresholds Comparison – AM Four-Hour Total

Criteria	Criteria Threshold	% Met Target	Southbound		Northbound	
			% Met	**Pass/Fail**	**% Met**	**Pass/Fail**
Link Volumes						
< 700 vph	100 vph	> 85%	100%	Pass	100%	Pass
Between 700 & 2,700 vph	15%	> 85%	100%	Pass	100%	Pass
> 2,700 vph	400 vph	> 85%	85%	Pass	100%	Pass
GEH Statistic	5	> 85%	91%	**Pass**	100%	Pass
Sum of Link Volumes						
Sum of All Links	5%	-	-	Pass	-	Pass
GEH Statistic	< 5	> 85%	-	Pass	-	Pass
Travel Time						
Travel Paths	15%	-	-	Pass	-	Pass
Visual Inspection						
Travel Speeds	match observations		-	Pass	-	Pass
Queuing	match observations		-	Pass	-	Pass

Table 5-2 Validation Criteria Thresholds Comparison – PM Four-Hour Total

Criteria	Criteria Threshold	% Met Target	Southbound		Northbound	
			% Met	**Pass/Fail**	**% Met**	**Pass/Fail**
Link Volumes						
< 700 vph	100 vph	> 85%	100%	Pass	100%	Pass
Between 700 & 2,700 vph	15%	> 85%	100%	Pass	100%	Pass
> 2,700 vph	400 vph	> 85%	100%	Pass	89%	Pass
GEH Statistic	5	> 85%	100%	Pass	92%	Pass
Sum of Link Volumes						
Sum of All Links	5%	-	-	Pass	-	Pass
GEH Statistic	< 5	> 85%	-	Pass	-	Pass
Travel Time						
Travel Paths	15%	-	-	Pass	-	Pass
Visual Inspection						
Travel Speeds	Match observations		-	Pass	-	Pass
Queuing	Match observations		-	Pass	-	Pass

Table 5-3 Validation Criteria Thresholds Comparison – AM Individual Hours

Criteria	Criteria Threshold	% Met Target	Southbound		Northbound	
			% Met	Pass/Fail	% Met	Pass/Fail
Link Volumes						
< 700 vph	100 vph	> 85%	98%	Pass	93%	Pass
Between 700 & 2,700 vph	15%	> 85%	90%	Pass	85%	Pass
> 2,700 vph	400 vph	> 85%	82%	Pass	100%	Pass
GEH Statistic	5	> 85%	92%	Pass	91%	Pass
Sum of Link Volumes						
Sum of All Links	5%	-	-	Pass	-	Pass
GEH Statistic	< 5	> 85%	-	Pass	-	Pass
Visual Inspection						
Travel Speeds	Match observations		-	Pass	-	Pass
Queuing	Match observations		-	Pass	-	Pass

Table 5-4 Validation Criteria Thresholds Comparison – PM Individual Hours

Criteria	Criteria Threshold	% Met Target	Southbound		Northbound	
			% Met	Pass/Fail	% Met	Pass/Fail
Link Volumes						
< 700 vph	100 vph	> 85%		Pass	93%	Pass
Between 700 & 2,700 vph	15%	> 85%		Pass	88%	Pass
> 2,700 vph	400 vph	> 85%		Pass	83%	Pass
GEH Statistic	5	> 85%		Pass	89%	Pass
Sum of Link Volumes						
Sum of All Links	5%	-	-	Pass	-	Pass
GEH Statistic	< 5	> 85%	-	Pass	-	Pass
Visual Inspection						
Travel Speeds	match observations		-	Pass	-	Pass
Queuing	match observations		-	Pass	-	Pass

Goal 4: Visually Acceptable On- and Off-ramp Queuing

One of the qualitative goals for the model calibration was to avoid unrealistic queues at on- and off-ramps that might obstruct the vehicle sources (in case of on-ramps), or impact mainline operations (due to off-ramp queue spill over). All on- and off-ramps were checked by comparing the supplied ramp flows with the simulated ramp flows. There was a close match in all cases, indicating that none of the vehicles were obstructed by unrealistic on- and off-ramp queues. Refer to **Appendix A** for technical details on how realistic queuing was achieved in VISSIM.

In addition, the visual inspection of the model showed that the following on-ramps have significant queuing during the peak periods:

I-5 SB AM

- Fourth Plain Boulevard
- Mill Plain Boulevard
- SR 14 and City Center

I-5 NB PM

- Marine Drive
- Interstate Avenue/Victory Boulevard
- I-405
- I-84
- Morrison

VISSIM model results matched the field data.

Goal 5: Modeled Average Speeds to Be Within the Acceptable Range of Observed Speeds on the Mainline Links

The bulk of the calibration effort was dedicated to matching the response of the mainline flows, in terms of the start time, end time, and extent of the queue generated by each of the bottleneck locations identified under Goal 1, while maintaining realistic speeds. **Figures B-1** through **B-4** shows the results for modeled average speeds. These results closely match the observed speeds on the I-5 mainline for the respective time periods. Modeled speeds were compared with speed plots similar to the ones shown in **Figures 5-1** and **5-2** and data collected for this project and the I-5/Delta Park study.

Goal 6: Visually Acceptable Utilization of the Lanes at On-Ramps, Lane Drop Locations and the HOV Lane

Driver behavior parameters in VISSIM (refer to **Appendix A**) were adjusted on a segment basis to match the lane utilization of the I-5 mainline at the lane drop locations and the HOV lane. These parameters were also adjusted at on-ramps with ramp meters. The state DOTs require that the vehicles form two lines at many on-ramp locations for capacity utilization when ramp meters are operating. Based on the visual inspection of the model, vehicle utilization at lane drop locations on the I-5 mainline, HOV lane, and the on-ramps closely match reality.

6. Random Seed Variations

Once the calibrated model was established, the calibrated parameter set was run with at least five different random seeds. The random seed affects the realization of the stochastic quantities in VISSIM, such as inlet flows and vehicle capabilities. For congested corridors, at least five seed runs are generally recommended. The results presented in **Appendix B** were based on the average of at least five different random seeds.

