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Joy Dahlgren, Alex Skarbardonis**

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BAY AREA SIMULATION AND RAMP METERING STUDY

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EXECUTIVE SUMMARY

This research project focuses on the investigation of a portion of the southbound morning peak I-680 freeway facility, between I-580 in Pleasanton and SR 237 in San Jose. The project provided an opportunity for testing the Paramics model capabilities to replicate freeway traffic conditions, and assess to what extent the existing model can simulate various operational strategies such as HOV lanes and ramp metering.

In the initial phase of the project, and prior to the large-scale application, several simple networks were developed to provide the opportunity for conducting some initial experiments with the Paramics model. The intent was to apply the model to very simple situations in which the predicted model results could be compared with known accepted results or observed real-life data. Three test freeway networks were first developed: the lane-drop, ramp merge, and weaving experiments. Another pilot test network was later developed in order to investigate the modeling of ramp metering, including the use of a local traffic-responsive control strategy.

Once the initial pilot studies had been successfully completed, the application to the I-680 network began. There are three major steps in building a traffic model prior to its use for scenario analysis: data collection, network coding and model calibration.

The work on the I-680 application started with data gathering, which included freeway design features, traffic counts, tachography runs, origin-destination matrices, and FREQ simulation outputs. The modeled network covers 19 miles of I-680 (southbound direction) and includes 15 on-ramps and 12 off-ramps. The study period is the morning peak, from 5 am to 10:15 am.

The network was coded in Paramics to include precise geometric description (curvatures, elevation), allowing the visual aspect of the simulation to be quite realistic. This process involved the use of a network Autocad drawing provided by Caltrans, and its importation into Paramics as an overlay.

The calibration phase of the model was considered critical, as predicted results of uncalibrated models should never be used. As a relatively new tool, few references were available for freeway applications of Paramics. As a result, a process for calibrating Paramics was developed. It consisted in identifying and fine-tuning the key parameters that affect the model outputs, so that the model realistically represents real-life traffic conditions, in terms of predicted flows and speeds.

Finally, once the model was considered properly calibrated, a number of scenarios were investigated. Improvement options involving the use of ramp metering, added auxiliary lanes or HOV lanes were simulated, so that the effects of each strategy could be evaluated.

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Several units of Caltrans Headquarters in Sacramento were involved in this project. Larry Jellison (New Technologies and Research), Mary Rose Repine, Charles Chenu and Leo Gallagher (Transportation Systems Information) and Steve Hague (Traffic Operations) provided valuable support and guidance throughout the project.

Caltrans District 4 (San Francisco Bay Area) was instrumental in collecting and sharing all the necessary data and information used in this study, as well as supporting and reviewing the work as it progressed. Judy Chen, Albert Yee, Cesar Pujol, Rod Oto and Mei-Ling Long were actively involved in the project.

Scott Aitken and Ewan Speirs, from Quadstone in Scotland, provided invaluable technical support in the process of applying the Paramics model. Their continuous collaboration to the project greatly facilitated the work.

The TJKM transportation consulting firm (Gary Kruger) generously shared a dataset previously developed for the same site, reducing the cost and duration of the data collection effort.

CHAPTER 1: INTRODUCTION

1.1 Project Scope and Objectives

This report describes the first phase of an ongoing research project carried out at PATH to investigate the use of the Paramics traffic simulation model in freeway operation studies. As part of this project, the I-680 freeway in the San Francisco Bay Area was selected as a site for testing the model in a real life environment.

The research has multiple objectives, which includes obtaining an in-depth knowledge of the Paramics model for freeway applications, developing and evaluating a calibration process, assessing the model's ability to serve as a tool for evaluating freeway improvement strategies and investigating various improvement strategies for the I-680 study section.

This study supports a state-wide program of Paramics model applications. The California Department of Transportation has purchased a large number of licenses for the Paramics model, distributed copies to all of its District offices, provided training sessions, and supports a user group. Progress reports on this research and practical guidance from Caltrans professionals are shared at the local Caltrans District office as well as with other districts and through the state-wide Paramics model user group meetings.

1.2 Organization of the Report

The report follows the project development cycle.

The first chapters of this report describe the Paramics model in general (Chapter 2) and the initial tests on simple hypothetical freeway networks (Chapters 3 and 4).

The preparation of the I-680 application is described next with the freeway site presentation (Chapter 5), and the assembling of input and performance data (Chapter 6).

A major section of the report (Chapter 7) is devoted to describing the calibration procedure that was developed and its use to obtain a calibrated heavily congested freeway model.

The calibrated model is described in detail in Chapter 8, which presents how the validity of the model was checked.

Another section of the report (Chapter 9) describes the design of the investigation of freeway improvement strategies: ramp metering, added auxiliary lanes, and HOV lanes.

The final portion of the report includes a summary of experiences and future plans (Chapter 10) and a list of references (Chapter 11).

CHAPTER 2: THE PARAMICS MODEL

2.1 Introduction to Paramics

The Paramics microsimulation traffic model has become increasingly popular worldwide due to its ability to model the many elements in road traffic networks and its powerful visualization capabilities.

The model originates from Scotland in the UK where it was originally developed as a driving behavior model. (Ref. 1 to 4). Since this time, Paramics has been developed into a full traffic simulation model with a suite of powerful features making it popular for problem solving from single intersections to entire road traffic networks (Ref. 5 to 25).

These features have also allowed PARAMICS to be used for investigations including:

- HOV lanes and freeway performance in California (Ref. 26)
- Road pricing and public transport operation in Singapore (Ref. 39)
- Impact of ITS in Toronto, Canada
- Performance of motorways in Germany
- Intelligent highway systems in Japan (Ref. 38)
- Speed based emissions and VMS speed signs on the M25 Motorway in England
- Modeling of complex road junctions in Adelaide, Australia

One of the main advantages of PARAMICS over other traffic models lies in its ability to model network interactions as a whole. The effects of queue lengths, driver aggression and successive traffic signals can all interact to present a fairly complete picture of what is happening in a road network.

Other significant advantages include its animation and its integration of traffic assignment and traffic simulation.

Paramics can provide a vast array of dynamic real time output data ranging from point specific data, link data or network data. Public transit routes, car parking, road restrictions, roundabouts, vehicle actuated signals, lane usage, and complex road geometry (including 3D modeling) can be included in modeled networks.

Paramics is a microscopic and stochastic model that simulates the individual components of traffic flow and congestion, and presents its output as a real-time visual display for traffic management and road network design..

In addition to the inclusion of the detailed physical description of the road network and influencing features, driver behavior characteristics and vehicle kinematics are represented. This can provide an accurate representation of the variable circumstances that lead to congestion in all types of road network.

Paramics is unique in providing dynamic assignment over road networks of unlimited size.

The data requirement is similar to that of other modeling systems, although Paramics can take advantage of other data sources, such as digitized road layouts and aerial photographs.

2.2 Vehicle Dynamics

The PARAMICS Training Course document prepared by Dowling Associates (Ref. 37) provides an excellent introduction to the simulation approach used in the Paramics model.

First, vehicles are generated each time step of the simulation. Then, they are assigned to specific links in the network. They are then moved through the network according to car-following, lane changing and path finding algorithms. Gap acceptance is used inside intersections to determine the movement of vehicles in conflicting vehicle streams.

Vehicle Generation

At the start of every time step in the simulation, Paramics makes a decision about whether or not to release one or more vehicles onto the system. Vehicles are only released at zones. The zones can be located anywhere in the network. The decision to release is a random decision with a mean probability specified by the mean trip generation rate (vehicles/time step) for the zone. A random number seed, which varies with each model run (but can be fixed by the user), is used to select a random number that determines whether or not a vehicle is released.

This process does not guarantee that the final number of vehicles released onto the network will actually match the value coded in the Origin-Destination table. It should be close, but not exact. The user can set a flag to force this consistency if desired.

At the time the vehicle is generated, it is randomly assigned a vehicle type, a driver type (level of aggressiveness and awareness) and a destination. The length, weight, width, height, maximum acceleration rate and the braking rates can be set by the user for each vehicle type.

The probability of being assigned to a destination is proportional to the number of trips in the Origin-Destination table for that vehicle type and time period.

Assignment to a Starting Link

Once it is determined that one or more vehicles are to be released by a zone, Paramics then makes a choice as to which link or links within the zone to put the vehicle. The choice is a random choice with the probability of being assigned to a link proportional to the relative length of each link to the total length of all links within the zone. The set of

eligible links for a given zone consists of all links for which more than 50% of the link length lies inside the zone boundary.

If there is no available space on the link to accept the vehicle (eg. a queue is blocking the link), then the vehicle is held back for a later time period.

Vehicle Movement on a Link

Paramics employs car following and lane changing routines to move a vehicle along a link.

- Single Vehicle on Link

Each time step within each second, Paramics moves the vehicle down the link at the desired speed of the vehicle. The desired speed of the vehicle is determined by the user coded free-flow speed for the link and the driver type (aggressiveness). Vehicles are randomly assigned to a distribution of desired speeds that vary around the link free-flow speed. The distribution of aggressive drivers influences the distribution of vehicle speeds around the mean.

- Car Following

When the vehicle catches up to another vehicle, a car following algorithm and a lane changing algorithm are used to decide how the vehicle will respond to the lead vehicle. The default mean target headway in Paramics is 1.00 seconds between vehicles (it is user adjustable). The actual target headway between vehicles varies around the mean. The variance itself is increased or decreased according to driver type and network conditions. Vehicle type, two lane roads, proximity to merges, proximity to signal, turning movement type, driver aggressiveness, driver awareness of a downstream lane drop all affect the distribution of vehicle headways around the mean target headway of 1.0 seconds.

- Lane Changing

The probability of a vehicle changing lanes to overtake a vehicle is a function of the difference in speed between the two vehicles and the available gap in the adjacent lane. The available gap must be at least as large as the vehicle's target headway for car following.

Vehicles will also change their lanes to pre-position themselves for a downstream turn. Signposting is used by Paramics to trigger the point where a vehicle decides to start to change lanes, and the distance over which the vehicle tries to complete the maneuver.

Vehicle Path Choice

Paramics uses a dynamic lowest cost path finding algorithm to select the path for the vehicle and decide on its turning movement at the intersection. A perturbation factor is

used to randomly send some vehicles down other paths that are almost as fast as the lowest cost path. The parameters used in the path finding algorithm can be modified by the user.

Unfamiliar drivers (the proportions of which are set by the user) are assumed to be relatively (but not completely) unaware of minor streets in the network (each minor street is given a cost equal to twice that of an equivalent major street link in the network for path finding purposes). Familiar drivers receive traffic reports at user specified intervals informing them of downstream congestion which then is used to recompute their shortest path.

2.3 Presentation of the Five Modules

The Version 3 suite of Paramics software released in early 2000 (Ref. 36) comprises five software modules: Modeller, Processor, Analyzer, Programmer, and Monitor. The Quadstone website at www.paramics-online.com provides an overview of each module.

The latest version of Paramics (Version 3 Build 7) was released in the summer of 2001 (Ref. 42).

Paramics Modeller

Paramics Modeller (Ref. 30) provides the three fundamental operations of model build, traffic simulation (with 3-D visualization) and statistical output accessible through a powerful and intuitive graphical user interface. Many aspects of the transportation network can be investigated in Modeller including:

- Mixed urban and freeway networks
- Right-hand and left-hand drive capabilities
- Advanced signal control
- Roundabouts
- Public transportation
- Car Parking
- Incidents
- Truck-lanes, high occupancy vehicle lanes

In Modeller, individual vehicles are modeled in detail for the duration of their entire trip, providing accurate and dynamic information about traffic flow, transit time and congestion. Modeller has been validated against existing macroscopic modeling tools, traffic survey information and site observation.

The high quality visualization of the vehicles in the network makes Modeller a powerful tool for presenting project results to non-technical audiences.

Paramics Processor

Paramics Processor (Ref. 31) is a simulation configuration tool that allows the user to set up multiple network simulations to be run in batch mode.

Processor provides a graphical user interface, which allows the user to:

- Set simulation parameters
- Select various statistics for output
- Vary the attributes of the vehicles released into the network for different simulation runs of the same network.

This is useful, for example, when examining the variation within the model when running sets of simulation runs. The variations can be due to changes in the input parameters or use of different random numbers.

Once the Processor graphical interface has been used to configure the different simulations, Processor can then launch the simulations in batch mode. The batch mode of Processor simulates offline, without visualizing the vehicle positions, to generate the statistics required for analysis in a reduced amount of time.

The statistical results are the same as those statistics output from Modeller, but can be produced in a much shorter time.

Paramics Analyser

Paramics Analyser (Ref. 32) is an analysis tool for displaying the output obtained from Paramics traffic simulation. The primary aim of Analyser is to display and report on statistical data produced by running the simulation through Modeller and/or Processor.

Analyser's flexible and easy-to-use graphical user interface can be used to load the results from an individual simulation run and visualize a range of statistics such as:

- Link statistics including traffic density, speed and delay
- Traffic flow volumes by link and turn
- Maximum or average queue lengths and blocking of traffic
- Simulated travel time data
- Simulated vehicle paths
- User customized link data such as Level of Service.

The information can be displayed graphically or numerically on-screen, or saved as reports in ASCII text format. The text files can then be included in documents or imported to further analysis tools such as spreadsheets and databases.

The Analyser module includes an Excel Wizard that is used to filter the mass of simulation data to produce comparisons and mean statistics for multiple simulation runs.

These comparisons allow the user to quickly pinpoint average simulation results as well as boundary results where the variation in the model output produces upper and lower limits for simulation

Params Programmer

Params Programmer (Ref. 33) is an Application Programming Interface (API) for traffic modeling research, which allows users to customize some critical parts of the Params core models.

This customization work often involves the tuning of driver and vehicle models and parameters to reproduce specific observed behavior. Params was originally developed to reflect UK driver and vehicle characteristics. Several research teams working on behavioral models worldwide have later tried to better reproduce local driver characteristics (Ref. 43,46). This can be done by overriding Params default behavioral models such as car following, gap acceptance, lane changing or route choice models.

Another area of customization is the implementation of specific traffic control strategies. By developing plug-in code, Programmer users can carry out comprehensive modeling and analysis of the very latest transportation technologies and techniques. Some Programmer applications that have been developed include:

- Vehicle-actuated signal control and complex ramp metering algorithms
- Modeling of variable message signs and driver re-routing
- Development of traffic management strategies and real-time traffic control
- Analysis of speed control algorithm performance
- Modeling of Automated Highway Systems and Intelligent Cruise Control
- Simulation of incident and accident management systems

Params Monitor

Params Monitor (Ref. 34) calculates the levels of traffic emission pollution on a road network. The pollution levels are collected for every link in the network by summing the emissions for all vehicles on the link.

These levels can be written to a statistics file at regular intervals, and can be viewed graphically while the simulation is running.

The Params Monitor module has been developed as a "plug-in". Plug-ins add functionality to Params Modeller and are developed using Params Programmer. Monitor features include:

- Graphical display of levels of emissions
- A simple dispersal model
- Emission statistics may be output in ASCII text format

- Vehicle characteristics (time on network, speed, acceleration) and network characteristics (link gradient) are cross referenced to pollution emission data
- Pollutant types (e.g. carbon monoxide, oxides of nitrate) may be specified by vehicle engine types (e.g. small diesel engine).

2.4 Paramics Applications and Validation Studies

The Paramics software has been used for a variety of different modeling applications including:

- New intersection design, signalized and unsignalized roundabouts
- High occupancy vehicle lanes
- Ramp metering
- Toll plazas
- Vehicle actuated loop detection
- Transit dedicated lanes and priority measures
- Incidents
- Automated highway systems
- Automated speed control
- Pollution emissions

The current user base includes government bodies (both central and local), academic researchers and consultants in Argentina, Australia, Belgium, Canada, France, Germany, Hong Kong, Japan, Malaysia, Singapore, Spain, Taiwan, UK and USA.

Model Validation

In the UK, model results have been validated against a wide variety of observed data.

In a report published in 1996 (Ref. 12), validation results are presented. Traffic data was collected on several congested multi-lane motorways for comparison with the model predictions. A representative cross-section of measurements is presented, including headway distributions and average speeds. It was concluded that Paramics was able to “model congested networks with an accuracy and depth not previously achieved”.

Three articles by Stephen Druitt (SIAS) published in 1998 and 1999 (Ref. 19,20,23) describe examples of Paramics application projects ranging from individual intersections to wide area problems of rural and urban congestion.

More recently, the Institute of Transport Studies at the University of California at Irvine, published a validation report (Ref. 26). A problem referred as “virtual congestion” was identified when vehicles were being prevented from starting their trip because of queue spillback in some origin zones.

CHAPTER 3: INITIAL TESTS WITH THE PARAMICS MODEL

3.1 Introduction

In a first set of experiments with the Paramics model, several simple networks were developed to gain some experience with the model and provide the opportunity for conducting initial tests. The intent was to apply the model to very simple situations in which the predicted model results could be compared with known accepted results.

Three freeway test networks were initially simulated: a straight-pipe freeway section, a lane-drop freeway section, and a single on-ramp freeway section. These test networks were modeled under a range of traffic demand situations, and the model results were compared to expected freeway traffic performance based on the Highway Capacity Manual (Ref. 57).

A fourth experiment was later developed to test the modeling of a traffic responsive ramp metering system with Paramics and is described in Chapter 4.

The first three experiments are briefly described in this chapter, and the main results and findings are presented. Two unpublished working papers provide more extensive material on these initial experiments, and a complete set of simulation results (Ref. 40,48).

3.2 Design of Experiments

Straight-Pipe Section

A single directional two and one-half mile three-lane freeway that was level and straight was the basic design of the simple networks that were simulated. An origin zone was placed at the upstream end of the freeway and a destination zone was placed at the downstream end of the freeway. The first one-half mile was used as the warm up section (its statistics were not included in the results) and the remaining two-mile section was divided into twenty 0.1-mile long subsections with a detector station located five feet from the end of each subsection. The free-flow speed was assumed to be 65 miles per hour.

The directional freeway was simulated for 65 minutes at a constant flow rate with predicted station hourly flow rates and speed statistics provided at the end of each five minute time interval. The first five-minute time interval was used for loading the freeway and its statistics were not included in the results. All simulated vehicles were considered to be typical passenger vehicles.

Lane-Drop Experiment

In the second experiment, a lane-drop was introduced at milepost 1.5 mile, which provided a one-mile three-lane directional freeway followed by a one-mile two-lane directional freeway.

A constant input hourly demand rate of 4000 passenger vehicles per hour was used which was below the expected facility capacity.

It was found necessary to input a free-flow speed of 60 rather than 65 miles per hour in this and all other Paramics experiments in order to obtain output results more compatible with the expected 65 miles per hour free-flow speed results.

Ramp Merge Experiment

In the third experiment, an on-ramp was introduced at milepost 1.5 miles replacing the lane-drop, providing a one-mile three-lane directional freeway in advance of the on-ramp and a one-mile three-lane directional freeway downstream of the on-ramp.

Figure 1 presents a screen capture of the Paramics ramp merge experiment. The on-ramp merge function of Paramics was engaged, and the merging vehicles were using the acceleration lane parallel to the freeway prior to merging. This acceleration lane is different from the 30-degree ramp, so that the angle does not affect the behavior of the vehicles in the merging area

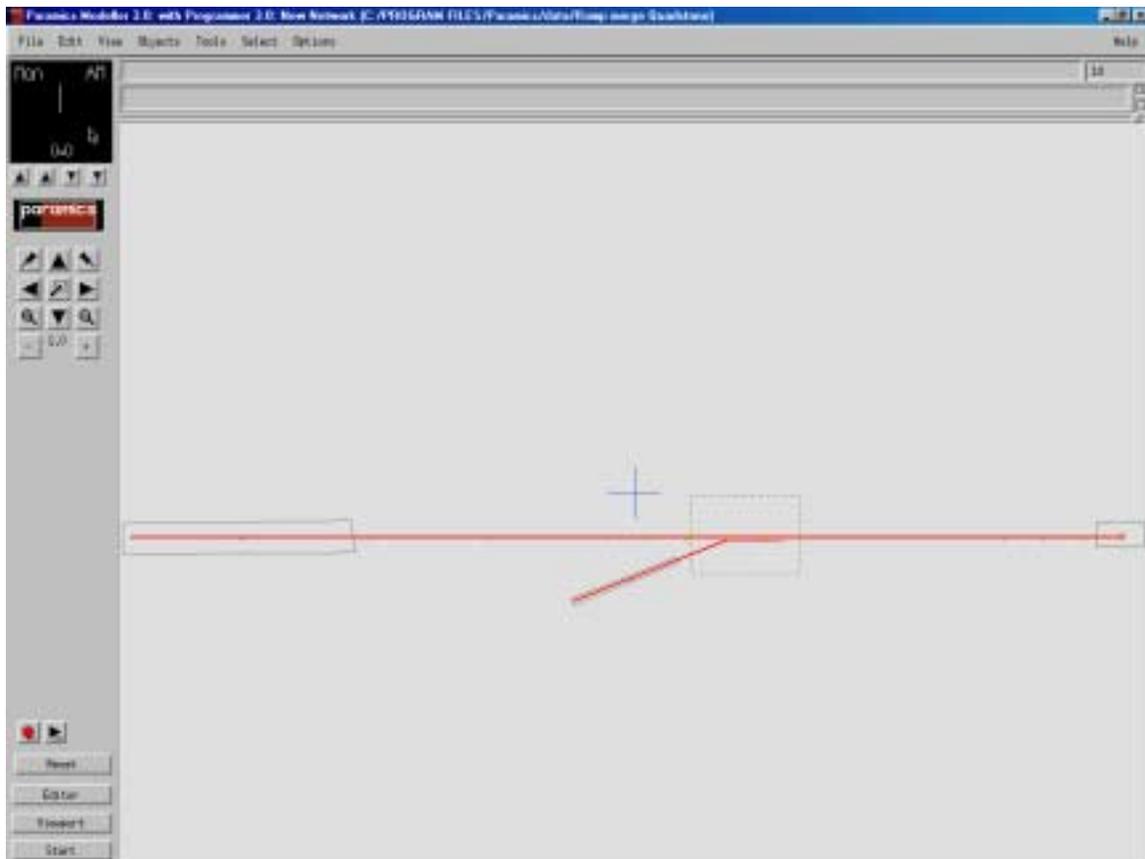


Figure 1: Paramics ramp merge experiment

A constant freeway input demand rate of 5000 passenger vehicles per hour and a constant ramp input hourly demand rate of 500 passenger vehicles per hour was used, which was well below the expected facility capacity.

3.3 Main Findings

In an initial set of runs, the default values were used for all input parameters and the output information was collected using loop detectors in Paramics Modeller (as described in Ref. 30 - Modeller Reference Manual Appendix B).

As the model predictions were out of the expected range, the project staff members shared the results with Quadstone and sought advice and guidance from the model development support company. Two main issues were highlighted in the discussions: the fine-tuning of some key calibration parameters and the method used for data gathering with Paramics.

Quadstone suggested a number of changes to be made to the model input default values. These modifications included the following:

- Add a (random) seed value which allows runs to be recreated
- Increase the freeway signpost distance from the default value of 2461 feet to 4461 feet, which allows vehicles to see the hazard further away
- Increase the lane change distance from 3 feet to 2000 feet, which gives vehicles more time to change lanes, avoiding forced maneuvers
- Increase the ramp length from 448 feet to 2199 feet and the associated signpost length from 445 feet to 2199 feet which will allow drivers to move from lane 1 (shoulder lane) on the mainline in anticipation of merging vehicles
- Increase the simulation time steps from 2 to 5 steps per second because high density flows often require more time steps per second to operate in a freer manner
- Increase the speed memory from 3 to 8 time steps in conjunction with the time step change
- Reduce either the mean target headway or the mean reaction time (numerical changes in these values were not proposed). Previous experiences suggested that vehicles on the US freeways accepted smaller gaps and tended to have lower reaction times than the default values that had been calibrated under UK traffic conditions.

Site-specific performance data can be gathered with Paramics by using different methods:

In Modeller using loop detectors to gather point data:

Point data is gathered as each individual vehicle passes over the loop. The flow, speed, headway, occupancy and acceleration of each vehicle is calculated in the last time step

that the vehicle occupies the loop detector. Loops in Modeller have been specifically designed to emulate the output of real loop detectors. Point data does not aggregate the flows over user-defined time intervals.

In Modeller using loop detectors to gather link data:

Data from loop detectors can also be used to analyze traffic flow on a link at a user-defined point in time and a lane-by-lane basis. It gives a “snapshot” of the vehicles in the lane at the precise moment defined by the user to collect the information. Link flows, speeds and densities are collected at the specified point in time, but are not aggregated over defined time periods. The data is gathered by lane over the entire length of the link. Therefore, if two loops are present of the same link, they will return the same values for each of the time periods.

In Analyzer to gather link data:

Analyzer was developed to allow users to analyze aggregated data by user defined time intervals. Data includes: link flow, density, speed, delay, maximum and average queue.

After Quadstone provided more explanation about the different ways of gathering information, it was concluded that for the purposes of our initial tests, the Analyzer option was the most appropriate.

3.4 Analysis of Results

Straight-pipe and lane-drop experiments – Flow analysis

The results presented below are based on an input demand rate of 4000 vehicles per hour. With this level of demand, no congestion was expected in the straight-pipe or in the lane-drop experiment. The expected ranges of flow rates are based on the Highway Capacity Manual 2000 (Ref. 54). They are typical of uncongested conditions, and the expected values of flow rates are identical in the straight-pipe case and the lane-drop case.

Table 1 presents the results of flows obtained with Paramics in the straight-pipe and lane-drop experiments, in comparison with the expected values. All flow values refer to link flows aggregated over a 5-minute periods along a 0.1-mile section of the freeway section.

The minimum/maximum over time represents the minimum/maximum of the average flows over a 5-minute period. The minimum/maximum over space represents the minimum/maximum of the average flows over a 0.1-mile section. The overall minimum/maximum represents the minimum/maximum of any flows collected over a 5-minute period along a 0.1-mile section. The asterisk indicates when predicted values meet the criteria.

Hourly Flow Rates	Expected values	Paramics Straight-pipe	Paramics Lane-drop
Overall Average	3950-4050	3902	3989*
Minimum over time	3900	3576	3785
Maximum over time	4100	4203	4175
Minimum over space	3900	3896*	3980*
Maximum over space	4100	3910*	3993*
Minimum overall	3800	3480	3708
Maximum overall	4200	4368	4296

Table 1: Flow analysis for straight-pipe and lane-drop experiments

In the straight-pipe case, it was found that the overall average flow and the variations in the hourly flow rates over time fell outside the expected range.

In the lane-drop case, the overall average flow rate and the variations of flows over space were very reasonable. However, the variations over time and the overall variations were outside the expected ranges.

Straight-pipe and lane-drop experiments – Speed analysis

Table 2 presents the results of speeds obtained with Paramics in the straight-pipe and lane-drop experiments. All speed values refer to average link speeds aggregated over a 5-minute periods along a 0.1-mile section of the freeway section.

Average Speeds	Expected values	Paramics Straight-pipe	Paramics Lane-drop
Overall Average	61-63	62*	59
Minimum over time	59	61*	57
Maximum over time	65	64*	62*
Minimum over space	59	61*	57
Maximum over space	65	65*	65*
Minimum overall	57	60*	46
Maximum overall	67	68	68

Table 2: Speed analysis for straight-pipe and lane-drop experiments

In the straight-pipe case, the overall average and the variations of average speeds over space and time were within the expected range. The overall average speed was 62 miles per hour and the overall average speed values varied between 60 and 68 miles per hour.

In the lane-drop example, the central tendencies of the average speeds were marginally within the expected range (57 to 62 miles per hour over time, 57 to 65 miles per hour over space, and 59 miles per hour overall). However, individual average speeds varied from 46 to 68 miles per hour. Average speeds below 50 miles per hour occurred in sections located near the hazard warning sign and in advance of the lane-drop.

Ramp Merge Experiment – Flow analysis

The results presented below are based on an input freeway demand of 5000 vehicles per hour and a ramp demand of 500 vehicles per hour. No congestion is expected in this case.

Table 3 presents the flow results obtained in the ramp merge experiment, in comparison with the expected values based on the Highway Capacity Manual.

The minimum/maximum flows over space and overall minimum/maximum flows are further divided into two categories: sections before the ramp (Upstream) and sections after the ramp (Downstream).

Hourly Flow Rates	Expected values	Paramics Ramp-merge
Overall Average	5200-5300	5174
Minimum over time	5150	4837
Maximum over time	5350	5496
Minimum over space (Upstream)	4900	4981*
Maximum over space (Upstream)	5100	4988*
Minimum over space (Downstream)	5400	5487*
Maximum over space (Downstream)	5600	5507*
Minimum overall (Upstream)	4800	4416
Maximum overall (Upstream)	5200	5400
Minimum overall (Downstream)	5300	5487*
Maximum overall (Downstream)	5700	6036

Table 3: Flow analysis for ramp-merge experiment

The overall central tendency, temporal variation and spatial variation in the average hourly flow rates were marginally within the expected range. However, overall flow rates varied from 4416 to 6036 vehicles per hour; these values were outside of the expected range values.

Ramp Merge Experiment – Speed analysis

Table 4 presents the results of average speeds obtained in the ramp-merge experiment, in comparison with the expected values. Since no congestion was expected, the target values are typical of free-flow conditions.

Average Speeds	Expected values	Paramics Ramp-merge
Overall Average	61-63	62*
Minimum over time	59	59*
Maximum over time	65	63*
Minimum over space (Upstream)	59	61*
Maximum over space (Upstream)	65	64*
Minimum over space (Downstream)	56	60*
Maximum over space (Downstream)	65	63*
Minimum overall (Upstream)	57	59*
Maximum overall (Upstream)	67	67*
Minimum overall (Downstream)	57	52
Maximum overall (Downstream)	67	65*

Table 4: Speed analysis for ramp-merge experiment

The central tendencies as well as the variations of average speeds were within the expected range. The overall average speed was 62 miles per hour and varied from 59 to 63 miles per hour over the time intervals. The average speeds varied from 59 to 67 miles per hour upstream of the ramp-merge and from 52 to 65 miles per hour downstream of the ramp-merge.

3.5 Conclusions

With few exceptions, it was found that predicted hourly flow rates fell outside the expected ranges both in terms of the central tendency and the temporal and spatial variations for all three simple networks. The variations of flows were generally higher

than expected. This could be due to the very nature of the microscopic simulation: by modeling individual vehicles instead of using an aggregated macroscopic approach, the range of predicted values over the time–space domain is likely to be wider when the vehicles are re-aggregated into flows. One important point to notice is that the model user has the capability of calibrating the average output flows by fine-tuning some input parameters. This will be described in detail in the chapter dealing with the calibration of Paramics on the I-680 network.

In terms of speeds, it was found that the average speeds predicted by the model generally matched expected values in the lane-drop and ramp-merge examples. However, it was noticed that the speeds were slightly lower than expected at the vicinity of lane-drops and ramp-merges. Some additional investigations were proposed to address this issue and to better match expected speed values, and the later work on I-680 highlighted some further tips and recommendations for the calibration of Paramics (see Chapter 7).

CHAPTER 4: RAMP METERING EXPERIMENT

4.1 Objectives

After the first series of simple freeway tests, and before moving on to the large-scale application of the model, it was thought useful to develop a new experiment focusing on ramp metering since ramp metering was one of the primary focuses for the I-680 research project.

This investigation involved the following tasks:

- Design and code a simple freeway section with a single on-ramp
- Develop a traffic-actuated ramp metering control strategy
- Implement the traffic-actuated control strategy in Paramics
- Test the control strategy and analyze the results

The key component of this investigation was to determine if Paramics could be used to effectively replicate a traffic-responsive ramp metering strategy.

4.2 Design of Experiment

The freeway test section was 6-mile long. It was homogenous, straight, and designed according to Caltrans design standards. The distance from mileposts 0.0 to 1.0 was designated as a warm-up section. The section from milepost 1.0 to 4.0 was the upstream freeway section. Statistics were gathered at every 0.1 miles until the section ended at the node of the ramp. Milepost 4.0 to milepost 5.0 was downstream of the ramp, and statistics were gathered at every 0.1 miles as well. The last section extended from milepost 5.0 to 6.0 and was a warm-down section.

The simulation was run for 120 minutes, allowing the initial 30 minutes for loading the facility and 30 minutes at the end to eliminate any effects from the simulation ending. Statistics are only collected for the middle one-hour period. Hourly flow rates, average speeds, and average lane densities were collected and aggregated over 5-minute intervals using the Analyzer module.

In terms of input traffic demands, a set of simulations was undertaken with each investigation consisting of a single freeway input demand and a single ramp input demand. All vehicles were standard-type passenger vehicles. The design of experiment was adjusted as results were obtained but the initial design of experiment was as follows:

- The initial set of simulation runs was undertaken with an on-ramp input demand of 500 vehicles per hour and with the freeway input demand varying from 5000 to 6500 vehicles per hour in steps of 500 vehicles per hour.

- The second set of simulation runs was undertaken with the freeway input demand of 5500 vehicles per hour and with the on-ramp input demand varying from 250 to 1500 vehicles per hour in steps of 250 vehicles per hour.
- The final sets of simulation runs were designed to determine the combination of freeway and ramp input demands that resulted in maximum flow in the downstream freeway section.

4.3 Development of the Traffic-Actuated Control Strategy

The four primary elements of a local traffic-responsive ramp metering control strategy are:

- the location of the mainline detectors
- the control variable
- the relationship between the control variable and the metering rate
- the ramp control limits.

In order to develop a specific local traffic-responsive ramp metering strategy to be simulated by Paramics, it was necessary to choose particular settings for each of these four elements, which will be described in the following four sections.

Location of the Mainline Detectors

For this experiment, it was decided that a single detector station (one detector in each lane) located 0.1 miles upstream of the on-ramp nose be employed in the control strategy experiment. Each detector would be a presence-type detector with a six-foot detection zone. Each lane detector would provide flow rate, average speed, average density, and average percent occupancy. Roadway hourly flow rate, average speed, average lane density, and average percent lane occupancy would be calculated. It was assumed that the detectors always provide accurate and continuous information.

Control Variable

The principal control variables employed in ramp metering control strategies are hourly flow rates, average speeds, average lane density, average percent lane occupancy, or combinations of these flow characteristics.

In this experiment, it was decided that percent lane occupancy alone be used in the initial local traffic responsive ramp metering control investigations. It was initially suggested that the percent lane occupancy value be calculated as a moving one-minute average.

Relationship Between the Control Variable and the Metering Rate

The metering rate was determined based on the value of the control variable measured at the detectors upstream of the on-ramp. As upstream traffic conditions get heavier, the percent lane occupancy increases, and the need for restricting the entering flow from the on-ramp increases. The percent lane occupancy range extended from 0% (the absence of vehicles) to 100% (vehicle stopped on the detector.)

It was decided that three metering rate regions be defined in the following manner:

- Metering would be implemented at the maximum metering rate if the percent lane occupancy was calculated to be between 0 % and 15 %
- Metering rate would vary inversely with the percent lane occupancy from the maximum metering rate to the minimum metering rate if the percent lane occupancy was calculated to be between 15 % and 25 %
- Metering would be implemented at the minimum metering rate if the percent occupancy was calculated to be greater than 25 %.

Ramp Control Limits

There are a number of ramp control limits placed upon the ramp metering rate in addition to being determined from the percent lane occupancy. These ramp control limits deal with the maximum and minimum ramp metering rates and selected threshold values for engaging ramp control overrides.

Ramp control limits on the ramp metering control strategy were exclusively concerned with the traffic on the on-ramp. Three types of detectors were employed on the on-ramp experiment to provide for the ramp control limits: presence detector, merge detector and queue detector.

The presence detector was located just before the ramp signal and controlled the changing of the ramp signal from red to green. The ramp signal rested on red and was allowed to change to green only when a vehicle was detected on the presence detector.

The merge detector was placed in the merge area and whenever the value of the percent lane occupancy exceeded a threshold value indicating a queue on the on-ramp, the ramp signal was locked in red. When the value of the percent lane occupancy dropped below a threshold value, the signal was unlocked.

The queue detector was placed at the beginning of the ramp and whenever the value of the percent lane occupancy exceeded a threshold value indicating a queue at the beginning of the on-ramp, the metering rate was increased to the maximum metering rate.

When the value of the percent lane occupancy dropped below a threshold value, the queue limit over-ride was released.

The following values were used for the ramp control limits:

- The minimum metering rate for a single lane on-ramp was 180 vehicles per hour (discharge rate of one vehicle every 20 seconds)
- The maximum metering rate for a single lane on-ramp is 900 vehicles per hour (discharge rate of one vehicle every 4 seconds)
- The maximum metering rate for a double lane on-ramp is 1200 vehicles per hour (discharge rate of one vehicle every 3 seconds)
- The threshold percent lane occupancy for the merge and queue detector was set to 30 %

4.4 Simulating and Testing the Control Strategy

The traffic-actuated ramp metering control strategy described earlier can potentially be modeled within Paramics using two different approaches: a ramp metering API, or the plan language for actuated signals.

Ramp Metering API in Programmer

The first approach is the use of an API (Application Programming Interface) in Paramics Programmer, which would have been specifically developed to replicate the desired control strategy. No existing tool was available by the time this study was carried out, and the development of such a tool was outside the scope of this project. It should be noted however, that another PATH research team at the University of California at Irvine has been working in parallel on the development and testing of an API for ramp metering (Ref. 43,47)

As these tools become fully operational, the API approach will have to be revisited for the I-680 application.

Plan Language in Modeller

Another approach could be investigated, as the Paramics Modeller provides a set of features called “Plan Language”, which allows the user to replicate the operation of traffic actuated signals (see Ref. 30, User Guide, Appendix B).

The Paramics plan language has been designed to mimic most of the common commercial signal controllers, so that any signal timings control strategy can potentially be simulated.

Each plan associates a set of loops and an optional set of parameters with one of the phases on a node, and defines a set of modifications that can be made on the detection of any one of trigger events. In general, the inputs to the signal plan are comparisons of measured values with variable parameters or pre-defined fixed threshold values. Depending on the outcome of these comparisons, a number of actions can be taken.

Other Paramics users at Caltrans (District 7 and District 5) had previously simulated ramp metering strategies using the plan language option, and the work reported here benefited from their experience.

Coding the Control Strategy

The ramp metering initial tests reported in this chapter, as well as the subsequent investigations on the I-680 corridor have been carried out using the plan language approach.

Once the network was set up, the mainline, presence and queue detectors were placed as described in paragraph 4.3 and shown in Figure 2. The merge detector was placed on the right-most lane of the freeway, just past the beginning of the merging area (see Figure 2). The key to tying them together in a ramp-metering strategy was placing a signal at the node found at the stopline on the ramp. Selecting the node and clicking the “Modify Junction” button on the Editor interface allowed the signal to be created. Saving after this function was performed created default priorities, phases, and plans files. The default files were then modified to reflect the features of the desired control strategy. These three files are shown in Appendices 1, 2, 3 and are described in the following paragraphs.

The priorities file (Appendix 1) described the timing of the green times in each direction of the signal. First, the node of the signal was identified. Then each phase was defined. In this case, the green time was set to 2 seconds in the direction of the ramp. All movements were barred except from node 44 to node 47, the nodes that defined the ramp. The phase 2 designated the red time seen by the ramp vehicles. It was set to 2 seconds with a maximum of 18 seconds. These extremes of 2 seconds and 18 seconds of red time corresponded to the maximum and minimum metering rates of 900 and 180 vehicles per hour. All movements in this direction were barred because there was no physical lane in this direction. It was merely used to control the red time seen by the ramp vehicles.

The phases files (Appendix 2) designated the plan used in the plan file and identified the signal node, the loops used in the plan, and the phase controlled by the loops. Each detector station had a loop detector in each lane. The phases file called out the detector station and then identified the loop by listing the lane the loop was in. Although not shown, the phases file numbers each loop detector consecutively from the top down. The term “loop2 lane 1” is now called out in the plans file as “1”, and so on for each detector specified in the phases file.

The plans file (Appendix 3) contained the logic controlling the actuated signal. It identified the number of plans available and the number of loops used in that plan. The

logic then followed with basic if-then logic. The first line stated “if (occupied [1])”, meaning if detector “1” is occupied, then proceed with the plan. If it was not occupied, the meter continually displayed red until it was occupied.

Following this first line of code, the next if statement dealt with the merge detector. If the percent occupancy of the merge detector was less than 30%, then the logic continued to check the queue detector. If its percent occupancy was less than 30%, then the logic checked the freeway detectors. As stated before, if their average percent occupancy is less than 15%, then the metering rate was set at the maximum (i.e. 2 seconds of green followed by 2 seconds of red). If their average percent occupancy was greater than 25% then the metering rate was at the minimum (2 seconds green followed by 18 seconds of red). If the average percent occupancy was between these values, the corresponding red time was found as inversely proportional to that percent occupancy.

If the merge detector percent occupancy was greater than 30% then the meter was stuck on red until the occupancy falls below 30%. If the queue detector occupancy was greater than or equal to 30% then the metering rate was set to the maximum, overriding all other controls. This was to ensure the queue on the ramp was dissipated and prevented from spilling onto the surface streets.

In each logic statement, a command was given to “report” the percent occupancy of the freeway detectors, the queue detector, and the merge detector. This was to be use in testing the ramp metering strategy and make sure the correct control values and commands were used.

Testing the Algorithm

Once the network and control logic were coded, test runs were made to determine how the simulation performed.

Using the graphical animation of Paramics, it was possible to display as the simulation was running the freeway ramp merge area with the detectors, the signal timings currently used, as well as the vehicles traveling through the test network.

In addition, the control variables and resulting metering rates computed using the plan language files could be called in the “Reporter” dialog box. Each second during the simulation, this dialog box reported occupancies on the mainline freeway, queue and merge detectors.