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7. Comments

This report summarized the methodology for constructing and calibrating the micro-simulation model for a 23-mile-long corridor of I-5. The procedure included gathering and processing field data supplemented by macroscopic modeling with VISUM and finally adjusting microscopic simulation specific parameters in VISSIM. Model development for I-5 presented several challenging features including ramp meters, HOV lane, lane drops, and several interacting bottlenecks. All of these features were included in the model.

The analysis of the supply and demand characteristics of I-5 led to the conclusion that while the Interstate Bridge and the Delta Park lane drop bottlenecks are caused by localized reductions in capacity, all other bottlenecks resulted from a combination of turbulence caused by weaving traffic and closely spaced on-ramps. It may be concluded that the VISSIM 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 on-ramps, HOV lanes, and general purpose lanes.

As part of the future steps under the CRC project, the calibrated AM and PM VISSIM models will be used as base models for studying future traffic operations under the no-build and several build alternatives.

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8. References

1. Gomes, G., A May, and R. Horowitz. “A Microsimulation of a Congested Freeway Using VISSIM.” Presented at 82nd Annual Meeting of the Transportation Research Board. Washington, D.C., January 2003.

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3. David Evans and Associates and Parisi Associates. “I-5: Delta Park (Victory Boulevard to Lombard Section).” Transportation and Traffic Technical Report. Oregon Department of Transportation, 2005.

4. Federal Highway Administration. “Analysis Toolbox Volume III: Guidelines for Applying Traffic Micro-simulation Modeling Software.” U.S. Department of Transportation, July 2004.

5. Oketch T. and M. Carrick. “Calibration and Validation of a Micro-Simulation Model in Network Analysis.” Presented at 84th Annual Meeting of the Transportation Research Board. Washington, D.C., January 2005.

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Appendix A

A. VISSIM Model Calibration - Technical Details

Model parameters related to the physical attributes of the VISSIM model development are listed in Sections 1 and 2 below. These parameters are assigned for each vehicle type. As a rule of thumb, once the vehicle population has been defined, the simulation should be tested with the default Driver Behavior Parameters. This defines the global calibration step in micro-simulation modeling. This initial calibration is performed to identify the values for capacity adjustment parameters that cause the model to best reproduce observed traffic capacities/traffic conditions in the field.

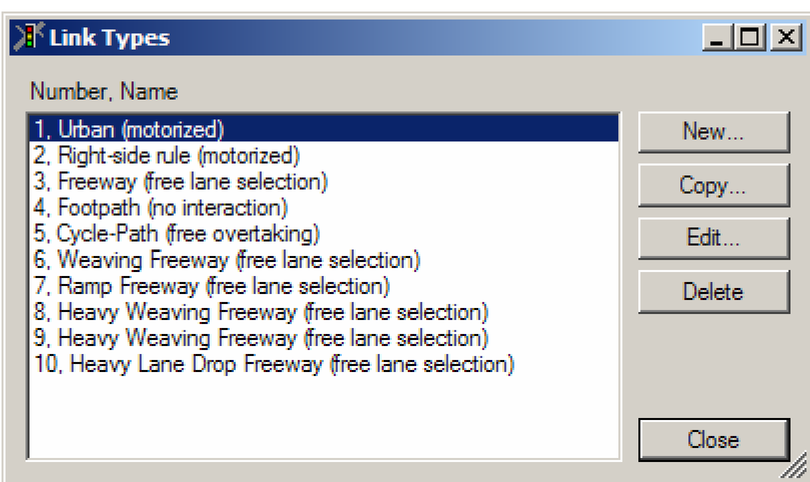
The initial calibration for the VISSIM models showed that several bottleneck locations and congested sections failed to reproduce field observations with default driver behavior settings. Thus, fine tuning of the model was necessary, which was achieved by modifying Driver Behavior Parameters that affected capacity. Section 3 below deals with the fine tuning of the VISSIM models.

1. Network Coding

VISSIM uses a link-connector network structure. A link cannot have multiple sections with a different number of lanes. Thus, multiple links need to be created for each section.

Several link types are defined in VISSIM by default. Link type controls the driving behavior. Five new link types were created in the VISSIM model to create appropriate congestion and queuing. These link types, along with the default link types, are shown in **Figure A-1**. In **Figure A-1**, link numbers 1 to 5 are default links and numbers 6 to 10 were created. Detailed discussion of link types and the associated driving behavior is provided in Section 3.

Figure A-1. Link Types



Implementation of HOV Lane

During the PM peak hours (3 p.m. to 6 p.m.), the inside lane of the three northbound through lanes on I-5 between the Going Street on-ramp and the Delta Park on-ramp operates as an HOV lane. Since the analysis time periods were between 3 p.m. to 7 p.m., the inside lane changed from an HOV lane to a general purpose lane during the last hour. Coding for the implementation of the HOV lane was an important aspect of the network coding. VISSIM allows particular lanes of a link to be closed to certain vehicle types (vehicle types are discussed in the next section). HOV-only restrictions were enforced by creating a separate vehicle type for HOV vehicles, and by closing the HOV-only lanes to all non-HOV types. This allowed the northbound section between Going Street and Delta Park to be analyzed with an HOV lane between 3 p.m. and 6 p.m.

Merge Sections and Ramps

Lane changing behavior of vehicles following their route was modeled using lane change and emergency stop parameters for connectors. For weaving/merge/diverge sections, at least 50 feet of emergency stop distance was used. This distance defines the last possible position for a vehicle to change lanes; i.e., if a vehicle could not change lanes due to high traffic flows but needs to stay on its route, it will stop at this position to wait for an opportunity to change lanes (Ref. 2). For weaving sections, care was taken that the lane changing distance (distance at which vehicles begin to attempt to change lanes) was greater than the weaving section itself. This helped in achieving the correct lane utilization at these locations.