Figure 2 shows the ramp metering test network with displays of signal timings, detector occupancies, and vehicle movements.

With these tools in place, it was confirmed that the algorithm worked correctly, increasing the red time as the freeway average percent occupancy increased above 15% and returning to the maximum metering rate when the ramp queue overran the queue detector. The merge detector was also tried successfully.

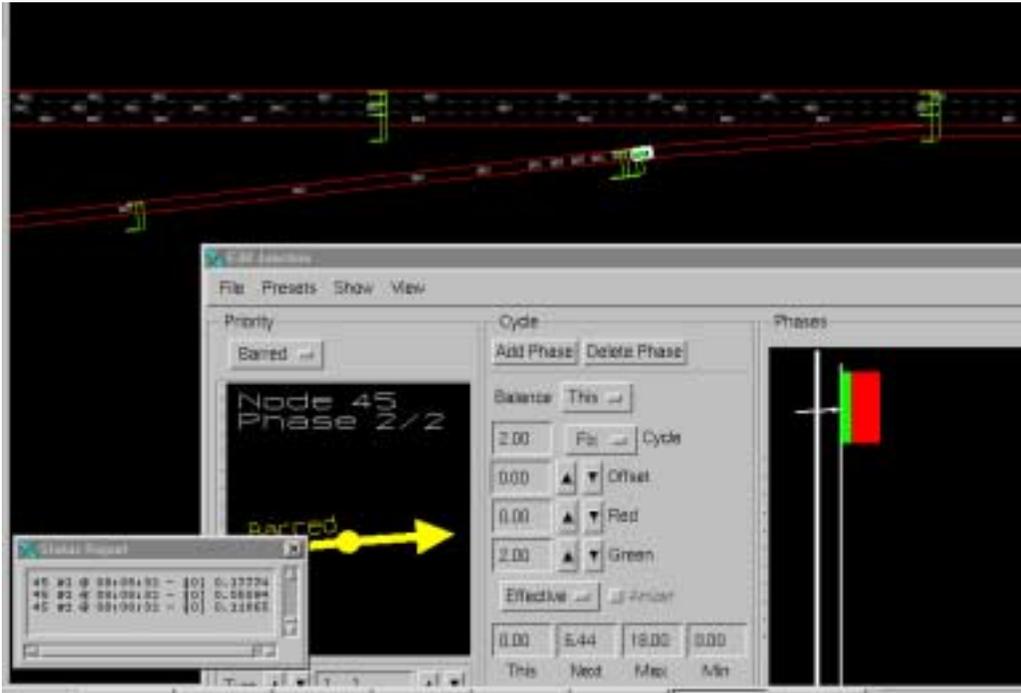


Figure 2: Freeway ramp metering test network

4.5 Test Runs to Determine the Effects of Ramp-Metering

Once the ramp-metering algorithm had been successfully tested, the focus turned to determine what if any benefits were realized due to ramp metering. Five different control strategies were studied and are shown in Table 5.

Control State	Detectors Used in Control			
	Freeway	Presence	Queue	Merge
1	No	No	No	No
2	Yes	Yes	No	No
3	Yes	Yes	Yes	No
4	Yes	Yes	No	Yes
5	Yes	Yes	Yes	Yes

Table 5: Ramp metering control states tested

Control state 1 was no control while state 2 used only the freeway and presence detectors. The queue and merge detectors were used separately along with the freeway and presence detectors in control states 3 and 4. Finally, control state 5 used all of the detectors to control the ramp meter.

Each of these runs was completed and compared to determine which improved the freeway operations. Table 6 below shows the results for each run.

Control State	Flow Entry	Flow Mid	Flow Gore	Flow Ramp	Flow Merge	Flow Exit
1	5997	5807	5838	526	6364	6374
2	5812	5880	5794	456	6250	6249
3	5741	5732	5777	489	6266	6272
4	5917	5827	5736	192	5928	5940
5	5701	5585	5732	506	6238	6243
Control State	Speed Entry	Speed Mid	Speed Gore	Speed Ramp	Speed Merge	Speed Exit
1	48	39	22		39	62
2	48	44	34		44	61
3	40	45	37		44	61
4	49	48	45		46	61
5	35	41	35		45	61

Table 6: Results of runs made with different control states

The flows and speeds were taken at various locations for comparison. The Flow Ramp column represents the flow from the ramp which enters the freeway.

It can be seen that the highest flows occurred during no control (state 1) with 6374 vehicles per hour. This indicates that the freeway downstream of the ramp has a capacity of at least 6374 vehicles per hour. Congestion was found on the freeway because all 500 vehicles entering via the ramp were able to get in.

As control was begun using the presence and freeway detectors (state 2), the flows dropped but speeds improved. This could be due to fewer vehicles entering the freeway from the ramp and thus less congestion.

When the queue detector was included in the controls (state 3), the flows dropped further because almost all of the ramp vehicles were able to enter the freeway. The queue detector did not allow the queue to grow beyond the detector.

When the merge detector controlled the flow of ramp vehicle (state 4), only 192 were able to enter the freeway. The flows were much lower but speeds were higher and much more consistent across the entire freeway.

Finally, when all the detectors were used to control the metering rate (state 5), the flows dropped once again. However, all the ramp vehicles were able to enter the freeway and

the speeds were relatively high. The meter still allowed all the vehicles on but it controlled when they entered. In watching the simulation, it was apparent that the meter controlled the flow of ramp vehicles so that they impacted freeway flow as little as possible.

It was clear that more investigations were needed to truly measure the benefits of ramp-metering on this test section. It appeared that the controls may have been too conservative because the highest flows were found in the no control runs. The metering strategies did not allow the downstream portion of the freeway to ever reach an exit flow as high as in the no-control state. It appeared that control state 5, using all the detectors, provided good results. However, control state 3, using the queue detector to control, gave better speeds and similar flows.

4.6 Conclusions

The main purpose of the ramp metering experiment was to investigate the capability of Paramics to simulate a specific local traffic-responsive control strategy. The Paramics plan language proved to be an efficient and powerful tool in developing and testing ramp-metering strategies. The process of developing, coding and testing the control logic for the simple test network was a very useful experience before starting the investigations on the real-life I-680 corridor.

Most of the difficulties encountered during the course of this initial test were overcome. However, some topics were identified as potential areas for further investigations:

- the presence detectors at the meter stopline were somewhat troublesome, as they would not always detect the vehicles. Increasing the number of time steps per second would help, but not solve the problem. Other options were tried, such as the use of multiple detectors or longer detectors, but none was found to be totally reliable.
- the placement of the merge detector raised a problem, as Paramics would not allow detectors to be located on the ramp link. Instead, the merge detector had to be placed on the mainline freeway, in the shoulder lane just downstream of the ramp nose. Placing the merge detector on the acceleration lane would be likely to provide better control.
- the gap acceptance of the ramp vehicles merging onto the freeway is a critical part of the merging process. It was observed that vehicles would queue in the acceleration lane and often shun gaps in the freeway traffic that appeared acceptable. The queue would grow until a large gap was available and then the ramp vehicles would all merge at once, forcing the mainline vehicles to slow down. Since this test was carried out, a new version of Paramics has been released, which allows ramp drivers to merge with the mainline traffic with a smaller headway and at a much faster rate.
- the placement of the warning sign and its effect on the lane distribution of the mainline traffic were other sources of concern. On the one hand, the warning sign is necessary for the mainline vehicles to attempt to change lanes to create a gap for the ramp vehicles to

merge (and the new version of Paramics allows more flexibility over the specification of this value). On the other hand, vehicles merging left as they pass the warning sign sometimes caused some unexpected congestion on the two left lanes, while the shoulder lane seemed underutilized.

- the aggregation over time of the detector information was probably the most serious issue. Without the use of an API, there is no way to aggregate over time the values collected by the detectors. The percentage lane occupancies used in the traffic-actuated ramp metering algorithm were not averaged over time, but instantaneous values varying with the passage of each individual vehicles. Even though a smoothing factor can be applied, the more desirable option of aggregating the values over time to provide for instance one-minute running averages is not available.

CHAPTER 5: INTERSTATE 680 EXISTING CONDITIONS AND PROPOSED IMPROVEMENTS

5.1 Introduction

The freeway study site consisted of a portion of the southbound I-680 extending from just south of the I-580 freeway near Bernal Avenue to SR 237 a distance of nineteen (19) miles that includes fifteen (15) on-ramps and twelve (12) off-ramps. The study period encompassed the morning peak period and extends from 5:00 to 10:15 AM. A map of the freeway study site is shown in Figure 3.

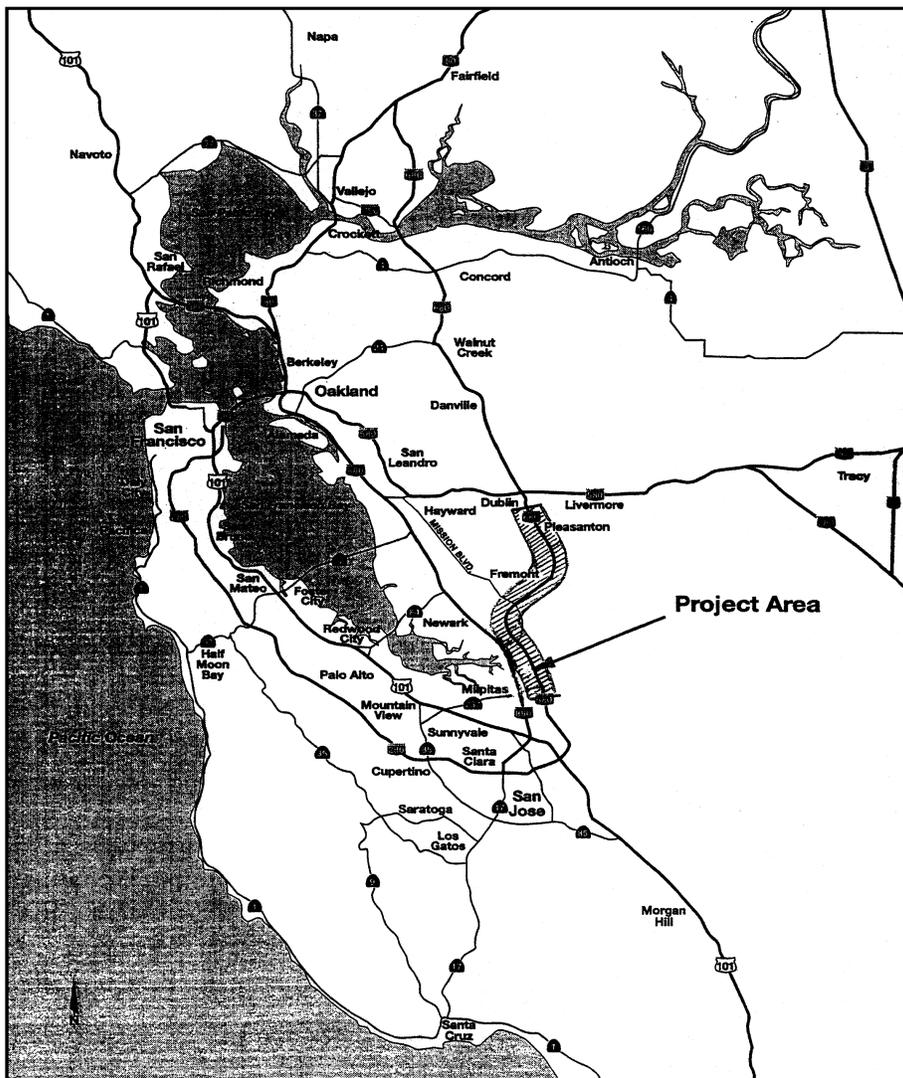


Figure 3: Freeway study site

The study was limited to the freeway only in the southbound direction during the morning peak period because of time and budget constraints. However this was considered adequate as a test for calibration and application of the Paramics model. There were two other factors that narrowed down the site selection to I-680. First, the Caltrans District 04 office expressed interest in applying the model to this particular freeway site, and agreed to support and review the study as it progressed. Further input data was readily available as will be discussed in the next section including a CAD design file, travel time tach runs, and traffic counts.

5.2 Existing Facility

I-680 is one of the primary north-south transportation corridors for local and inter-regional traveling vehicles between Alameda and Santa Clara counties, serving commuter, commercial, and recreational traffic.

In the study area, it traverses through flat, rolling and steep terrain with most grades being moderate to steep.

I-680 between I-580 and Route 237 is a six-lane facility with a few auxiliary lanes and collector-distributor lanes. Figure 4 shows the existing lane configuration along the corridor.

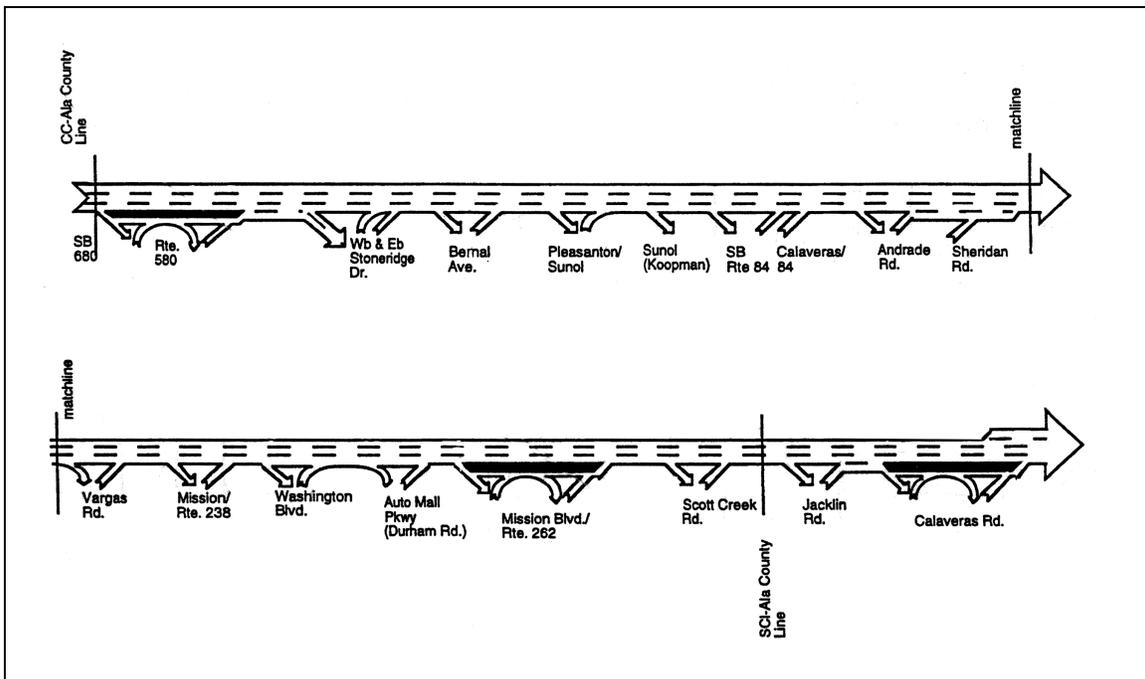


Figure 4: I-680 existing lane configuration

I-680 has a sixty-foot unpaved median between Washington Boulevard and State Route 237, and varies from 22 to 36 feet between I-580 and Washington Boulevard. Most of the median is unpaved and without curbs or shrubs.

The freeway lanes throughout the corridor are twelve feet wide lanes. The left and right shoulders vary in width from eight to twelve feet except between I-580 and Sunol Road where the left shoulder is twenty feet wide.

An auxiliary lane (truck climbing lane) exists along a steep-graded section from south of Andrade Road to south of Sheridan Road. The auxiliary lane is heavily utilized by trucks on this uphill segment.

5.3 Existing Traffic Conditions

Over the past several years a dramatic increase in traffic congestion has occurred during the weekday morning peak commute hours on the southbound I-680

The increased traffic in the corridor is largely due to the strong job market in Silicon Valley coupled with a shortage of affordable housing in that area. Many taking jobs in Southern Alameda County and Santa Clara County live in Southern and Eastern Contra Costa County, Eastern Alameda County and the San Joaquin Valley. The I-680 Corridor is the only major route that links these jobs to homes in the Tri-Valley area and the San Joaquin Valley (Ref. 51).

The resulting heavy congestion threatens the economic well being of businesses in the region for a number of reasons. Some of which include employees not getting to work on time, workers having to waste excessive time and effort commuting to work, and delays of just-in-time freight deliveries to major manufacturing plants in Alameda and Santa Clara counties.

Southbound volumes at the Route 262/Mission Boulevard interchange were approximately 70,000 vehicles per day and 6,500 vehicles per hour during the morning peak hour (Ref. 50). Because of the congestion, the number of vehicles counted on the freeway during the peak hour was substantially lower than the demand. The peak mainline demand was estimated to be 8,600 vehicles per hour.

The HICOMP (Highway Congestion Monitoring Program) report (Ref. 52) issued by Caltrans in 1998 indicates that the morning commute on southbound Route 680 over the Sunol Grade ranks as the worst congestion location in the Bay Area. The daily delay is estimated at 7,240 vehicle-hours. The truck percentage ranges between 7% and 9% of daily traffic volumes.

On a typical weekday morning, the southbound commute starts early. By 5:30 am, heavy on-ramp volumes from Route 84, Andrade Road and Auto Mall Parkway cause occasional slowdowns at these interchanges. By 6:00 am, two mainline bottlenecks develop, one at the section between Route 84 and Andrade Road, and the other at the

section between Route 262/Mission Boulevard and Scott Creek Road. Mainline traffic demands peak between 6:00 and 6:30 am. By 6:30 am, queues from the two bottlenecks have generally merged into one, with congestion extending from Route 262/Mission Boulevard to Sunol Boulevard, a distance of approximately 13 miles. The average speed through the entire length of congestion is approximately 16 mph, and maximum individual delays are as high as 33 minutes. Significant queuing also occurs at several on-ramps, including the ramps from Route 84, Route 262/Mission Boulevard, and Auto Mall Parkway. By around 10:00 am, the queue has largely dissipated; also some minor slowdowns remain near the Route 262/Mission Boulevard interchange.

5.4 Proposed Corridor Improvements

Several agencies have joined to provide a regional approach to the problem: the Alameda County Congestion Management Agency, the Contra Costa Transportation Authority, the Santa Clara Valley Transportation Authority, the Metropolitan Transportation Commission, and Caltrans.

Several studies have been conducted to investigate existing conditions, develop and evaluate project alternatives (Ref. 51,53).

The Phase 1 Major Investment Study describes the short-term project. The recommended alternative is shown in Figure 5 and includes the following features:

- Build an HOV lane between SR 84 and SR 237
- Install ramp metering facilities on all southbound ramps from Stoneridge Drive to Jacklin Road
- Construct southbound auxiliary lanes:
 - From Washington Boulevard to Auto Mall Parkway
 - From Mission/SR 262 to Scott Creek
 - From Scott Creek Road to Jacklin Road

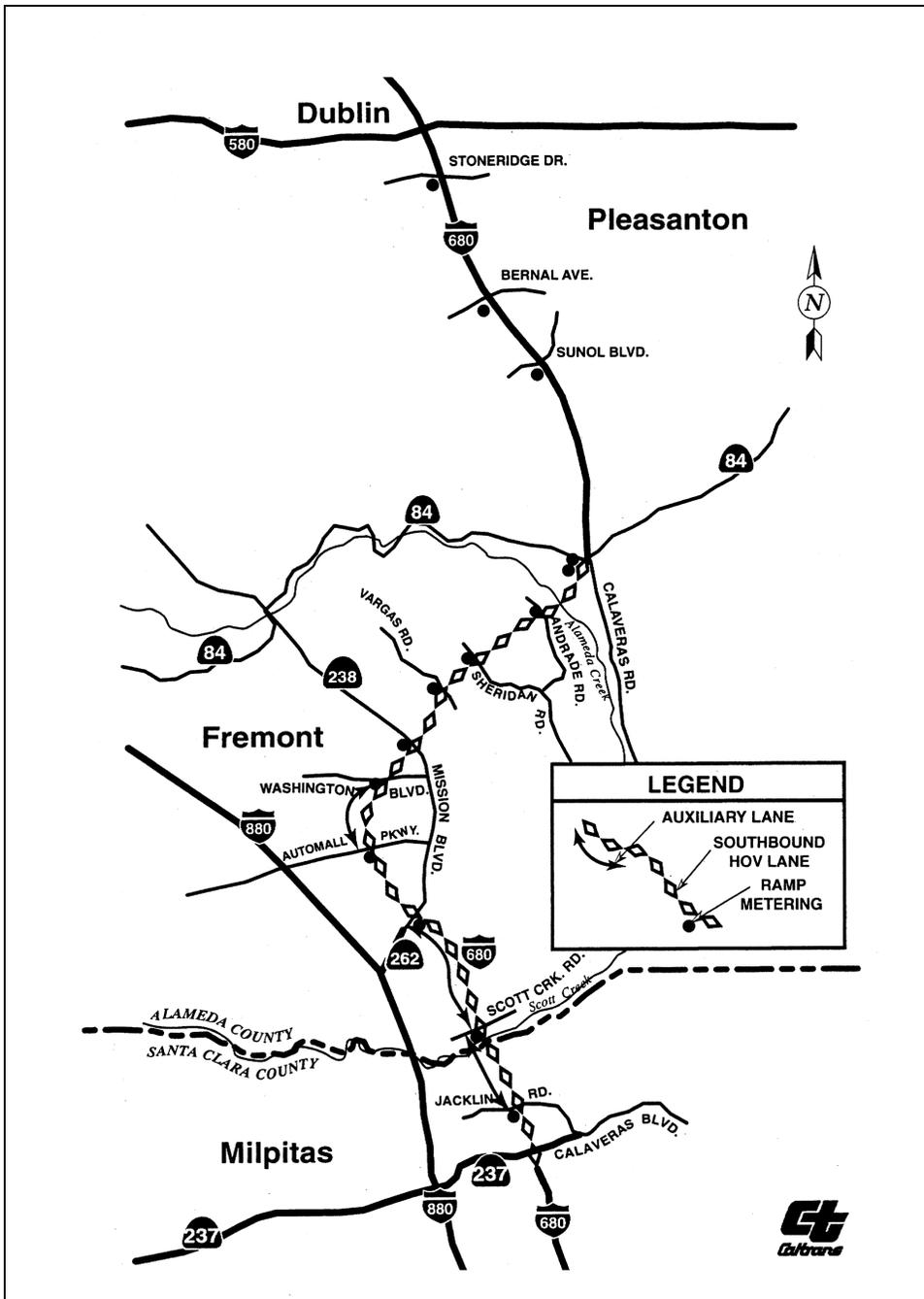


Figure 5: Proposed corridor improvements

CHAPTER 6: ASSEMBLING FREEWAY INPUT AND PERFORMANCE DATA

6.1 Introduction

One of the major demands on using simulation models is the need for a comprehensive quality data set which meets the data input requirements and also a set of traffic performance data that can be used for the critical model calibration. The availability of a comprehensive data set was a major factor in selecting the southbound I-680 freeway since budget constraints did not permit the collecting of such data.

The most important freeway input data requirements for the I-680 application fall into two categories:

- Network geometric design features
- Origin-destination demand tables

The process of collecting and assembling these data for the I-680 application is described in this chapter.

In addition to the input data, some freeway performance information was necessary for the purpose of calibrating the Paramics model. The last section of this chapter describes the data set available.

6.2 Geometric Design Features

Detailed road layout plans can be read directly into Paramics and used as template to build the model road network. This removes the need to measure road geometry manually from plans or site measurements. The latest version of Paramics (version 3.0 build 6) also supports the use of raster images and aerial photographs as overlays for network coding and enhanced visualisation while the simulation is running.

The overlays are used as a template to build the network model. These can be read into Paramics Modeller as an AutoCAD (DXF) file.

For the I-680 network model, the CAD files were provided by Caltrans District 4 under the form of 35 subsection files. These had to be combined in AutoCAD into a single drawing that could later be read by Paramics.

The procedure that was followed is described in details in Appendix B of the Paramics Training Course document from Richard Dowling (Ref. 37).

Once the overlay file is successfully recognized by Paramics and the scale has been correctly adjusted, the network coding process can start. The nodes are created first, making sure that their positions match the overlay. A node must be created when there is a change in curvature, an on-ramp or off-ramp or a lane addition or drop. Links are later

added to connect the nodes, with the appropriate curvature to match the overlay. Any significant grade changes were introduced on a link by link basis.

In the I-680 network, no surface streets were introduced. The zone boundaries were located at the mainline origin and mainline destination, at the beginning on the on-ramps for the origin zones, and at the end of the off-ramps for the destination zones.

An example of interchange coding is provided in Figure 6. All interchanges of the southbound I-680 were coded with a similar level of detail.

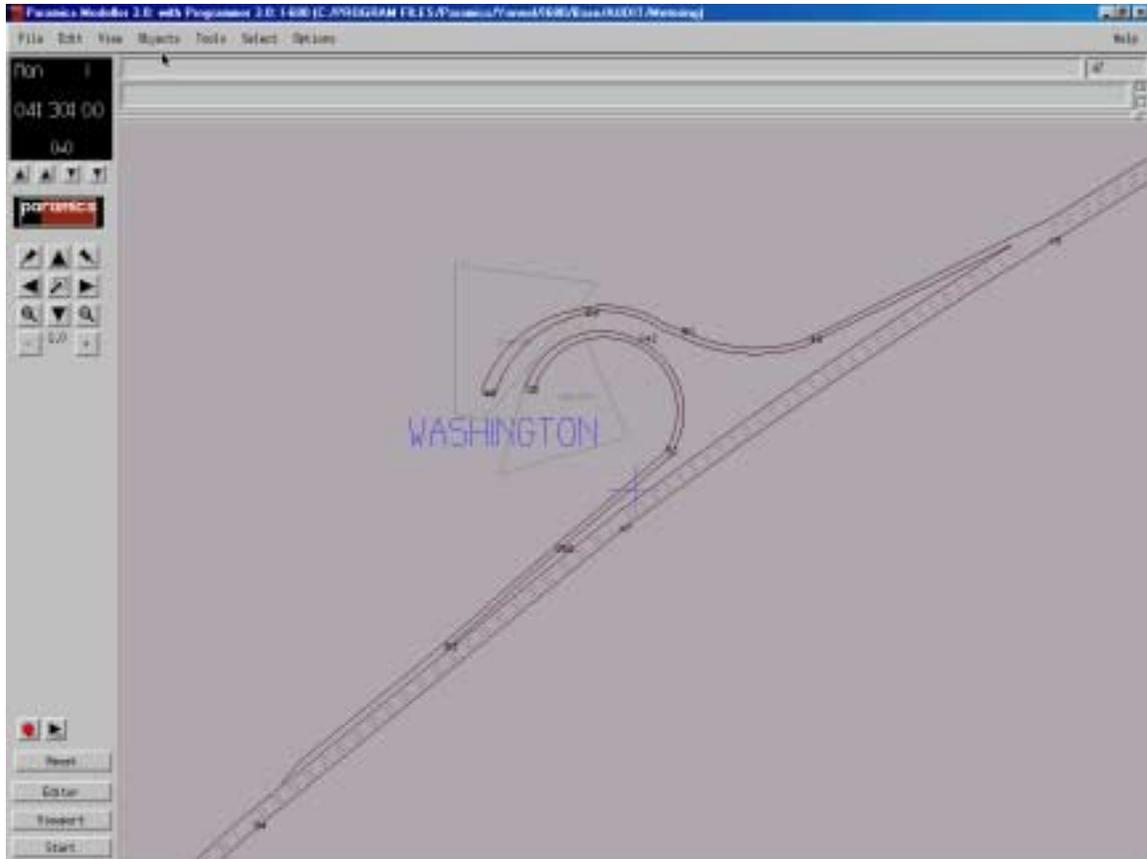


Figure 6: Example of interchange coding

6.3 FREQ Model of I-680 Developed by TJKM

As part of a traffic operation analysis on I-680, TJKM Associates had recently completed a study of the freeway site (Ref. 53). Mainline and ramp counts had been collected over a four-hour morning peak period (from 5:00 to 9:00 am) along the 20 miles of the corridor. These counts had been done simultaneously with the Caltrans tach runs.

The traffic count data set was accompanied by truck and HOV vehicle percentages as well as capacity estimates for each subsection along the freeway study site. This data set was provided to the PATH project team by TJKM in the form of an input data file to the FREQ model.

FREQ Input Data

The necessary demand and supply data to run the FREQ model included the following:

- Lengths, capacities and free-flow speeds for each of the 29 subsections extending from Bernal Avenue to Calaveras Boulevard, a distance of 19 miles.
- 15-minute demands for each entrance and exit. There were 15 freeway entrances (including the mainline entrance) and 13 freeway exits (including the mainline exit). The period extended from 5 am to 9 am and is divided into 16 time intervals of 15 minutes.
- The vehicle occupancy distribution was assumed to be constant over all entrances and was specified as 80%, 15% and 5% respectively for one person, two person, and three or more person vehicles.

FREQ Output Results

A FREQ run was made by the PATH team based upon the input data described above. Some of the more important observations are listed below.

The “Day-1” output, before implementing the HOV added lane, indicated that speeds during the morning peak period over the complete length of the freeway started in the 60 mph range at 5 am and continuously decreased to about 20 mph at 9 am.

The congestion map indicated several bottlenecks and hidden bottlenecks with congestion continuing to increase at 9 am.

Comparisons were made between the FREQ calibrated run output and the tach runs made on March 12, 1997. It was found that the FREQ speeds compared reasonably well with the field-measured speeds. The FREQ speeds were generally slightly higher than field-measured speeds. Both indicated that there is heavy congestion at 9 am, and the field-measured speeds indicated that congestion lasted beyond 10 am.

Generating Origin/Destination Table

The FREQ model has the capability of converting the set of traffic counts into time slice origin-destination tables, which served as an input to the Paramics model.

6.4 Freeway Performance Data

Tach runs from March 1997

The primary available sources of speed and delay information are “floating car” tachography runs conducted by Caltrans on March 12, 1997. This information was of critical importance in the process of calibrating the FREQ model for I-680, and later the Paramics model.

Figure 7 graphically illustrates the results of these tach runs. Fourteen tach runs were made on this day for the southbound morning peak period. Each picture of I-680 on the figure represents an individual travel time run and is annotated with the average speed on each segment during the run. Congested segments are coded to indicate severity: single thin line for speeds over 50 mph, thin double line for speeds between 30 and 50 mph, thick line for speeds below 30 mph.

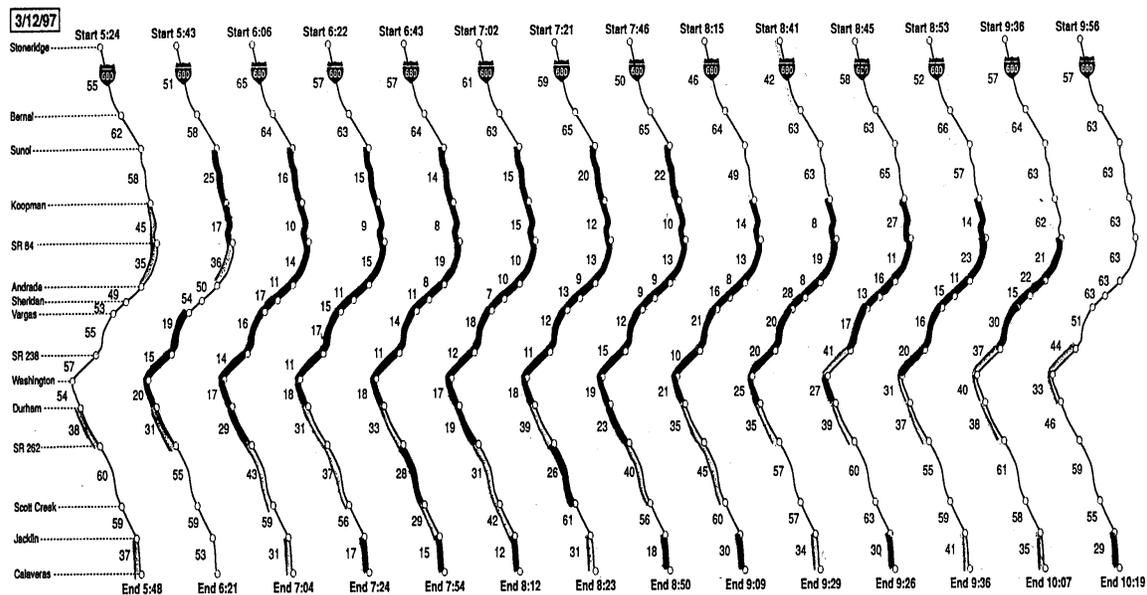


Figure 7: Southbound I-680 tach runs from March 12, 1997

Figure 7 indicates that, according to the March 1997 tach runs, severe congestion can begin before 6:00 am and continue beyond 9:30 am. Travel times from Stoneridge Drive to Calaveras Boulevard (a 20.5-mile segment) increased from 24 minutes for a run starting at 5:24 to a maximum of 70 minutes for runs starting at 6:43 and 7:02. Travel times then decreased back to 22 minutes for a run starting at 9:56 am.

Mainline loop detector data

Another source of freeway performance data was provided by Caltrans District 4 under the form of hourly traffic counts at four mainline locations along the southbound I-680 freeway.

The data was collected automatically over several days of October and November 1999. Table 7 shows for each mainline station, the number of weekdays for which counts were available, and the resulting average hourly volumes.

Location	number days	5-6 am	6-7 am	7-8 am	8-9 am	9-10 am	10-11 am
EB84 off - WB84 on	15	4577	3904	3363	3319	3502	3282
Mission/238 off - on	6	6519	5152	4461	4387	4653	4282
Mission/262 on - Scott Creek off	6	5162	7131	7397	7372	6916	5369
Scott Creek on - Jacklin off	12	3833	5828	6157	6295	5779	4595

Table 7: Average hourly flows (in vehicles per hour) at detector stations

Although this data was obtained at a different time than used in the simulation, this data was useful for the calibration of the Paramics model of I-680, in assessing the capacity of selected links along the freeway.

CHAPTER 7: I-680 MODEL CALIBRATION

7.1 Introduction

This chapter presents the validation and calibration effort carried out as part of the application of Paramics to the I-680 morning peak conditions. After an overview of the Paramics typical calibration procedure, the specifics of the I-680 application are described. The most important calibration parameters are identified and discussed. The calibration process that was used in the I-680 application for fine-tuning each of these key parameters is presented. Qualitative as well as quantitative recommendations for calibration are provided.

7.2 Model Calibration General Procedure

The main objective of the model calibration phase is to realistically replicate the movement of traffic to match existing observed conditions. When running Paramics Modeller, the user can assess the results from a visual or from a numerical point of view.

The visual analysis consists in the observation of the vehicle movements on the screen visualization, in order to check if the traffic is moving in a realistic manner.

The quantitative analysis is carried out in parallel. The user requests output model statistics for comparison to observed data. The assessment can be done at the network-wide level in terms of overall total travel time, total distance traveled, or average speed on the network. In some cases, the analysis must be carried out at the level of a specific intersection, interchange or link (or set of links). Specific statistics such as travel times, traffic flow levels etc. may be output to statistics files.

The Analyzer module allows the user to display and report a large number of statistics for comparisons with observed data. These include traffic flows, queue lengths, delays, speeds, density, travel times.

When the comparison between the simulation and observed (or known) operation is not within recommended guidelines, it is necessary to make some changes in the network, demand or assignment input files. The following issues should be addressed (Ref. 35):

- **Network**

- Check geometry based on the Autocad overlay (move kerb points and stop lines as necessary)

- Check link and intersection description (link gradients, link headway factor, link end speeds, intersection visibility)

- Check hazard warning distance

- Check for barred turns, closures and restrictions

- Check lane usage and behavior of traffic

- **Demand**

- Check the definition of zone areas
- Check level of demand to and from each zone
- Check vehicle proportion for each vehicle type
- Check the proportion breakdown for the demand by time period

- **Assignment**

- Check coefficients used in generalized cost equation
- Check proportion of familiar/unfamiliar drivers
- Check link cost factors
- Check assignment technique

In addition, the user may consider changing some default parameters coded in the **Configuration** file. These include:

- **Time step duration**, which specifies the number of steps of the simulation which are carried out in each second
- **Speed memory**, which specifies the number of time steps during which each vehicle remembers its own speed (affecting driver reaction time)
- **Mean target headway**, which governs the gap acceptance with the vehicle in front. If not constrained by an approaching intersection, a vehicle adjusts its speed so as to attain its target headway.
- **Mean reaction time**: each vehicle's acceleration is based on the speed at which the vehicle in front was traveling at some time in the past

Finally, once the model is properly calibrated, a sensitivity testing can be done by rerunning the simulation with different seed values. Paramics uses the random number generator as a means of getting a reasonable stochastic spread of results, hence different results with different seeds. The random number generator is used in most areas of the simulation model, including car following, vehicle top speed, lane changing, vehicle behavior, ramp merging, etc.

In the process of calibrating the I-680 morning peak conditions, the general calibration procedure described previously was applied, and a number of changes were made in the model input files. The most significant checks and changes that were made fall into four categories: network file, demand file, overall configuration file, and general driver behavior parameters (mean target headway and mean reaction time). Each of these checks and changes will be described in the next four sections.

7.3 Network Checks

Network Geometry

To start the calibration of the network, it is important to first ensure that the physical characteristics of the freeway are accurately represented in the modeled network geometry. The use of a CAD drawing as an overlay map in Paramics proved to be a very efficient and valuable tool in the process of building the network geometry for the I-680 application.

The network geometry is a major factor in the vehicles behavior and it is very important to model it correctly. Once the network is built, it can be checked by following individual vehicles traveling through the network and looking at instantaneous vehicle speeds. When the geometry is not correct, vehicles may be forced to make sharp turns at the beginning or at the end of links, and a drop of vehicle speed would occur. This is due to the vehicle reacting to the geometry of the turn and reducing its speed to make the turn safely. Due to vehicles braking, shockwaves can occur, leading to disruption to the traffic flow and possibly the generation of the vehicles in the nearby origin zone.

In order to avoid the badly aligned nodes and stoplines, it was found advisable to use **default kerb positions** whenever possible (the kerb is the edge of the traveled way). If the nodes are correctly placed and if the radius of curves are appropriate, Paramics will usually draw a good representation of the default kerb points and stoplines. By placing the nodes on the median edge of the freeway and setting the link category to be representative of the freeway (in terms of width), the link categories files will dictate the width of the traveled way and position the kerb points and stoplines accordingly.

Signposting

Signposts (also called hazards in Paramics) are associated with traffic signals, lane additions, lane drops, on-ramps or off-ramps. The idea is that signposting provides the driver with information in advance of the hazard so that they have time to react by changing lanes. The signposting specification in Paramics has two numbers. The first distance represents the location where vehicles will first be made aware of the upcoming hazard and the second distance represents the distance along the link that vehicles can react to the hazard in selecting the appropriate lane.

The default signposting distance is 2461 feet on highway links. It is possible to experience flow breakdown at the start of the signposting distance with all vehicles seeing the hazard at the same time. Extending the mainline signposting values usually helps. By increasing the distances, there is less friction in higher flows as vehicles have a greater distance to change lanes for diverge movements. Higher signposting distances are felt to be more appropriate to US highway operation. For the I-680 application, values of 4461 feet for the signposting distance and 2000 feet for the lane change distance were used.

Link Speeds

Although the vehicle speeds are influenced by the speed limit, it is justifiable to drop the links speed to match an observed average link speed. For example, the speed limit may be 70 mph, however, vehicles may travel at average free flow speeds of 60 mph; in this case, it would be justifiable to consider a link speed of 60 mph. For this reason, the link free-flow speeds of the categories used in the I-680 freeway coding were reset to 60 mph.

The curve speed factor was increased from the default value of 2 to 5 to represent the smooth flowing nature of US freeway traffic in reaction to curves. The larger the factor, the less the impact on the link speed of the curved link.

7.4 Demand Checks

Vehicle Proportions

The combination of vehicle types was changed so as to represent a typical fleet composition on a Californian freeway:

- Single occupancy cars: 70.0%
- Carpools: 15.0%
- Pickups, Vans, SUV's: 8.0%
- Single Unit Trucks: 3.0%
- California Design Vehicle (19.8m): 2.5%
- STAA Trucks (21m): 0.5%
- Unscheduled Buses: 1.0%

The resulting truck percentage is compatible with the proportions observed in the field studies on I-680 conducted by Caltrans in 1997 (Ref. 53).

Vehicle Mean Top Speed

The top speed (mean) of vehicles has been limited to 65 mph. Although the link speed was coded as 60 mph, vehicles tend to exceed the speed limit by about 10% in Paramics, under free flow conditions.

7.5 Overall Simulation Configuration

Time Steps per Seconds

The simulation time steps determine when calculations are carried out during every second of simulation. The default time step is 2 which means that calculation are done

every 0.5 seconds of simulation. If the time step is increased to 4, for example, the calculations will be performed every 0.25 seconds.

A number of the calculations such as vehicle speed and acceleration have some randomization associated with them. Hence the simulation results will differ if different time steps are used.

For the I-680 application, the time steps was increased from 2 to 5 steps per second, based on the fact that high density flows often require more time steps per second to operate in a freer manner.

Speed Memory

In conjunction with the time step change, the speed memory was changed from 3 to 8 time steps. Changing the size of the speed memory (the number of time steps for which a vehicle remembers its speed, with default value of 3) allows the modeling of the same reaction time with smaller time steps.

7.6 Mean Target Headway and Mean Reaction Time

Three basic models are implemented within Paramics to control the movement of individual vehicles in the network: the vehicle following, gap acceptance and lane changing models. These models are strongly influenced by two key user specified parameters: the mean target headway and the mean reaction time. The overall behavior of the model can be changed considerably by increasing or decreasing the mean headway and the mean reaction time.