For all on-ramp merges, vehicles entering from the on-ramps joined the mainline stream by changing lanes within the merge section. Similar to the findings from an earlier research (Ref. 1), it was found that this approach worked well for on-ramps with small or moderate flows. This analysis found that for locations where mainline flows were dense and on-ramp flows were closer to 1,000 vph, this approach failed and produced large queues on the on-ramps. An example of such a location is Victory/Denver Avenue where demand flows are at least 900 vph or more in the northbound direction during the PM peak period. This problem was addressed by forcing mainline vehicles (by using routing; refer to the section below for details) to evacuate the right-most lane upstream of the ramp junction, thereby opening space for the flow from the on-ramp.

2. Traffic Coding – Physical Attributes

In VISSIM, default vehicle types (Car, HGV (truck), Bus, Tram, Bike, and Pedestrian) may be used to define traffic composition. A user may also define its own vehicle types. For the current study, vehicle types Car-HOV Open and HOV were created. A single vehicle type shares common vehicle performance attributes. These attributes include model, acceleration/deceleration, weight, power, and length. The vehicle specification for these two types is identical to those of the default Car type in VISSIM (Ref. 2). These vehicle types were created for implementing HOV operations in the model.

Traffic compositions are the proportions of each vehicle type present in each of the vehicle input sources. Vehicle Inputs are time variable traffic volumes entered at the source node. For our modeling purpose, all on-ramps were defined as source nodes. Besides the on-ramps, two mainline locations (north and south ends of the model) also served as source nodes. Vehicle compositions varied for all these locations mostly due to a different HGV (truck) percentage. Thus, different traffic compositions were defined for all on-ramps and the mainline to match their proportions of SOVs, HOVs, HGVs (trucks), and buses. An example of one such ramp is shown in **Figure A-2**.

Traffic Assignment or Routing

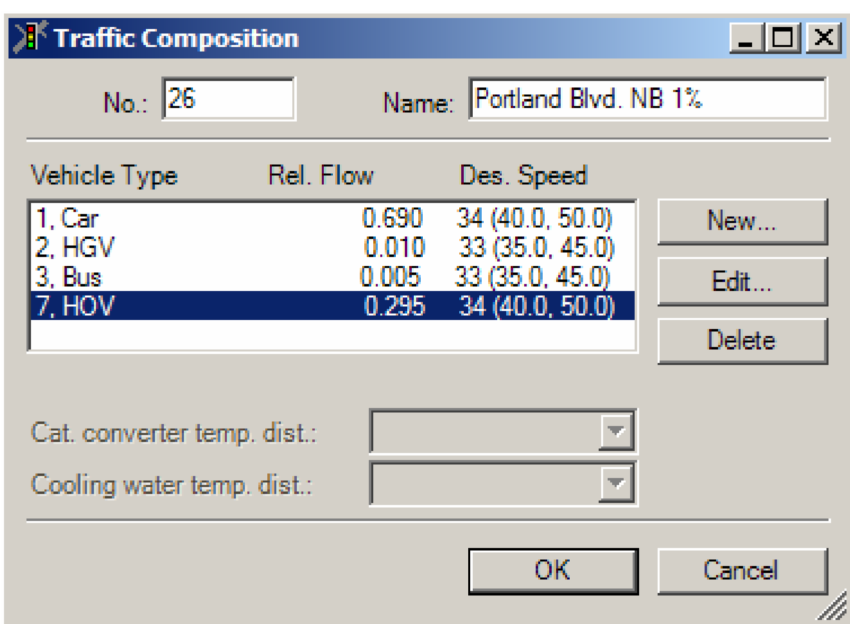
Traffic is assigned in VISSIM using Routing Decisions. A route is a fixed sequence of links and connectors from the routing decision point to one or multiple destinations.

In the model, each vehicle input source (on-ramp and the two mainline ends) had its routing decision point (origin). Routes stretched to each off-ramp (destination) resembling a "tree with multiple branches" (Ref. 2). An O-D matrix had to be created and traffic data processed before routing was fed into VISSIM. No vehicles are taken out or added to the network automatically; therefore, it is important that balanced volume flows are entered.

Speed Distributions

Stochastic distributions of observed speeds are defined for each vehicle type within each traffic composition. Observed speeds were used to create distribution for all on-ramps and for several locations of I-5 mainline since speeds vary on I-5. This speed is generally higher than the posted speed and may be defined as the free-flow speed for the highway. If not hindered by other vehicles, a driver would travel at his desired speed (with a small stochastic variation or oscillation). The more vehicles differ in their desired speed, the more platoons are created (Ref. 2).

Figure A-2. Traffic Composition



3. Driver Behavior Parameters

The driver behavior in VISSIM is modeled through the car following and the lane change models (Ref. 2). The driving behavior is linked to each link by its link type. For each vehicle class, a different driving behavior parameter set may be defined. By default, five parameter sets are predefined. These are shown in **Figure A-3** (numbers 1 to 5). As mentioned under Section1, new links with modified driver behavior parameters had to be defined for the reproduction of existing traffic conditions. These link types are shown in **Figure A-3** and are numbered 6 to 10. Based on the type of link, driver behavior was modified using the position of the driver/vehicle in the network. No correlation was assumed between vehicle type and the driver behavior. Drivers were assumed to behave differently under curved sections, or sections with inadequate sight distance, 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.

VISSIM includes two car-following models – urban driver and freeway driver. Only the freeway driver type was used. The car-following mode of the freeway driver model includes 10 tunable parameters: CC0 through CC9. Suitable values and variations of the car following behavior parameters (or CC- parameters) helped in reproducing the curvature/sight distance/inadequate design induced capacity drops on I-5. **Table A-1** shows only those CC-parameters that were modified from their default values (refer to table notes for definitions).

Figure A-3. Driving Behavior Parameter Sets Used in I-5 Model Calibration

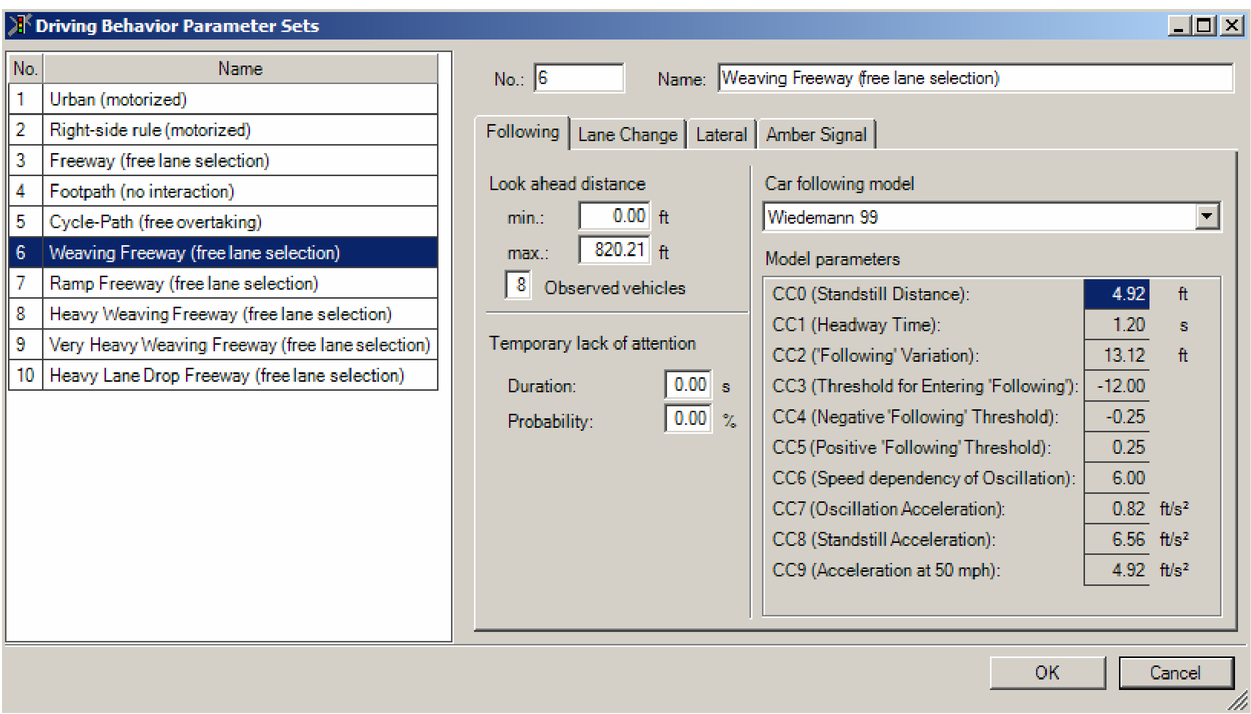


Table A-1. Driver Behavior Parameter Sets

Link Type	Modified Model Parameters				
Name	Observed Vehicles	CC1		CC4/CC5	
		AM	PM	AM	PM
Urban (motorized)	3	na	na	Na	na
Freeway (free lane selection)	2	1.00	1.00	-0.25/0.35	-0.25/0.35
Ramp Freeway (free lane selection)	8	1.10	1.10	-0.25/0.35	-0.25/0.35
Weaving Freeway (free lane selection)	8	1.20	1.20	-0.25/0.35	-0.25/0.25
Heavy Weaving Freeway (free lane selection)	8	1.30	1.30	-0.25/0.35	-0.25/0.35
Very Heavy Weaving Freeway (free lane selection)	8	1.50	1.50	-0.25/0.35	-0.25/0.25
Heavy Lane Drop Freeway (free lane selection)	8	1.70	-	-0.25/0.35	-/-

Notes:

1. CC1 or Headway time is the time in seconds that a driver wants to keep while following another car. The higher the value, the more cautious the driver is. CC1 has the strongest influence on freeway capacity.

2. CC4 and CC5 or following thresholds are dimensionless parameters influencing the speed differences during the “following” state. Smaller values result in driver behaviors that are more sensitive to changes in the speed of the preceding vehicle; that is the vehicles are more tightly coupled. CC4 is used for negative and CC5 for positive speed differences. The default values result in a fairly tight restriction of the following process (Ref. 2).

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Appendix B

B. Bottlenecks Along I-5 – Causes, Activation and Dissipation times, and Extent of Queues

I-5 undergoes a fairly predictable operational cycle during a typical weekday (no incident, or other outside factors like bad weather, etc.) in both directions of travel. The spatial and temporal operations of I-5 are shown in **Figures B-1** and **B-2** for the AM and **Figures B-3** and **B-4** for the PM peak periods. Key findings from this section are discussed below.

Southbound I-5 - AM

6 a.m. to 6:15 a.m. – Two Bottlenecks Activate

Around 6 a.m. on a typical weekday, traffic levels start approaching capacity through the Delta Park area where travel lanes drops from three to two lanes (for capacity discussions refer to Goal 2 under Section 5). Traffic peaks earlier in Vancouver than traffic originating from inner Portland areas possibly in an effort by longer distance commuters to "beat the peak". Generally within fifteen minutes of the first sign of slowing, the traffic approaches capacity at the lane drop. Closer to 6:15 a.m., the SR 14 merge section also starts to slow down due to a combination of high traffic demand from SR 14 trying to merge with the mainline traffic, the proximity of the Interstate Bridge to the ramp merge section and the Interstate Bridge that acts as a bottleneck restricting traffic from moving at desired mainline speeds.

The reduction in capacity at the Interstate Bridge results due to a variety of possible causes, including grades, curves, reduced sight distance, and the inadequate horizontal clearance.

6:15 a.m. to 6:30 a.m. – Congestion Worsens

Between 6:15 a.m. to 6:30 a.m., the end-of-queue at Delta Park is closer to the south end of the Interstate Bridge. The Interstate Bridge traffic is also operating at capacity by this time. The SR 14/Interstate Bridge queue continues to extend north and by 6:30 a.m. has already started to impact the traffic entering I-5 from the Mill Plain on-ramp.