The default values of 1 second for the mean headway and 1 second for the reaction time have been calibrated against UK traffic conditions. Experience indicates that vehicles on US freeways tend to accept smaller gaps and have lower reaction times than the default values. Therefore, when applying the model to US freeway conditions, it is generally recommended to reduce the target mean headway and/or the mean reaction time.

Earlier Studies

Several research teams had faced the issue of calibrating the mean target headway and mean reaction time when applying Paramics to a US freeway facility.

In a PATH research report published in May 1999, Baher Addulhai et al. from the University of California at Irvine (Ref. 26) reported a calibration effort on the southbound I-405 freeway, part of the California ATMS Testbed in Orange County, California. An empirical procedure was developed to calibrate the mean target headway (H) and the mean reaction time (R). The best results were obtained for H=1.65 seconds and R=0.42 seconds.

In a paper presented at the TRB Meeting in January 2001, Der-Horng Lee et al. from the National University of Singapore (Ref. 44) described another Paramics calibration effort using data from the California ATMS Testbed (I-5 freeway). In this case, a genetic algorithm technique was developed to calibrate the H and R values against loop data. The calibrated values were H=0.615 seconds and R=0.415 seconds.

Discussions with Paramics users at Caltrans showed that other calibration efforts carried out recently led to different combinations of H and R values. Caltrans District 7 (Los Angeles Area) came up with values of H=0.72 seconds and R=0.52 seconds in an application on the I-405 freeway. Caltrans District 4 (San Francisco Bay Area) applied Paramics on the I-80 freeway and found the best results for H=0.68 seconds and R=0.6 seconds.

Figure 8 illustrates the various combinations of calibrated mean headway / mean reaction time reported in earlier studies. The figure shows that no consensus was found among reported studies as to what values should be used when applying Paramics to California freeways.

Calibration of Mean Headway and Mean Reaction Time

The approach used in the I-680 study was an empirical one. The simulation was run with multiple combinations of H and R values, and for each simulation, two key output indicators were computed: the average network speed and the maximum vehicle throughput among the three-lane mainline freeway links.

Figure 9 shows a plot of the results, presenting the maximum flow output and the network average speed for each set of H and R values.

It is interesting to note the very wide range of network performance indicators: the average speeds varied between 23.8 and 55.3 mph; the maximum flows varied between 4700 and 6968 vehicles per hour. This is an indication of how the model is highly sensitive to the values used for these two parameters.

Since the I-680 freeway is heavily congested during the morning peak period, some freeway sections operate at capacity, and therefore the maximum vehicle throughput was expected to be in order of 2200 vehicles per hour per lane. An acceptable range of output maximum flow was identified: between 6200 and 6600 vehicles per hour.

In the floating car studies carried out in 1997, the average network speed on the modeled section over the morning peak period was measured to be 34 mph. An acceptable range of simulated average speeds was identified: between 30 and 40 mph.

On Figure 9, it was possible to draw contour lines representing points with similar speeds or maximum flows. Contour lines are shown for speeds of 30, 40 and 50 mph, and for maximum flows of 6200 and 6600 vehicles per hour.

Based on the target speed and capacity values, it was possible to identify a range of combinations of target headway and reaction time values that would give acceptable results for both criteria. It is the area highlighted on Figure 9, located between the 40 mph contour and the 6200 vehicles per hour contour. One particular combination within this area was chosen for further analysis and validation: a mean target headway of one second and a mean reaction time of 0.6 seconds.

7.7 Summary of Calibration

In summary, the calibration process carried out for the I-680 application involved checks and changes in the following input parameters:

- Network geometry (position of nodes and kerbs)
- Signposting
- Link speeds
- Vehicle types
- Vehicle mean top speed
- Number of simulation timesteps per second
- Speed memory
- Mean target headway
- Mean reaction time

The resulting base run is analyzed in details in the next chapter.

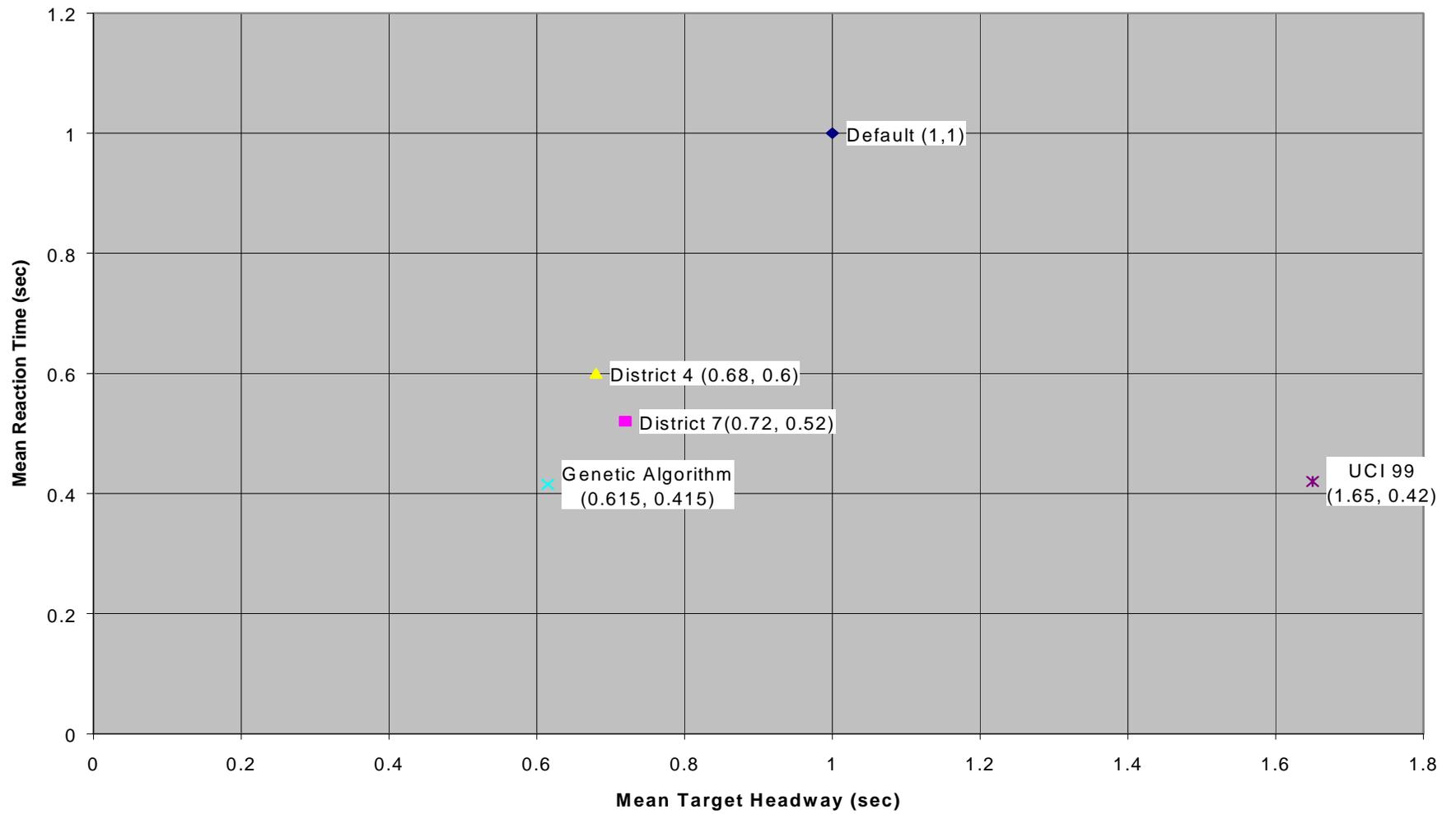


Figure 8: Range of reported (H, R) values

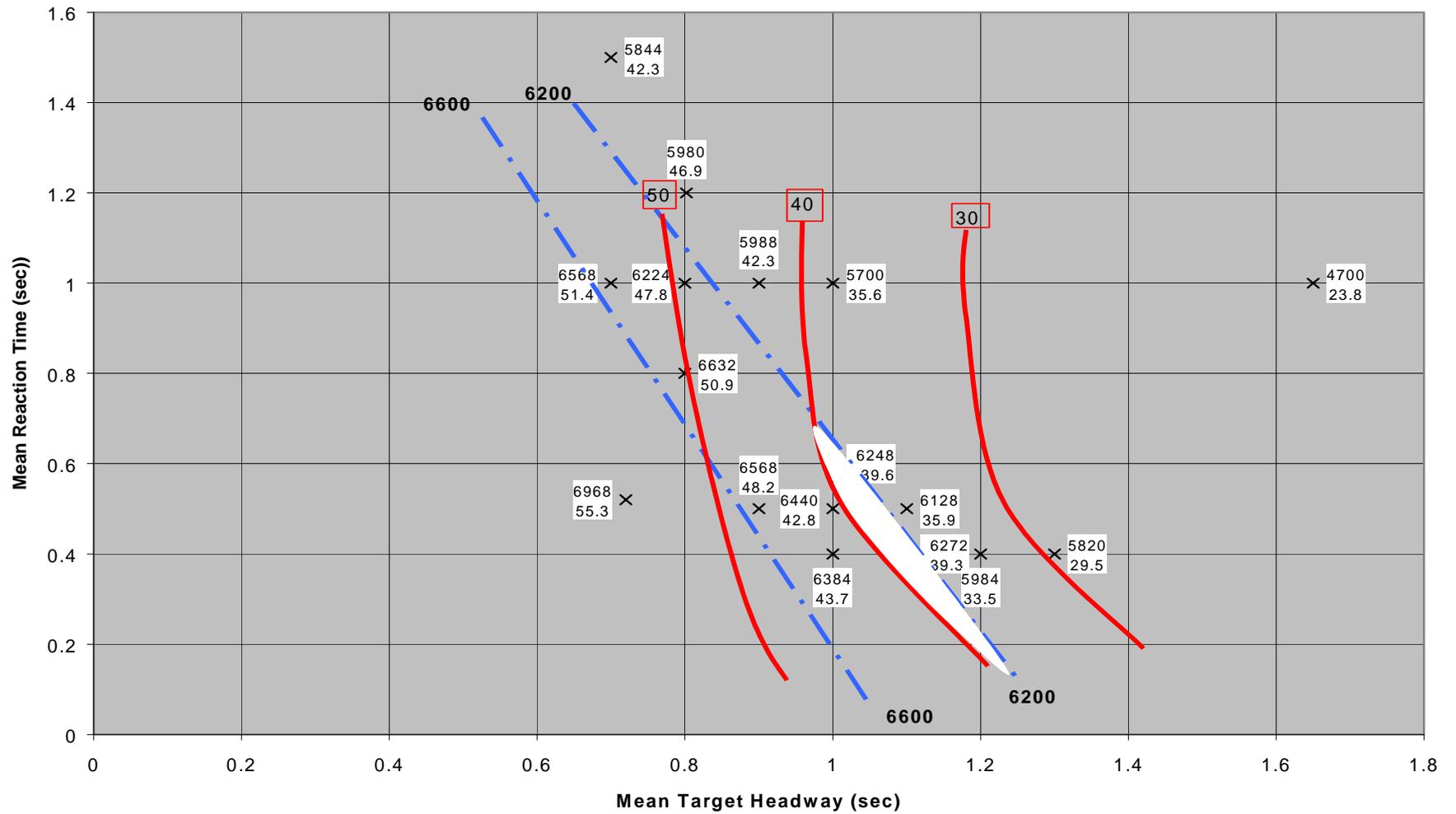


Figure 9: Analysis of output maximum flows and average speeds

CHAPTER 8: VALIDATION OF THE I-680 BASE CONDITIONS

8.1 Introduction

In order to check the validity of the modeled base conditions for the I-680 network, a number of checks and analysis were carried out. Some of these analyses were mostly qualitative. In addition, when field data was available, some quantitative comparisons of modeled versus observed data were also made.

The base simulation run was first studied at the macroscopic network-wide level: statistics such as average network speed or total travel time were computed, and the relationships between speeds, flows and densities were analyzed.

Further analysis consisted in presenting the speeds and flows predicted by the model in a time-space diagram, with average values aggregated over 15-minute time periods for each of the 29 freeway mainline subsection. Statistical comparisons of predicted speeds versus measured speeds were made. The flow table derived from Paramics was also compared to the one derived from the earlier FREQ simulation.

Finally, the flows predicted by Paramics were compared to the flows collected by the detector stations.

8.2 Overall Network-Wide Statistics

The “general” output file from Paramics Modeller contains information about the performance of the network. The information is generated for each minute of simulation, and can be presented in two ways:

- **“current vehicles”**: relating to vehicles that are being simulated at the instant of the time stamp
- **“all vehicles”**: relating to all vehicles (all trips) released since the simulation began, including those that have not yet reached their destination (the current vehicles)

The Paramics Excel Wizard was used to process the "general" statistics file.

Examples of results are presented in Figures 10 and 11.

In Figure 10, the Current Mean Speed is plotted over time. It shows, for each minute of simulation, the average speed of all vehicles currently between origin and destination, including those that are stopped, in miles per hour. According to this chart, southbound I-

680 was highly congested between 6 am and 9:30 am, with average network speeds below 30 mph. Before 5:30 am and after 10 am, the freeway was operating under free-flow conditions, with average speeds above 55 miles per hour. This network performance pattern was similar to what was expected based on the real-life traffic conditions described under the Chapter 6 of this report.

Figure 11 is an example of cumulative performance indicator (for all vehicles). On this chart, the total travel time for all vehicles is plotted over time. It includes the vehicles currently traveling and those that have already finished their trip. At the end of the simulation (10:15 am) the total travel time was found to be 21,714 vehicle hours. This is a good indicator of the freeway overall performance over the entire simulation period, allowing for comparisons between different scenarios.

8.3 Macroscopic Relationships between Speeds, Flows and Densities

The Analyzer module of Paramics allows the user to compute average speeds and average flows on a link-by-link basis for a given time period. This feature was used to compute all the 15-minute speeds and flows predicted by the model for each freeway mainline link with three lanes. The densities could be derived from speed and flow data.

Based on this information, it was possible to draw the curves representing the relationships between flows, speeds and densities. These curves are shown in Figures 12, 13 and 14.

The speed-flow curve derived from the Paramics run is shown in Figure 12. The general shape of the curve was considered acceptable, as it matches observed data on similar US freeway facilities. The top part of the curve with freeway sections operating at 60 miles per hour under non-congested conditions is appropriate. The bottom part of the curve, with a high concentration of points around 20 miles per hour is typical of congested conditions. The capacity value (highest flow) of 6256 vehicles per hour for a three-lane freeway falls within the range of expected values.

The flow-density curve is shown on Figure 13. As expected, densities grow linearly with flows under non-congested traffic conditions. With higher flows, the range of densities spreads out between 40 and 120 vehicles per mile per lane. This type of curve is typical of a congested freeway facility.

Figure 14 presents the speed-density curve. Once again, the general shape of the curve, as well as the numerical values are fairly close to what would be expected for this type of freeway section. The scatter of points generally follows what might be expected based on the HCM 2000 (Ref. 54). Three points pretty well define the HCM upper 60mph curve:

- Speed of 60 mph at zero flow and zero density
- Speed of 60 mph at about 60-70 percent of capacity and about 20-25 vpmpl
- Speed of 52-54 mph at capacity and density of about 35-40 vpmpl

It can be seen on Figure 14 that the curve derived from the simulation follow this pattern.

8.4 Speed Analysis

As described in Section 6.4 of this report, tach runs had been made by Caltrans on southbound I-680 in March 1997. This information was used to compare the freeway performance predicted by the model against real-life traffic conditions.

On the basis of the fourteen tach runs, a speed contour map was developed, and the resulting diagram is shown on the upper part of Figure 15. Each cell of the time – space diagram represents the average speed over a 15-minute time period for a specific mainline freeway subsection. The freeway subsection numbering system that was used is indicated in Table 8.

Minimum, average and maximum speeds are computed over time (row summary) and over space (column summary). Three levels of speed are represented by different levels of shading: below 35 mph, between 35 and 50 mph, and over 50 mph. The resulting speed contour map in Figure 15 provides an effective tool to visualize the level of performance of the freeway, to identify the location of the bottlenecks and the extent of congestion conditions.

The bottom part of Figure 15 shows the speed contour map derived from the simulation, based on the calibrated run scenario. The speed data was obtained using the Analyzer module of Paramics, which produced link by link speed report over 15-minute periods. In most cases, a freeway subsection used in the time-space diagram included several links in the Paramics network, so the link by link information had to be aggregated to produce “subsection” data for each of the 29 subsections.

Once both speed contour maps were available, comparisons could be made either qualitatively or quantitatively. A direct comparison of the two tables shows that the general pattern of the speed diagrams is similar.

The overall average speed was found to be 39 mph in the simulation and 34 mph in the tach runs, which can be considered as a good match.

Statistical Tests

Numerical comparisons of the two speed tables were carried out using two statistical tests: the GEH and the Chi-square tests. Figure 16 presents the results of the statistical comparisons.

In the GEH test, the comparison criteria is derived from the following formula:

$$GEH = \sqrt{\frac{(S_t - S_p)^2}{(S_t + S_p)/2}} \quad \text{where } S_t \text{ is the target speed and } S_p \text{ is the predicted speed.}$$

GEH values below 5 are considered good, while values between 5 and 10 are considered acceptable. Values over 10 would be rejected as unacceptable. In our comparison, most of the GEH values were found to be in the 0 to 5 range, as shown on the upper part of Figure 16.

The Chi-square test was also used to compare the two speed tables. In this case, the comparison is criteria is given by the following equation:

$$X^2 = \frac{(S_p - S_t)^2}{S_t} \quad \text{where } S_t \text{ is the target speed and } S_p \text{ is the predicted speed.}$$

The bottom part of Figure 16 presents the results of the Chi-square comparison. The shaded cells correspond to values exceeding 10.

8.5 Flow Analysis

Flow Contour Maps

As explained in Section 6.3, the FREQ simulation had been developed based on the same input data that was later used for the Paramics simulation. The FREQ simulation had been successfully calibrated under the 1997 traffic conditions. Since the Paramics simulation output is to be validated using the same traffic performance dataset, it is interesting to compare the flow output information as predicted by the two simulation models.

Figure 17 shows two time-space diagrams representing average flows over 15 minutes in the FREQ simulation output (upper part) and in the Paramics simulation (bottom part).

The three levels of shading correspond respectively to flows over 5500 vehicles per hour (dark shade), between 4500 and 5500 (light shade) and below 4500 (no shade).

A general comparison of the two diagrams indicates that the pattern is similar, which means that the two models tend to predict similar flows. This also suggests that the bottleneck location and the extent of congestion conditions are similar in the two models.

Loop Data

In order to complement the flow output analysis, a set of traffic counts from detector stations located on the mainline freeway study section was used. As explained under section 6.4, Caltrans District 4 could provide hourly counts collected at four mainline stations in October and November 1999.

Even though the Paramics model had been calibrated for 1997 traffic conditions, it was interesting to compare the simulation output against the 1999 loop detector data. The four charts presented on Figure 18 show the comparison between hourly flows predicted by Paramics and collected in the field.

In general, the results appear to be consistent. On average, the flows are lower in subsections 6 and 16 because of the congestion effects. At the peak of congestion (between 7 and 8 am), the flows are at the lowest. On the other hand, subsections 23 and 25 can operate under free-flowing conditions and therefore can serve more vehicles. The highest flows are found between 7 and 9 am, when the demand reached its peak. These results are observed with the loops and are reflected by the model.

Another observation is that the model consistently predicted flows lower than the loop data. This can be partly explained by the fact that the demand side of the simulation was derived from information from 1997. As the demand is likely to have increased slightly between 1997 and the end of 1999, higher volumes in the loop information collected in 1999 were expected.

8.6 Conclusions

The Paramics model for the I-680 base traffic conditions was validated in a three-step process.

First, a macroscopic analysis of the model output was carried out, using aggregated network-wide indicators and charts representing the relationships between speeds, flows and densities.

Secondly, a speed analysis was performed to compare the simulation results with the data from the tach runs.

Finally, the flow output information was studied and compared with loop data and the results of the earlier FREQ simulation.

The model was found to perform well when compared to common expert knowledge, measured data or other simulation results. Based on these findings, it was possible to move forward and apply the model to various alternative scenarios.