6:30 a.m. to 6:45 a.m. – Two Bottlenecks Interact

Traffic demand continues to increase along the I-5 mainline. The Delta Park queue reaches the Interstate Bridge and starts to impact downstream flows from SR 14/Interstate Bridge bottleneck. Congestion worsens between SR 14/Interstate Bridge section to Mill Plain on-ramp and the Mill Plain on-ramp traffic merging operations deteriorate causing long queues on this ramp.

6:45 a.m. to 7 a.m. – One Long Queue

Between 6:45 a.m. to 7 a.m., the Delta Park queue has merged with the SR 14/ Interstate Bridge queue and appears as one extended queue. The two bottlenecks are no longer distinguishable as they have blended together. The Delta Park bottleneck now controls the throughput of the upstream bottleneck and the Interstate Bridge. This throughput is lower than what these locations could have served if Delta Park were not the controlling bottleneck.

7 a.m. to 7:15 a.m. – Third Bottleneck Activates

Vancouver tends to peak earlier in the morning, traffic demand seeking to enter I-5 from Portland-area on-ramps increases about 7 a.m. Increased I-405 exiting traffic causes drivers to change lanes much in advance of the I-405 split. Increased mainline volume in the Portland area and closely spaced ramps from Going Street, Alberta Street, Portland Boulevard, and Lombard Street, along with the heavy I-405 exiting traffic, triggers this bottleneck.

By this time in Vancouver, I-5 mainline queuing has started to impact traffic operations at the SR 500/39th Street on-ramp merge.

7:15 a.m. to 7:45 a.m. – Congestion Worsens North of I-405

The traffic operations further worsen north of I-405/I-5 split. During this period, the end-of-queue is at the Portland Boulevard off-ramp. It becomes increasingly difficult for merging drivers to enter I-5 mainline due to the growing right-lane queue. This in turn causes drivers destined to exit I-5 before the I-5/I-405 split to move into the right lane sooner, further exacerbating growth of the queue. In addition, some aggressive drivers who desire to exit I-5 before the I-405 exit try to bypass the right-lane queue and find it difficult to merge over into the right lane. This causes lane changing and slowing in the adjacent I-5 lanes.

In Vancouver, stop-and-go conditions exist all the way to the 39th Street off-ramp until 7:30 a.m. The queue extending from Delta Park to SR 500/39th Street starts to show first signs of dissipation after 7:30 a.m.

7:45 a.m. to 8 a.m. – Vancouver Queue Starts to Dissipate

The Alberta queue continues to grow and traffic conditions worsen south of the Interstate Bridge.

The extended Delta Park queue recedes during this time period and the end-of-queue is near the Fourth Plain Boulevard off-ramp.

8 a.m. to 8:15 a.m. – Fourth Bottleneck Forms

A fourth bottleneck activates much later in the AM peak along the Rose Quarter section of the southbound I-5. A combination of heavy I-5 southbound demand, lanes drop from three to two lanes south of the Broadway Street off-ramp and weaving operations between Weidler Street to I-84 causes this bottleneck to activate.

In the meantime, the Vancouver queue continues to recede and the end-of-queue is close to Mill Plain Boulevard on-ramp.

8:15 a.m. to 9:15 a.m. – Alberta Queue Peaks, Two Bottlenecks Interact, and Vancouver Back to Free Flow Operations

About 8:30 a.m., Alberta queue briefly merges with the Delta Park queue that has already started to dissipate. The Alberta queue does not impact upstream dissipation operations because the throughput of the upstream (Delta Park) bottleneck is lower than the downstream (Alberta) bottleneck. By 9:15 a.m., segments north of Delta Park are operating near free flow conditions while stop-and-go conditions persist between the Alberta Street on-ramp and Victory Boulevard on-ramp.

The Rose Quarter section of I-5 is also operating at lower speeds during this time period.

9:15 a.m. to 9:45 a.m. – Alberta and Rose Quarter Recover

The Alberta bottleneck starts to dissipate around 9:15 AM. By 9:45 AM, I-5 southbound is operating closer to free flow conditions in the Alberta section and the Rose Quarter section has recovered.

9:45 a.m. to 10:00 a.m. – I-5 Study Corridor Back to Free Flow Operations

About 10 a.m., the entire I-5 southbound corridor has recovered and is back to operating near free flow conditions.

Northbound I-5 - AM

6 a.m. to 8 a.m. – I-5 Slows Down Between I-84 and I-405

I-5 mainline in the northbound direction during the AM peak period slows down near the I-84 on-ramp. Heavy commute traffic from westbound I-84 causes disruption along I-5 mainline between I-84 on-ramp and Weidler off-ramp. This in turn causes slowing of traffic between Morrison and I-84 on-ramps.

In addition, there is a large traffic demand that exits I-5 at I-405 off-ramp. I-405 and Broadway Street weaving section operates under dense traffic conditions during the AM peak period that peaks between 7 a.m. to 8 a.m. Traffic packs densely into the right-most lane of I-5 as drivers destined for the I-405 change lanes in advance of their eventual departures from I-5. This causes both I-405 exiting traffic as well as traffic on the I-5 mainline to slow down.

8 a.m. to 10 a.m. – Back to Free Flow Operations

I-5 mainline between I-84 on- to I-405 off-ramp starts to recover around 8:15 a.m. and is back to free flow operations around 9 a.m..

Southbound I-5 - PM

3 p.m. to 4 p.m. – Congestion Emerges at Two locations

In the Portland area, I-84 off-ramp demand volume from I-5 between 3 p.m. to 4 p.m. This, along with heavy southbound I-mainline demand, causes Weidler Street and I-84 section to slow down during this time period.

Slowing of traffic also occurs near I-405/I-5 split in the early PM peak period. Heavy I-405 demand volume along with the heavy I-5 mainline volume causes vehicles to slow down between the Portland Boulevard on-ramp and the I-405 off-ramp. Slowing and minor queuing in this section also results as drivers destined for I-405 try to change lanes in advance of their eventual departure. This slowing also causes disruptions to the I-5 mainline traffic as some aggressive drives choose to make their lane changing decisions later and closer to the exit instead of queuing in the right lane that exits to I-405.

4 p.m. to 6 p.m. – Rose Quarter Section Operates as a Bottleneck and Alberta Recovers

Weidler Street and I-84 section slowing along with the lane drop from three to two lanes at the Rose Quarter causes significant slowing and queues to form between Greeley Avenue on-ramp to I-84 off ramp. This congestion peaks around 5:15 p.m. and starts to dissipate around 5:30 p.m.

Slow downs in the Alberta Street to I-405/I-5 split section end around 5:30 p.m. as the exiting traffic demand for the I-405 reduces.

6 p.m. to 7 p.m. – Free Flow Conditions

The I-5 mainline is back to near free flow operations in this time period, with the Rose Quarter bottleneck recovering by about 6:15 p.m.

Northbound I-5 - PM

Around 3 p.m. – Bottleneck Activated

I-5 experiences severe congestion in the northbound direction in the PM peak period as traffic from Portland on-ramps tries to merge with the heavy I-5 mainline traffic and the Interstate Bridge acts as a bottleneck that restricts traffic throughput. The Interstate Bridge capacity is also affected by the close proximity of the Hayden Island on-ramp which further compounds the problem. This bottleneck is already active by 3 p.m

3 p.m. to 3:15 p.m. – Interstate Bridge/Hayden Island Queue Grows and Congestion Emerges at another Location

Queue shock waves that started at the Interstate Bridge/ Hayden Island merge area move rapidly towards Portland since the HOV lane is active by 3 p.m. and restricts capacity between Going Street and Denver Avenue/ Victory Boulevard on-ramps. Between 3 p.m. to 3:15 p.m., northbound I-5 freeway operations have deteriorated enough to impact the ability of drivers to access northbound I-5 from Hayden Island to Columbia Boulevard on-ramps.

The segment of I-5 between the southern terminus of the study area and the I-84 off-ramp (Marquam Bridge) starts to show congestion during this time period. The I-84 off-ramp exiting traffic is affected by the congested operations on I-84 which does not allow traffic to merge freely causing back-ups and slow downs on I-5.

3:15 p.m. to 3:30 p.m. – Ramps Impacted

Queuing related to the Interstate Bridge bottleneck reaches the Portland Boulevard off-ramp. Congestion worsens on the I-5 mainline impacting merging traffic from all on-ramps north of this location up to the Interstate Bridge.

3:30 p.m. to 3:45 p.m. – Ramp Meters Activate and Mainline Queue Build-up Slows Down

The extent of the Interstate Bridge queue approaches the Going Street off-ramp between 3:30 p.m. to 3:45 p.m.. Except for Morrison and Broadway on-ramps, ramp meters for northbound I-5 turn on at 3:30 p.m.. This slows down the progression of the southward queue and for a brief period after 3:30 p.m., the queue appears to have reached an equilibrium state between Going Street on-ramp and I-405 on-ramp.

3:45 p.m. to 4 p.m. – Mainline Queue Impacts I-405 Merge and Congestion Emerges at another Location

The Interstate Bridge queue impacts merging traffic from the I-405 on-ramp causing I-405 to start queuing around 3:45 p.m. The heavy traffic demand from the I-405 on-ramp further deteriorates I-5 mainline traffic operations and causes traffic slow downs south of the I-5/I-405 merge.

During this time, congestion emerges near Morrison as traffic demand from the Morrison on-ramps peaks around 4 p.m. and causes disruptions to the I-5 mainline. This leads to stop-and-go conditions on I-5 between Morrison on-ramps to the I-84 off-ramp.

4 p.m. to 4:15 p.m. – Two more Locations Show Congestion

Heavy merging traffic from the I-84 on-ramp coupled with high Broadway Avenue off-ramp volumes causes disruptions to mainline flows at these locations which results in slowing of traffic south of the weave. At this time the I-405 off-ramp to Broadway on-ramp section of I-5 is also operating at slow speeds due to weaving occurring in this section. Between 4 p.m. to 4:15 p.m., I-5 is close to break-down and significantly slows downs in speed between the I-405 off-ramp to the south of Morrison on-ramps.

4:15 p.m. to 4:30 p.m. – One Long Queue

Around 4:15 p.m., the Interstate Bridge, the Broadway Avenue to I-405 weave, and the I-84 to Broadway Avenue weave bottlenecks appear to have blended together and are no longer distinguishable. This state, however does not last for long.

4:30 p.m. to 6 p.m. – Congested Traffic Operations Continue

The section of I-5 between Greeley Avenue off-ramp to I-405 on-ramp recovers. The extent of the Interstate Bridge bottleneck moves north into the Going Street/I-405 section and remains there until dissipation of queue begins. Stop-and-go conditions persist between the Interstate Bridge and I-405 on-ramp in this time period. I-5 between I-405 off-ramp to I-84 off-ramp also continues to remain congested during this time period.

6 p.m. to 6:15 p.m. – HOV Lane Restriction Ends and the Interstate Bridge/Hayden Island Queue Starts to Dissipate

The northbound HOV lane restriction between Going Street and Denver Avenue/Victory Boulevard on-ramps ends at 6:00 PM. With additional capacity available for the SOVs and trucks, the queue recovers fast between I-405 on-ramp and Lombard off-ramps and around 6:15 p.m. the end-of-queue has moved closer to the Victory Boulevard off-ramp.

Sections of I-5 south of I-405 off-ramp also start to show signs of relief during this time period.

6:15 p.m. to 6:45 p.m. – Queue Recovery

Between 6:15 p.m. to 6:45 p.m., both the Interstate Bridge and the Broadway Avenue to I-405 weave bottlenecks continue to dissipate.

6:45 p.m. to 7 p.m. – I-5 Back to Free Flow Operations

Around 7 p.m., I-5 northbound has recovered and is back to operating near free flow traffic conditions.