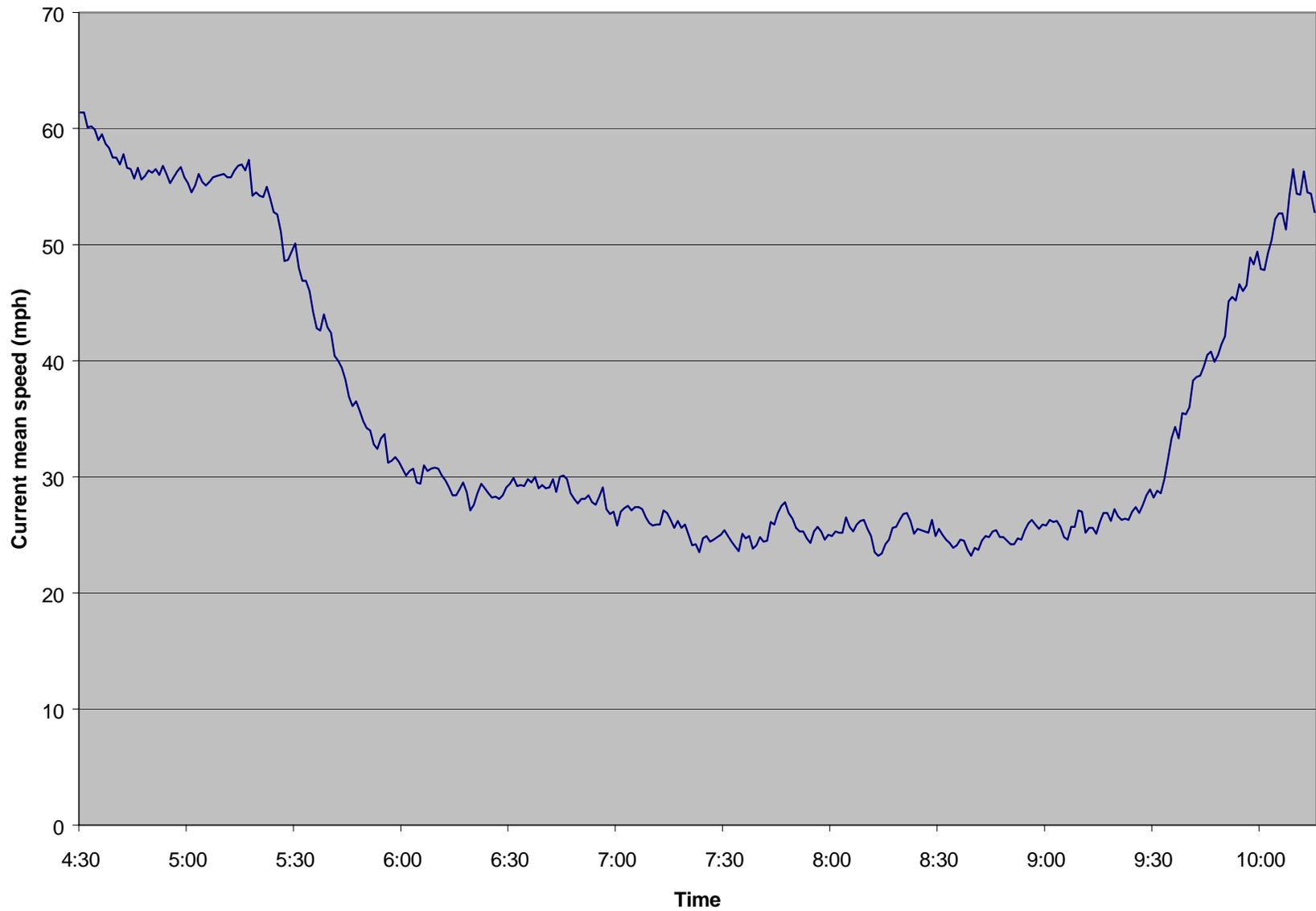


Figure 10: Current mean speed

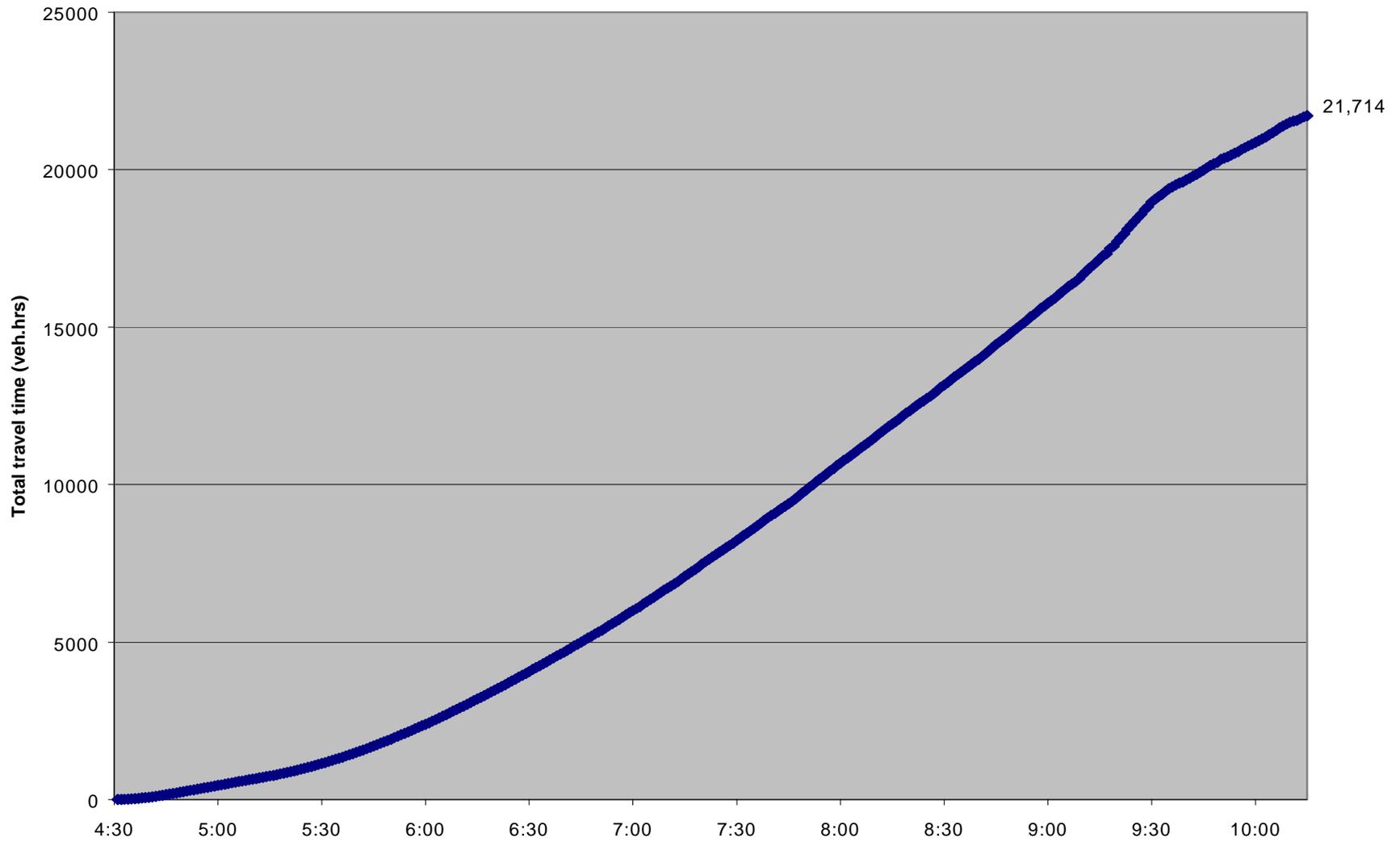


Figure 11: Total travel time

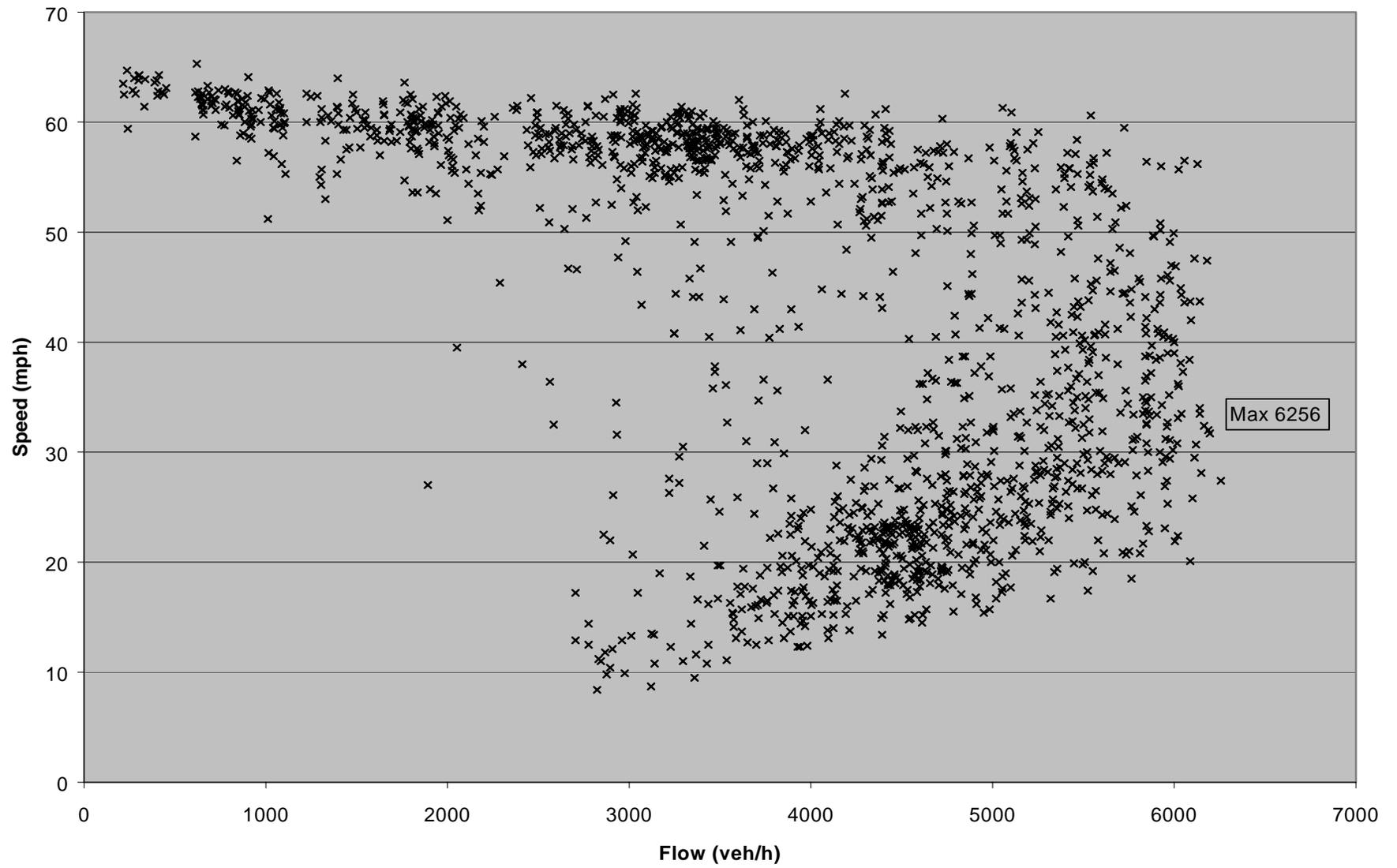


Figure 12: Speed-flow curve

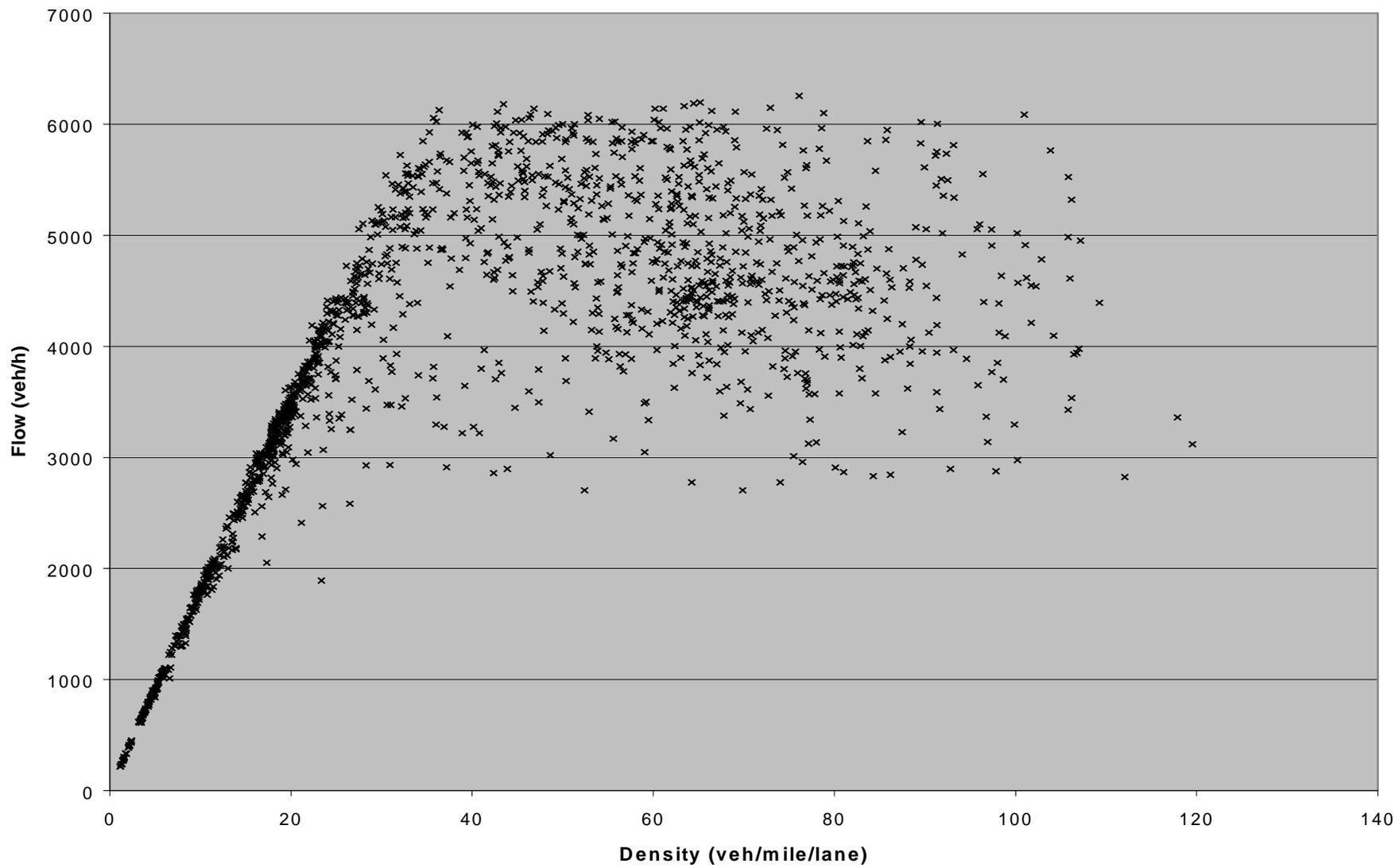


Figure 13: Flow-density curve

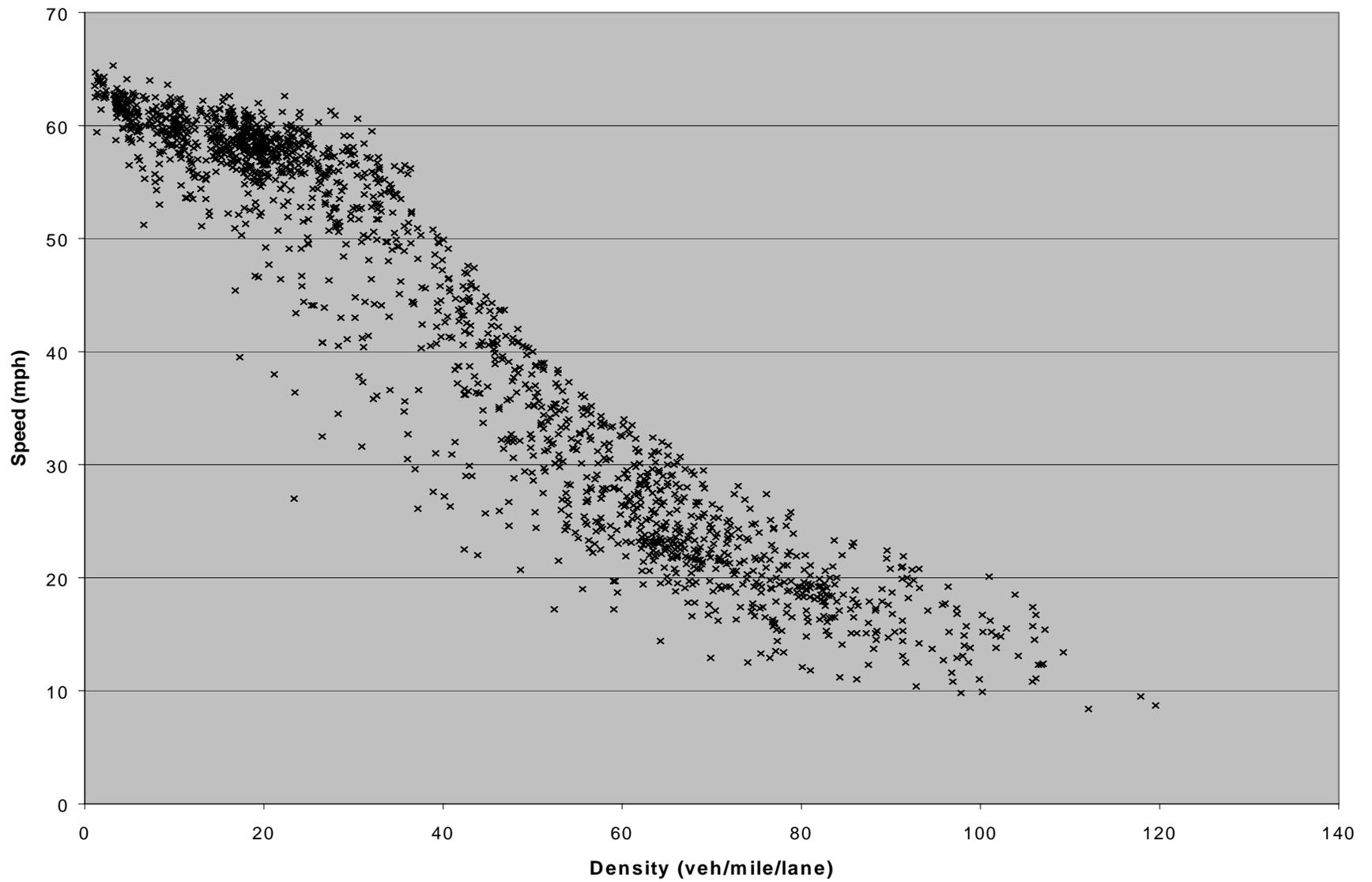


Figure 14: Speed-density curve

Subsection	From	To
1	Mainline origin	Bernal On
2	Bernal On	Sunol Off
3	Sunol Off	Sunol On
4	Sunol On	Kopmann Off
5	Kopmann Off	RT84EB/NILEWB Off
6	RT84EB/NILEWB Off	RT84WB On
7	RT84WB On	NileEB On
8	NileEB On	Lane Drop
9	Lane Drop	Andrade Off
10	Andrade Off	Andrade On
11	Andrade On	Sheridan On
12	Sheridan On	Lane Change (4-3)
13	Lane Change (4-3)	Vargas Off
14	Vargas Off	Vargas On
15	Vargas On	Mission(N) Off
16	Mission(N) Off	Mission(N) On
17	Mission(N) On	Washington Off
18	Washington Off	Washington On
19	Washington On	Auto Mall Off
20	Auto Mall Off	Auto Mall On
21	Auto Mall On	Mission(S) Off
22	Mission(S) Off	Mission(S) On
23	Mission(S) On	Scott Creek Off
24	Scott Creek Off	Scott Creek On
25	Scott Creek On	Jacklin Off
26	Jacklin Off	Jacklin On
27	Jacklin On	Calaveras Off
28	Calaveras Off	Calaveras On
29	Calaveras On	Mainline destination

Table 8: Freeway subsection numbering system

TACH RUNS SPEED CONTOUR MAP																																			
		Section number																																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Row Summary				
Time slice end																														Time	Min	Avg	Max		
5:15																														5:15					
5:30	55	62	62	58	58	45	45	35	35																							5:30	35	50	62
5:45	51	60	60	56	56	45	45	35	35	49	49	53	53	55	55	57	57	54	54	38	38	60	60	59	59	59	37	37	37	5:45	35	51	60		
6:00	51	58	58	25	25	17	17	36	36	50	50	54	54	19	19	15	15	37	37	35	35	52	52	59	59	59	42	42	42	6:00	15	39	59		
6:15	65	64	64	16	16	13	13	25	25	30	30	35	35	19	19	15	15	20	20	31	31	55	55	59	59	59	48	48	48	6:15	13	34	64		
6:30	57	63	63	16	16	10	10	14	14	11	11	17	17	18	18	15	15	18	18	30	30	51	51	59	59	59	53	53	53	6:30	10	30	63		
6:45	57	63	63	15	15	9	9	15	15	11	11	17	17	16	16	14	14	17	17	29	29	47	47	59	59	59	42	42	42	6:45	9	28	63		
7:00	57	64	64	15	15	8	8	15	15	10	10	15	15	17	17	11	11	18	18	29	29	43	43	59	59	59	31	31	31	7:00	8	27	64		
7:15	61	63	63	14	14	8	8	19	19	8	8	11	11	14	14	11	11	18	18	31	31	37	37	56	56	56	17	17	17	7:15	8	25	63		
7:30	59	63	63	15	15	15	15	10	10	10	10	7	7	18	18	11	11	18	18	33	33	33	33	56	56	56	17	17	17	7:30	7	25	63		
7:45	50	65	65	20	20	12	12	13	13	9	9	7	7	18	18	12	12	17	17	33	33	28	28	29	29	29	15	15	15	7:45	7	22	65		
8:00	50	65	65	22	22	10	10	13	13	9	9	13	13	12	12	11	11	17	17	19	19	31	31	42	42	42	15	15	15	8:00	9	22	65		
8:15	46	64	64	22	22	10	10	13	13	9	9	9	9	12	12	13	13	18	18	39	39	26	26	42	42	42	12	12	12	8:15	9	23	64		
8:30	42	64	64	49	49	14	14	13	13	9	9	12	12	12	12	15	15	19	19	23	23	33	33	61	61	61	31	31	31	8:30	9	29	64		
8:45	58	63	63	56	56	14	14	13	13	8	8	16	16	21	21	10	10	21	21	23	23	40	40	56	56	56	18	18	18	8:45	8	29	63		
9:00	55	59	59	64	64	18	18	15	15	12	12	20	20	21	21	10	10	21	21	35	35	45	45	60	60	60	24	24	24	9:00	10	32	64		
9:15	56	58	58	60	60	22	22	17	17	13	13	14	14	17	17	32	32	26	26	34	34	53	53	60	60	60	30	30	30	9:15	13	35	60		
9:30	57	56	56	60	60	42	42	19	19	17	17	14	14	16	16	30	30	29	29	35	35	53	53	60	60	60	32	32	32	9:30	14	37	60		
9:45	57	64	64	63	63	62	62	21	21	22	22	15	15	23	23	34	34	35	35	36	36	57	57	61	61	61	35	35	35	9:45	15	41	64		
10:00	57	63	63	63	63	62	62	42	42	22	22	15	15	30	30	37	37	40	40	38	38	61	61	58	58	58	35	35	35	10:00	15	44	63		
10:15	57	63	63	63	63	63	63	63	63	63	63	63	63	51	51	44	44	33	33	46	46	59	59	55	55	55	29	29	29	10:15	29	54	63		
Column Summary																														Overall Row Summary					
Min	42	56	56	14	14	8	8	10	10	8	8	7	7	12	12	10	10	17	17	19	19	26	26	29	29	29	12	12	12	Min	7	22	59		
Avg	55	62	62	39	39	25	25	22	22	20	20	21	21	21	21	25	25	32	32	32	32	45	45	55	55	55	30	30	30	Avg	14	34	63		
Max	65	65	65	64	64	63	63	63	63	63	63	63	63	63	63	55	55	57	57	54	54	46	46	61	61	61	61	61	61	Max	35	54	65		

PARAMICS BASE RUN SPEED CONTOUR MAP																																	
		Section number																															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Row Summary		
Time slice end																														Time	Min	Avg	Max
5:15																														5:15			
5:30	60	59	58	57	56	59	59	54	52	56	55	55	48	56	52	59	57	56	55	61	50	62	60	60	59	58	61	58	60	5:30	48	57	62
5:45	57	55	52	50	51	53	41	33	45	54	53	58	40	55	53	58	56	56	55	61	50	61	60	61	60	59	61	59	61	5:45	33	54	61
6:00	58	54	56	42	26	33	22	21	39	51	44	46	34	53	48	57	51	47	52	36	31	60	59	60	59	57	59	58	61	6:00	21	47	61
6:15	59	57	50	27	25	20	19	21	28	37	38	36	25	52	42	40	27	27	31	22	30	61	58	60	58	58	61	58	61	6:15	19	41	61
6:30	60	59	58	27	22	19	17	20	30	35	25	17	20	20	19	21	25	33	34	24	32	60	57	60	57	56	59	57	62	6:30	17	37	62
6:45	60	57	57	29	15	10	12	15	27	36	29	16	22	25	29	29	24	23	24	19	33	58	55	59	56	55	58	54	61	6:45	10	36	61
7:00	60	58	58	36	19	16	17	17	33	34	19	11	20	28	24	20	18	23	30	23	35	56	49	59	54	49	53	45	61	7:00	11	35	61
7:15	60	59	58	49	24	14	13	15	24	28	20	11	22	18	22	26	26	25	22	38	50	40	54	40	47	43	36	61	7:15	11	33	61	
7:30	61	59	58	58	46	17	13	17	26	27	16	11	18	24	21	21	22	23	26	24	37	38	32	32	39	49	35	33	61	7:30	11	32	61
7:45	60	59	58	57	53	21	14	16	26	25	13	10	18	25	21	15	16	16	23	24	35	38	27	32	45	43	28	33	61	7:45	10	31	61
8:00	61	59	58	57	57	36	11	13	18	16	12	10	17	22	27	28	19	18	24	22	27	35	38	39	34	37	33	34	61	8:00	9	32	61
8:15	61	60	59	57	56	30	14	15	23	22	13	9	17	19	23	23	23	25	24	20	31	34	35	35	32	38	29	33	61	8:15	9	32	61
8:30	61	59	58	57	57	21	12	16	28	27	16	10	21	19	22	22	21	21	23	23	31	30	33	34	28	35	29	34	61	8:30	10	31	61
8:45	60	59	58	57	51	21	14	17	22	21	13	12	20	27	26	25	20	15	23	21	28	31	37	31	31	41	29	33	61	8:45	8	30	61
9:00	60	59	58	56	36	17	14	13	20	20	12	8	16	16	17	16	18	17	25	23	34	37	37	36	34	43	28	33	61	9:00	11	31	61
9:15	60	59	58	57	33	11	11	13	15	16	12	11	18	22	24	23	21	26	31	22	31	32	34	41	39	43	30	34	61	9:15	9	32	61
9:30	61	61	59	58	39	13	14	15	22	23	17	9	19	19	19	18	21	21	27	25	31	35	36	54	39	43	30	33	61	9:30	9	31	61
9:45	62	61	60	59	58	51	24	22	27	33	15	11	21	21	16	16	20	24	33	27	35	44	34	31	36	42	28	34	61	9:45	11	35	62

GEH SPEED COMPARISON																																	
Time slice end	Section number			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Time	Row	Sum	
	1	2	3																											Time	Total	Avg	
5:15																															5:15		
5:30	0	1	1	1	1	1	1	0	2																						5:30	8	1
5:45	1	1	1	2	5	2	4	3	1	0	1	1	3	0	1	0	1	1	0	0	1	0	0	0	0	0	3	3	3	5:45	38	1	
6:00	1	0	1	0	0	1	0	3	1	2	2	3	5	6	4	5	3	2	1	2	1	1	1	0	0	0	3	2	3	6:00	52	2	
6:15	1	1	1	2	1	1	1	1	1	1	1	4	3	0	0	1	2	3	3	1	0	1	0	0	0	0	1	1	2	6:15	36	1	
6:30	0	1	1	3	0	0	1	0	3	5	4	0	1	2	2	3	2	1	1	2	0	1	1	0	0	1	1	0	1	6:30	38	1	
6:45	0	1	1	4	1	2	2	1	4	5	2	1	1	2	2	1	1	1	3	1	1	1	0	0	1	1	2	0	3	6:45	45	2	
7:00	0	1	1	6	2	2	1	0	2	4	3	1	2	0	1	3	3	2	2	1	2	1	1	1	3	2	2	1	4	7:00	53	2	
7:15	0	1	1	7	6	3	2	0	1	4	2	0	2	2	2	2	3	1	2	1	1	0	1	4	3	1	4	3	7	7:15	65	2	
7:30	0	1	1	7	7	1	0	2	4	4	1	1	3	1	1	1	1	0	1	2	0	1	1	4	2	2	2	3	7	7:30	61	2	
7:45	1	1	1	6	6	5	0	0	1	2	1	1	3	1	2	4	2	0	2	2	1	1	2	2	1	1	4	4	7	7:45	63	2	
8:00	1	1	1	6	5	4	1	1	2	3	1	1	1	2	3	3	3	2	2	0	2	1	1	1	2	1	3	4	7	8:00	64	2	
8:15	2	1	1	6	6	3	1	1	3	4	2	0	3	2	2	2	2	1	1	3	1	1	1	2	1	4	5	8	8:15	69	2		
8:30	3	1	1	1	0	2	0	1	2	3	1	0	2	3	3	2	1	1	1	0	1	0	1	4	4	3	0	0	4	8:30	48	2	
8:45	0	1	1	0	3	1	0	0	2	3	1	2	0	1	1	2	2	1	1	0	2	0	1	3	3	2	2	3	7	8:45	45	2	
9:00	1	0	0	1	4	2	2	1	0	1	0	2	1	1	1	3	3	1	2	2	1	2	2	3	3	2	1	2	6	9:00	49	2	
9:15	1	0	0	0	3	2	2	1	1	2	1	1	1	1	1	3	2	1	0	2	1	3	3	1	3	2	0	1	5	9:15	42	1	
9:30	1	1	1	0	0	1	3	1	2	3	1	1	2	1	0	3	2	1	1	1	0	1	3	4	3	2	1	0	4	9:30	44	2	
9:45	1	0	0	0	1	0	0	6	6	5	2	1	4	1	3	3	3	1	1	1	0	1	3	2	2	2	1	0	4	9:45	57	2	
10:00	1	0	0	0	0	0	0	3	3	6	6	4	6	4	3	3	3	2	0	0	0	1	2	0	0	1	1	0	4	10:00	53	2	
10:15	1	0	0	0	0	0	0	0	0	0	1	0	2	1	1	2	2	4	4	2	2	0	0	1	0	0	4	3	5	10:15	36	1	
Column Summary																														Overall Row Sum			
Total	16	10	12	53	52	34	22	23	41	59	31	25	43	32	33	48	41	26	26	27	19	17	22	30	33	26	38	36	91	Total	967	34	
Avg	1	1	1	3	3	2	1	1	2	3	2	1	2	2	2	3	2	1	1	1	1	1	1	2	2	1	2	2	5	Avg	48	2	

CHI-SQUARE SPEED COMPARISON																																	
Time slice end	Section number			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Time	Row	Sum	
	1	2	3																											Time	Total	Avg	
5:15																															5:15		
5:30	0	1	2	1	1	2	0	0	3																						5:30	9	1
5:45	1	1	0	4	16	3	12	6	0	0	0	1	7	0	1	0	1	1	0	0	1	0	0	0	0	0	13	12	15	5:45	95	3	
6:00	1	0	1	0	0	0	0	6	2	4	3	6	15	58	28	40	10	3	1	5	1	2	1	0	0	0	8	6	8	6:00	209	7	
6:15	0	0	1	7	2	2	1	1	1	1	1	10	7	0	0	2	7	9	10	2	0	0	0	0	0	0	2	2	4	6:15	73	3	
6:30	0	1	1	10	0	0	1	0	11	58	28	0	2	3	6	13	5	1	2	4	0	1	0	0	0	0	1	0	1	6:30	150	5	
6:45	0	0	0	28	1	6	7	0	22	47	6	2	1	8	4	2	1	2	9	1	1	2	0	0	0	2	3	0	9	6:45	166	6	
7:00	0	0	0	76	5	5	3	0	5	31	11	1	3	0	1	21	20	3	3	2	3	1	0	0	6	3	5	1	30	7:00	239	8	
7:15	0	0	0	136	72	10	3	0	3	43	7	0	4	7	3	9	10	1	4	2	1	0	1	10	5	1	20	16	112	7:15	481	17	
7:30	0	0	0	117	97	2	0	4	26	22	1	1	18	2	1	2	3	0	1	3	0	1	1	11	2	3	8	16	112	7:30	453	16	
7:45	2	1	1	70	67	48	0	0	2	6	1	2	15	1	4	21	4	0	3	4	1	2	3	3	1	2	20	23	141	7:45	449	15	
8:00	2	0	1	56	53	40	1	0	7	18	2	1	1	4	10	12	14	4	3	0	8	0	1	1	2	0	13	22	140	8:00	418	14	
8:15	5	0	0	57	55	13	1	0	17	37	5	0	15	4	8	6	5	0	1	7	2	1	2	2	5	1	25	39	198	8:15	510	18	
8:30	8	0	1	1	0	4	0	1	7	16	2	0	6	18	17	6	1	1	1	0	1	0	1	0	1	14	15	6	0	28	8:30	157	5
8:45	0	0	0	0	7	1	0	0	4	19	2	4	0	1	1	4	6	1	1	0	6	0	0	7	8	3	6	13	102	8:45	197	7	
9:00	1	0	0	1	15	3	3	0	0	1	0	4	0	1	2	17	12	1	4	5	1	4	3	6	7	5	2	4	56	9:00	157	5	
9:15	1	0	0	0	7	4	3	0	1	7	1	2	1	2	0	6	4	1	0	2	0	6	6	1	7	5	0	0	32	9:15	98	3	
9:30	0	0	0	0	0	2	8	1	4	14	0	1	3	2	0	7	4	1	0	2	0	1	7	14	9	5	0	0	26	9:30	112	4	
9:45	1	0	0	0	0	0	0	69	59	36	3	0	35	2	13	16	10	2	0	2	0	2	7	3	5	4	1	0	19	9:45	292	10	
10:00	1	0	0	0	0	0	0	9	8	69	56	21	83	20	11	15	10	5	0	0	0	3	0	0	1	0	0	18	10:00	333	11		
10:15	1	0	0	0	0	0	0	0	0	0	0	0	2	1	1	7	7	21	22	6	3	0	0	0	0	0	23	12	34	10:15	142	5	
Column Summary																														Overall Row Sum			
Total	24	6	9	565	398	145	43	100	182	431	129	56	219	133	113	207	132	58	67	46	30	23	36	73	75	42	150	167	1085	Total	4742	164	
Avg	1	0	0	28	20	7	2	5	9	23	7	3	12	7	6	11	7	3	4	2	2	1	2	4	4	2	8	9	57	Avg	237	8	

Figure 16: Statistical comparison of speed contour maps

FREQ FLOW CONTOUR MAP																																		
Section number																																		
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																																		
Time slice end																													Time	Row	Summary			
																													Min	Avg	Max			
5:15	3228	3540	3368	3380	3328	3108	4468	4476	4476	4400	4416	4420	4420	4416	4416	4240	4364	4268	4344	3608	3812	1912	1996	1832	1872	1808	1872	1328	1416	5:15	1328	3398	4476	
5:30	5412	5932	5656	5740	5656	5016	6450	6494	6192	6092	6100	6100	6100	6096	6096	5881	6109	5991	6079	5160	5364	3085	3201	2960	3032	2931	3039	2208	2324	5:30	2208	5052	6494	
5:45	5104	5596	5372	5460	4473	4008	5052	6151	6151	6068	6100	6148	6148	6145	6153	5960	6316	6092	6300	5346	5642	3344	3588	3291	3387	3266	3422	2391	2579	5:45	2391	5025	6316	
6:00	4104	4496	4304	4032	3972	3696	4972	6128	6128	6036	6100	6156	6156	6152	6172	5977	6142	6036	6300	5456	5820	3907	4387	4030	4134	3985	4153	2943	3247	6:00	2943	5004	6300	
6:15	3932	4256	3740	4148	3992	3572	5000	6500	6500	5940	5996	6124	6124	6111	6135	5324	5748	6004	6721	5302	5850	4946	5722	5281	5593	5356	5608	4109	4601	6:15	3572	5284	6500	
6:30	3516	3928	3472	4488	4008	4008	5052	6500	6500	5859	5894	6450	6450	6388	6400	4598	5198	5035	5387	4970	5850	4648	5800	5404	5740	5524	5796	4424	4892	6:30	3472	5204	6500	
6:45	3132	3564	3168	3452	3336	3016	3896	5116	6434	5842	4385	4987	4987	4987	4991	4160	4820	4642	5090	4650	5326	4372	5800	5363	5767	5526	5850	4330	4886	6:45	3016	4685	6434	
7:00	3052	3536	3132	3364	3244	2876	3872	4812	3772	3192	3340	4184	4184	4184	4204	3500	4036	3896	4448	4072	5476	4524	5800	5383	5755	5525	5821	4383	5011	7:00	2876	4227	5821	
7:15	3264	3780	3296	3532	3344	3092	4236	5032	4576	3900	4060	4788	4788	4784	4808	3788	4316	4060	4652	4312	5600	4704	5800	5349	5745	5498	6042	4795	5619	7:15	3092	4537	6042	
7:30	3168	3600	3172	3404	3216	2976	3513	3985	3985	3409	3637	4277	4277	4273	4333	3325	3801	3597	4369	4069	5569	4672	5800	5284	5756	5471	6119	4714	5386	7:30	2976	4247	6119	
7:45	2956	3444	3032	3256	3092	2462	3402	3854	3854	3314	3518	4298	4298	4294	4342	3274	3686	3418	4298	3918	5418	4480	5800	5281	5769	5485	6153	4734	5750	7:45	2462	4168	6153	
8:00	2852	3268	2892	3156	2375	2143	3047	3431	3431	2927	3087	3907	3907	3907	3951	3015	3527	3291	4063	3723	5223	4396	5800	5355	5795	5545	6149	4924	5880	8:00	2143	3964	6149	
8:15	3036	3464	3228	3464	2398	2226	2922	3382	3382	3190	3350	4122	4122	4118	4142	3478	3930	3690	4310	3890	5386	4488	5800	5252	5640	5284	5936	4636	5612	8:15	2226	4065	5936	
8:30	3444	3948	3672	2728	2502	2274	2946	3494	3494	3298	3394	4094	4094	4090	4154	3550	4066	3802	4466	4006	5442	4508	5800	5258	5650	5296	5956	4659	5665	8:30	2274	4131	5956	
8:45	3400	3760	3504	3326	3046	2862	3406	3842	3842	3670	3882	4450	4450	4446	4490	3750	4242	3962	4634	4154	5474	4564	5800	5312	5640	5322	5874	4735	5443	8:45	2862	4320	5874	
9:00	3448	3732	3476	3159	2875	2703	3223	3567	3567	3371	3547	4307	4307	4303	4323	3735	4227	3995	4587	4179	5519	4508	5800	5230	5626	5249	5909	4558	5358	9:00	2703	4220	5909	
9:15	2416	2616	2436	3956	3752	3628	3992	4236	4236	4096	4220	4792	4792	4788	4808	4392	4740	4580	4992	4700	5640	4896	5800	5236	5516	5152	5616	4333	4893	9:15	2416	4457	5800	
9:30	1692	1832	1708	1820	1676	1592	1844	2016	4692	4596	4684	5112	5112	5108	5120	4828	5076	4956	5244	5036	5688	5172	5800	5251	5443	5080	5404	4173	4565	9:30	1592	4149	5800	
9:45	1188	1284	1192	1276	1172	1112	1296	1408	1408	1340	1404	1724	1724	1720	1724	1524	5284	5200	5400	5260	5720	5356	5800	5234	5370	4994	5222	4050	4326	9:45	1112	3094	5800	
10:00	828	900	840	896	828	784	904	984	984	936	976	1216	1216	1212	1216	1076	1192	1136	1280	1176	1496	5356	5672	5101	5197	4873	5033	3891	4083	10:00	784	2113	5672	
10:15	580	628	584	624	572	536	624	692	692	664	692	864	864	860	860	760	844	804	904	828	1052	868	1088	984	1052	984	1096	840	976	10:15	536	807	1096	
Column Summary																														Overall Row Summary				
Min	580	628	584	624	572	536	624	692	692	664	692	864	864	860	860	760	844	804	904	828	1052	868	1088	984	1052	984	1096	840	976					
Avg	3036	3386	3107	3234	2971	2757	3551	4100	4205	3911	3942	4406	4406	4399	4421	3816	4365	4212	4613	4182	5065	4224	5088	4651	4928	4674	5051	3865	4405					
Max	5412	5932	5656	5740	5656	5016	6450	6500	6500	6092	6100	6450	6450	6388	6400	5977	6316	6092	6300	5456	5850	5356	5800	5404	5795	5545	6153	4924	5880					