Figure B-1: Southbound I-5 Existing Observed Conditions – AM Peak

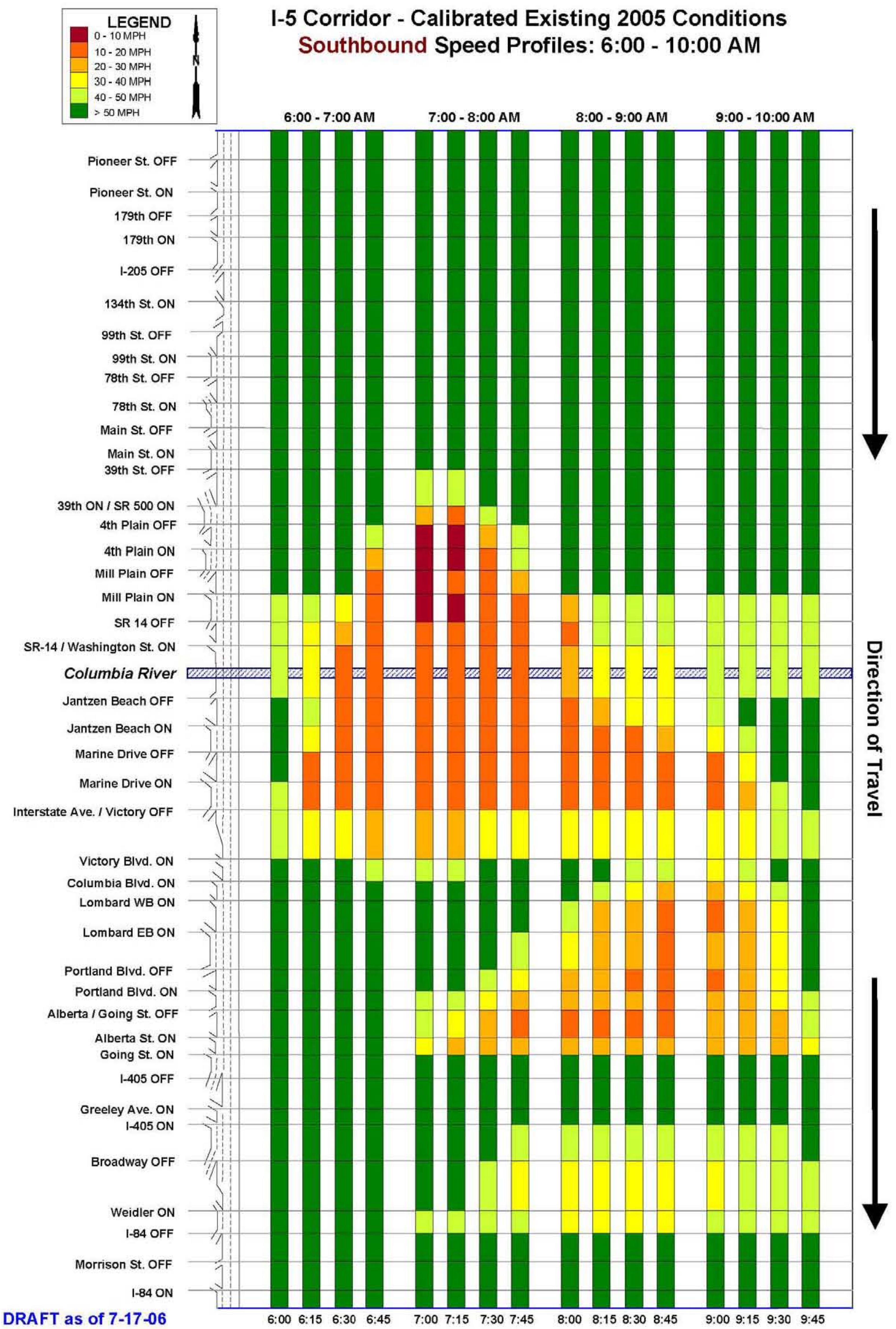

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Figure B-2: Northbound I-5 Existing Observed Conditions – AM Peak

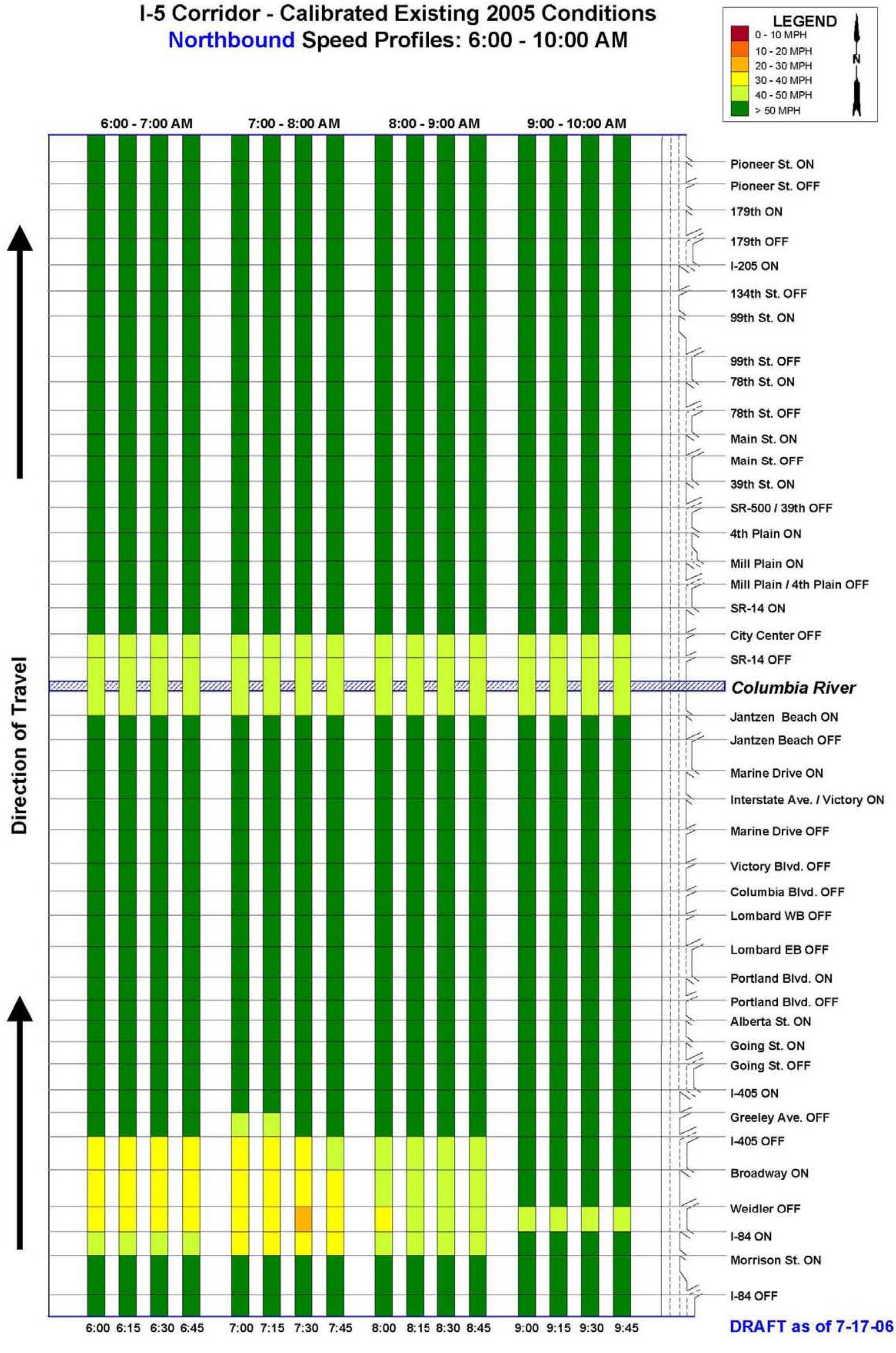

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Figure B-3: Southbound I-5 Existing Observed Conditions – PM Peak

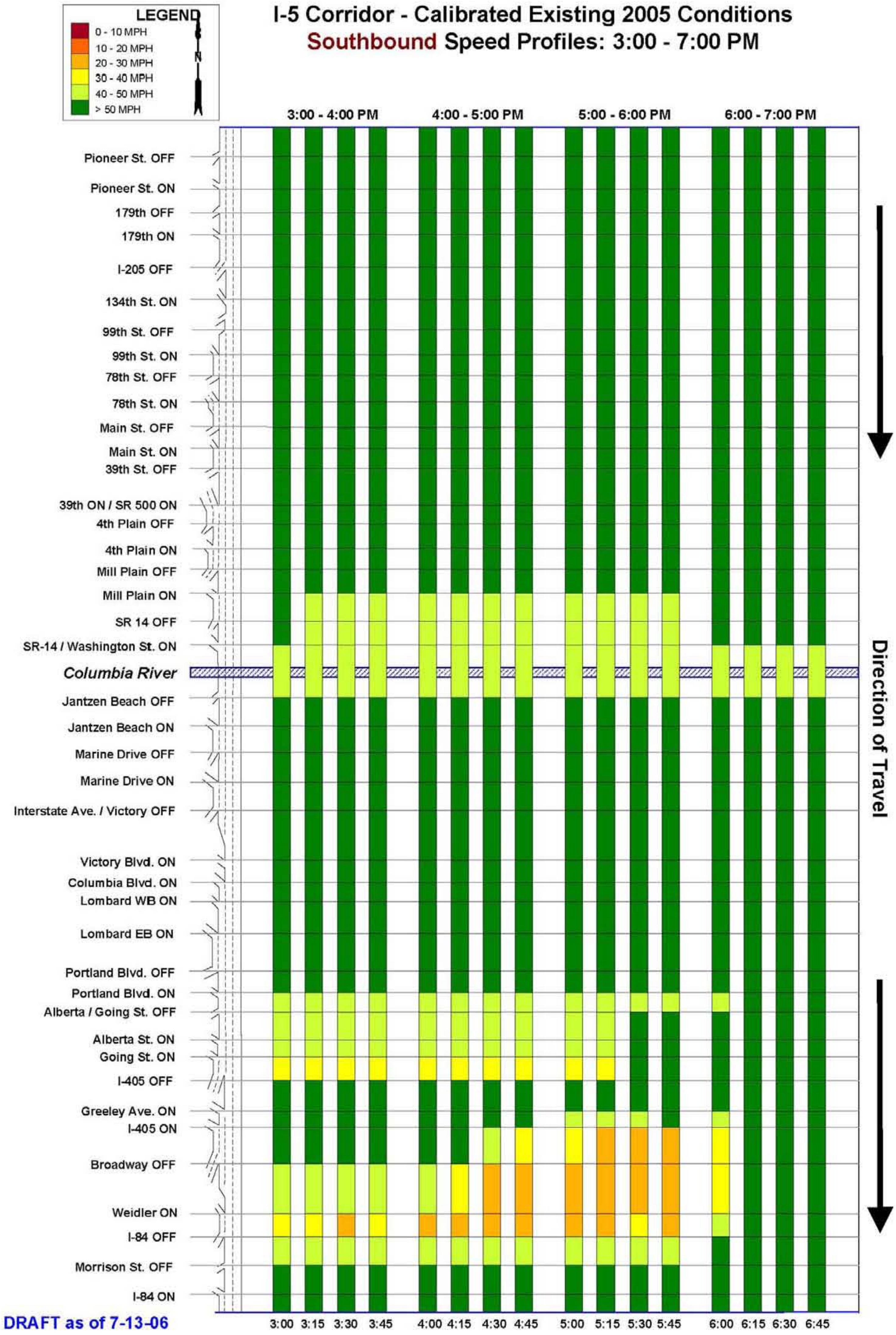

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Figure B-4: Northbound I-5 Existing Observed Conditions – PM Peak