PARAMICS FLOW CONTOUR MAP																																	
Section number																																	
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																																	
Time slice end																													Time	Row	Summary		
																													Min	Avg	Max		
5:15	3265	3532	3339	3319	3206	3017	4324	4340	4320	4284	4291	4352	4564	4372	4351	4183	4200	4072	4016	3344	3685	1803	1888	1668	1717	1640	1652	1317	1388	5:15	1317	3291	4564
5:30	5136	5532	5213	4985	4598	4147	5444	5440	5207	5025	4830	4760	5160	4738	4653	4419	4568	4428	4439	3632	3835	2007	2066	1932	1924	1790	1740	1306	1436	5:30	1306	3944	5532
5:45	5117	5610	5399	5141	4887	4476	5220	5812	5979	5927	5751	5628	5692	5540	5576	5451	5676	5478	5540	4600	4452	2500	2660	2452	2565	2494	2484	1807	1916	5:45	1807	4546	5979
6:00	4155	4596	4393	4617	4501	4061	5056	5716	5609	5516	5704	5788	5202	5744	5588	5189	5044	4812	5093	4248	4651	2768	3156	2888	2932	2800	2816	2163	2436	6:00	2163	4388	5788
6:15	4049	4436	4016	4330	4279	3990	4584	5448	5317	4985	4765	4752	4916	4456	4560	4540	4356	5388	5441	4520	5100	3325	4019	3600	3897	3710	3648	2656	3208	6:15	2656	4389	5448
6:30	3479	3924	3460	3713	3523	2924	3940	4952	5084	4703	5034	5040	5274	5310	5352	4804	4988	4680	5104	4624	5337	3832	4794	4404	4649	4442	4392	3350	3756	6:30	2924	4444	5352
6:45	3240	3776	3337	4054	3962	3877	4544	5524	5432	4575	4522	5492	4984	5344	5015	3925	4656	4758	5329	4760	5820	4739	5772	5118	5479	5174	5160	3829	4292	6:45	3240	4707	5820
7:00	2944	3412	3052	3413	3788	3239	3700	4612	4771	4497	4513	4476	4644	4640	5019	4687	4896	4766	5169	4892	6076	5075	6154	5576	5575	5232	5236	3897	4548	7:00	2944	4569	6154
7:15	3317	3824	3332	3477	3269	3060	3852	4828	4833	4148	4431	5064	5036	4750	4748	4272	4856	4710	5244	5044	5872	4776	5947	5284	5853	5654	5588	4345	5232	7:15	3060	4643	5947
7:30	3392	3862	3356	3674	3530	3448	4124	4912	4876	4185	4228	5012	5046	4760	4437	3591	4092	3922	4784	4524	5904	4696	5518	5420	5984	5568	5544	4440	5156	7:30	3356	4551	5984
7:45	3033	3534	3104	3348	3158	2906	3536	4096	4133	3643	4153	4952	4810	5178	5208	3875	4460	4242	4861	4560	5377	4949	6069	5352	5753	5466	5500	4385	5396	7:45	2906	4450	6069
8:00	3020	3476	3109	3402	3223	3027	3620	4616	4507	3987	3915	4528	4476	4772	5088	4288	5040	4662	5016	4544	5761	4875	6132	5492	5841	5558	5464	4429	5460	8:00	3020	4529	6132
8:15	2953	3432	3148	3394	3131	3008	3928	4784	4895	4325	4159	4356	4978	4496	4671	4060	4288	3702	4901	4680	5740	4727	5797	5522	5677	5448	5524	4432	5308	8:15	2953	4464	5797
8:30	3652	4098	3812	3940	3583	3286	3968	4528	4385	3863	4308	5656	4800	5406	5319	4159	4124	4048	4867	4396	5396	4695	5984	5350	5953	5668	5636	4569	5484	8:30	3286	4653	5984
8:45	3369	3730	344																														

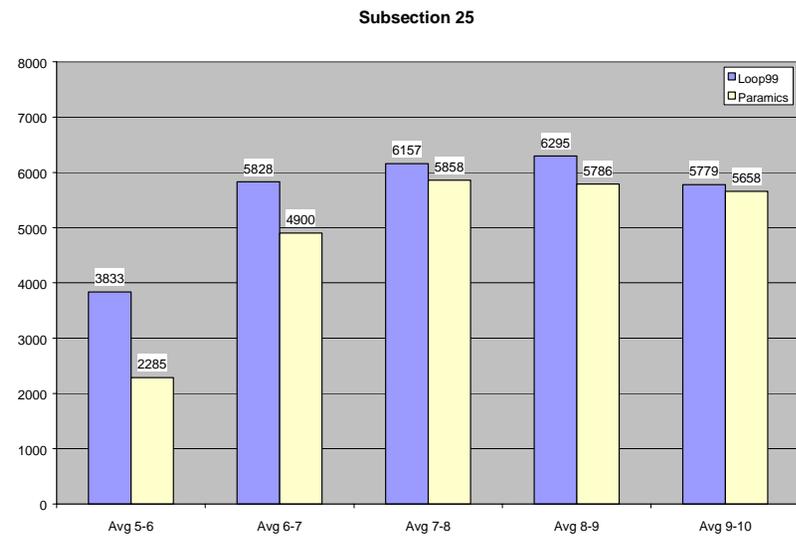
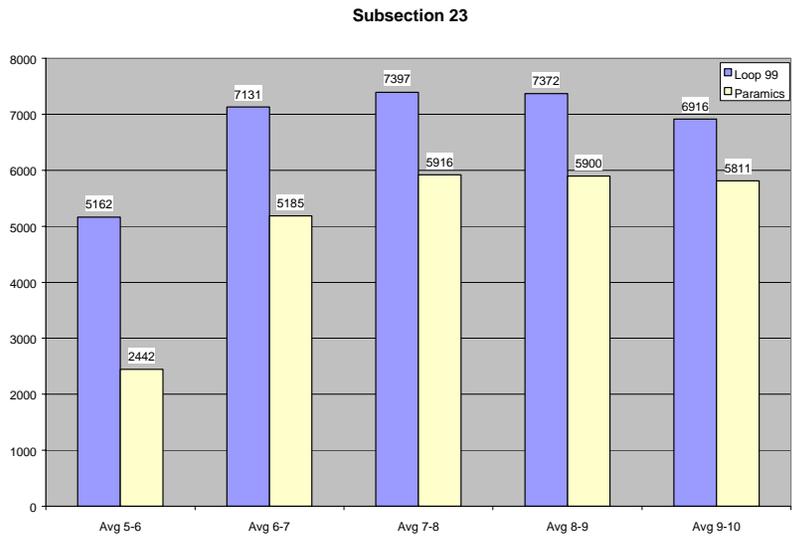
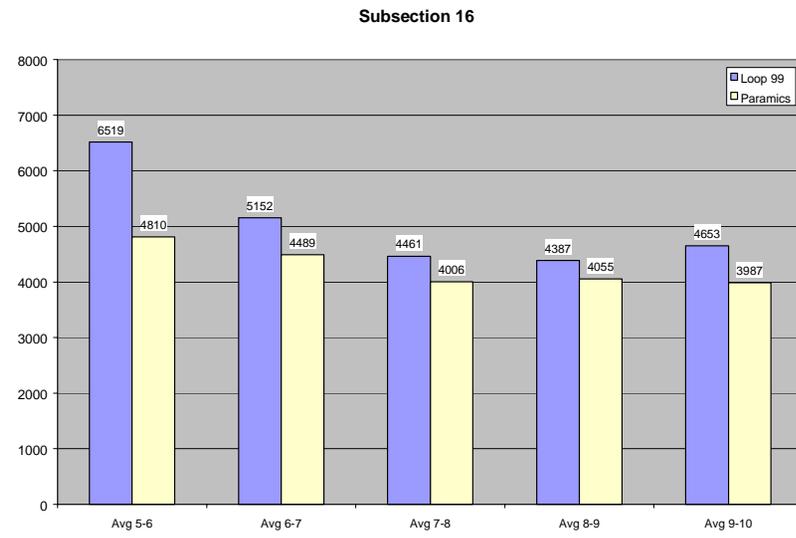
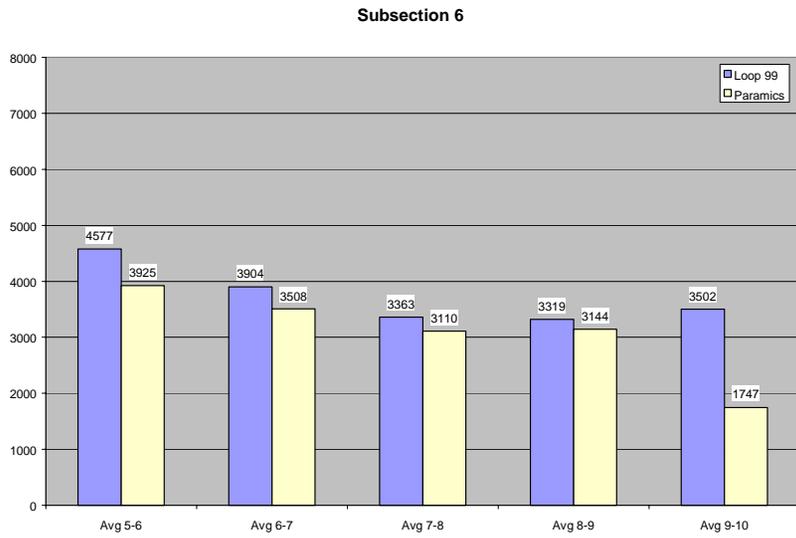


Figure 18: Flow comparison with loop data

CHAPTER 9: APPLICATIONS OF THE MODEL

9.1 Experiment Plan

Once the model was calibrated and validated for the base traffic conditions (see chapters 7 and 8), the next phase involved the model application to assess to what extent the Paramics model could simulate various alternative improvement scenarios.

The strategies under consideration include:

- Implementing a ramp metering strategy
- Adding a mixed-flow auxiliary lane at various locations
- Adding an HOV lane.

Each of these strategies was separately modeled with Paramics. Within each alternative strategy, several options were investigated, so that their relative impact on the overall traffic performance could be assessed. The objective was to provide an assessment of the potential benefits of each scenario compared to the reference base conditions.

9.2 Ramp Metering Investigations

The ramp metering scenario which was simulated assumed that all fourteen on-ramps of the I-680 southbound direction were metered with a local traffic responsive ramp metering strategy.

As in the single on-ramp experiment presented in chapter 4 of this report, the traffic actuated control logic was simulated on the I-680 network with the Paramics Plan Language for traffic actuated signals.

The metering approach used in this study is a generic strategy and do not replicate a typical strategy used in the field by Caltrans.

Ramp Metering Strategy

The metering strategy used is the one that was developed for the initial ramp metering experiment reported under section 4.3.

The metering rate is determined based on the value of the average lane occupancy on the freeway measured at the detectors upstream of the on-ramp. As upstream traffic conditions get heavier, the percent lane occupancy increases, and the need for restricting the entering flow from the on-ramp increases.

The metering rate varies between a maximum of 900 vehicles per hour (with mainline occupancy below 15%) and a minimum of 180 vehicles per hour (with mainline occupancy over 25%).

In the cases of on-ramps with two lanes, the meter can discharge two vehicles at a time. The maximum metering rate used in this case is 1200 vehicles per hour instead of 900 vehicles per hour.

When activated, the queue detector located at the beginning of each on-ramp can override the metering rate determined from the mainline percent occupancy. It is used to prevent the queue from the freeway on-ramp to spillback onto the surface streets. Whenever the value of the percent lane occupancy exceeds a threshold value of 30% indicating a queue at the beginning of the on-ramp, the metering rate is increased to the maximum metering rate. When the value of the percent lane occupancy drops below 30%, the queue limit over-ride is released.

Presentation of the Results

The results are presented for two ramp metering scenarios. In the first ramp metering scenario, the queue detector was activated, preventing the ramp queues from spilling back onto the surface streets. In the second case, the queue detector was not activated.

For each scenario, the impact of the ramp metering implementation was studied separately for the mainline freeway and for the on-ramps. In order to evaluate the impact on the mainline freeway side, the time-space diagrams for average speeds that were developed in the validation phase (see section 8.4) were again used.

For the on-ramps, the indicator used was the number of blocked vehicles at each on-ramp origin. These vehicles could not be released from their origin zone because there was no space available on the on-ramp initial link. Using the “release counts” function of Paramics Modeller, it was possible to gather the number of blocked vehicles every 15 minutes throughout the simulation.

- Scenario with Queue Detectors

The results of the scenario with queue detectors activated are presented in Figure 19 and Figure 20.

As indicated in the overall row summaries of the two diagrams in Figure 19, the overall freeway mainline average speed increased from 39 mph to 43 mph with the implementation of this ramp metering strategy. This represents an increase of 11% in the mainline average speed.

With the implementation of the ramp metering strategy, traffic conditions are shown to have slightly improved on the mainline freeway throughout the study section. Some subsections such as subsections 5, 6, 11, 20 and 26 exhibit a rather significant increase of average speeds of 7 mph or more. However, the general congestion pattern that was found in the no-meter case is still prevailing. The congestion remains severe on the freeway, with average speeds across the study section below 35 mph from 7 am to 9 am. The general speed contour map and the congestion pattern appear to be similar in the no-

metering and the metering scenario, which suggests that the metering strategy has not been really successful in reducing congestion on the freeway.

Figure 20 shows the results of the ramp block analysis, by indicating the number of vehicles blocked at each on-ramp origin. It gives an indication of whether or not the metering system has contributed to an increase of delays on the on-ramps, or the surface streets feeding these ramps. The comparison of the two tables presented in Figure 20 suggests that the metering strategy with queue detectors did not lead to more vehicles being blocked at their origin zones. The no-metering case already resulted in a large number of blocked vehicles (a total of 3374); in the metering case, the figure is 3155 blocked vehicles. This suggests that with the implementation of the ramp metering, the queue detectors were often activated because of long queues on the ramp. As a consequence, the meter was often operated at the maximum metering rate, which means that the effect of the metering system for the freeway mainline performance is minimal.

- Scenario without Queue Detectors

Another scenario was tested in which the same ramp metering strategy was applied, but without the use of the queue detectors.

The results of the scenario without queue detectors activated are presented in Figure 21 and Figure 22.

As indicated in the overall row summaries of the two diagrams in Figure 21, the overall freeway mainline average speed increased from 39 mph to 53 mph with the implementation of this ramp metering strategy. This represents an increase of 37% in the mainline average speed.

With the implementation of the ramp metering strategy, traffic conditions are shown to have significantly improved on the mainline freeway throughout the study section. The congestion has almost totally disappeared. Even if a slight bottleneck remains on subsection 29, the whole stretch from subsection 5 to 27 is showing a significant improvement.

The ramp block analysis presented on Figure 22 illustrates the impact of the metering strategy without queue detectors on the on-ramps operation. As expected, conditions have worsened on the on-ramps, and the number of blocked vehicles has increased from 3374 vehicles in the base no-meter case to 5616 vehicles. A number of ramps such as ramps 4, 8, 11, 6,10, and 14 experienced an increase in the number of blocked vehicles. However, given the high benefits on the freeway mainline, one can argue that the level of increased queuing on the ramps may be acceptable. Only one origin zone (at ramp 8) still has vehicles blocked at the end of the simulation period. All other origin zones have been able to release all vehicles by the end of the simulation period.

9.3 Added Auxiliary Lanes

The second set of corridor improvement alternatives considered for I-680 was the creation of new mixed-flow auxiliary lanes.

Several options were considered in terms of location of added auxiliary lanes. The bottleneck locations, as identified in the base run, provided a hint as to where an added lane could be most profitable.

Among the potential locations for an added auxiliary lane were the following subsections (refer to Figure 4 in section 5.2):

- Subsection 28: from the Calaveras off-ramp to the Calaveras on-ramp
- Subsection 25: from Scott-Creek on to Jacklin off
- Subsection 23: from Mission on to Scott Creek off
- Subsection 21: from AutoMall on to Mission off
- Subsection 19: from Washington on to AutoMall off

In a first scenario, an auxiliary lane was added in Subsection 28 only. The reason for focusing on this subsection is that a bottleneck had been identified at this location in the base run. By adding an auxiliary lane, thus increasing the capacity of this subsection, it was expected that this bottleneck could be removed.

Figure 23 illustrates the results obtained with an added auxiliary lane in Subsection 28. The figure presents the speed contour map with the auxiliary lane, compared to the one obtained in the base reference case. It shows that the traffic conditions have improved in subsections 28 and 27, which do not experience any congestion anymore. However, upstream of subsection 26, the congestion conditions remain more or less identical. The impact is limited to the stretch of freeway from subsections 26 to 28. The overall mainline average speed for the entire study section and the entire simulation period has increased from 39 to 42 mph, an increase of 7%.

Other scenarios were developed by combining the addition of new auxiliary lanes at various locations. A total of six scenarios were considered:

- Subsection 28 only
- Subsections 28 and 21
- Subsections 28 and 23
- Subsections 25, 23 and 19
- Subsections 28, 25, 23 and 21
- Subsections 28, 25, 23, 21 and 19

The model was then used to compare the various alternatives, providing a sense of the relative benefits versus costs of the different options.

Figure 24 illustrates the results that were obtained. The performances of the various options can be compared in terms of their relative benefits (on the vertical axis, in terms of total travel time savings) and their relative costs (on the horizontal axis, in terms of the length of added auxiliary lanes). For instance, the scenario with added lanes on subsections 28+25+23+21+19 is the one resulting in the highest benefits (total travel time down by 22%) but it is also the most expensive option with a total length of added lanes of 5.2 miles.

The slope of the line linking the graph origin to each of the six points is representative of the resulting benefits over costs ratio. The scenario “28 only” has the highest performance, and the scenario “28+23+19” has the lowest performance.

Based on this analysis, it appears that three options would have the best benefits over costs ratio:

- Subsection 28 only
- Subsections 28 and 21
- Subsections 28 and 23

9.4 Added High Occupancy Vehicle Lane

The last set of investigations was made with the introduction of an additional lane restricted to High Occupancy Vehicles.

The potential impact of an HOV lane was introduced in the model by adding a separated lane, only open to carpool vehicles. The HOV lane extended from the Route 84 interchange to the Calaveras/237 interchange. Connector links were located upstream of each off-ramp and downstream of each on-ramp to allow for vehicles to move in and out of the carpool lane.

The carpool lane had a free-flow speed of 70 miles per hour, which was faster than the mainline freeway even under non-congested traffic conditions. As a result, all eligible vehicles would tend to travel on the carpool lane whenever possible.

The percentage of carpool vehicles was applied to the overall demand. By varying the percentage of carpool vehicles, four scenarios were developed: 5, 10, 15 and 20%.

Figure 25 provides an example of the results that were obtained. It shows the speed contour map resulting from the simulation with 10% HOV vehicles (at the bottom) compared to the base case (on top). The overall average speed on the freeway has increased from 39 mph to 44 mph, an increase of 13%. Subsections 5 to 12 appear to have benefited the most from the HOV lane, as the congestion has almost disappeared.

The results of the four scenarios are presented in Figure 26. The horizontal scale is the percentage of carpool vehicles. The vertical scale is the percentage reduction of total travel time for the entire network. The most favorable case is the one with 20% carpool vehicles: the total travel time reduction reached 36%. The benefits appear to increase linearly with the percentage of carpool vehicles.

9.5 Summary of Investigations

Table 9 presents a summary of the results obtained with the different scenarios. The criteria for comparison is the average mainline freeway speed across the entire study section and over the entire simulation time.

	Average Speed (mph)	Variation (%)
Base case	38.87	
Ramp Metering with Queue Detectors	43.11	+10.9
Ramp Metering without Queue Detectors	53.42	+37.4
Auxiliary Lane 28	41.78	+7.5
Auxiliary Lane 28+21	44.38	+15.1
Auxiliary Lane 28+23	43.55	+12.0
Auxiliary Lane 25+23+19	43.47	+11.8
Auxiliary Lane 28+25+23+21	45.61	+17.3
Auxiliary Lane 28+25+23+21+19	49.26	+26.7
HOV 5%	41.07	+5.7
HOV 10%	43.79	+12.7
HOV 15%	47.35	+21.8
HOV 20%	50.65	+30.3

Table 9: Summary of results

It is interesting to notice that the best overall performance on the mainline freeway is obtained in the second ramp metering scenario, without queue detectors. This scenario is shown to perform better than even the most ambitious auxiliary lane or HOV scenario.

BASE RUN SPEED CONTOUR MAP																																	
Time slice end	Section number																													Time	Row Summary		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29		Min	Avg	Max
5:15	60	59	58	57	56	59	59	54	52	56	55	55	48	56	52	59	57	56	55	61	50	62	60	60	59	58	61	58	60	5:15	48	57	62
5:30	57	55	52	50	51	53	41	33	45	54	53	58	40	55	53	58	56	56	55	61	50	61	60	61	60	59	61	59	61	5:30	33	54	61
5:45	58	54	56	42	26	33	22	21	39	51	44	46	34	53	48	57	51	47	52	36	31	60	59	60	59	57	59	58	61	5:45	21	47	61
6:00	59	57	50	27	25	20	19	21	28	37	38	36	25	52	42	40	27	27	31	22	30	61	58	60	58	58	61	58	61	6:00	19	41	61
6:15	60	59	58	27	22	19	17	20	30	35	25	17	20	20	19	21	25	33	34	24	32	60	57	60	57	56	59	57	62	6:15	17	37	62
6:30	60	57	57	29	15	10	12	15	27	36	29	16	22	25	29	29	24	23	24	19	33	58	55	59	56	55	58	54	61	6:30	10	36	61
6:45	60	58	58	36	19	16	17	17	33	34	19	11	20	28	24	20	18	23	30	23	35	56	49	59	54	49	53	45	61	6:45	11	35	61
7:00	60	59	58	49	24	14	13	15	24	28	20	11	22	18	22	26	26	25	22	38	50	40	54	40	47	43	36	61	7:00	11	33	61	
7:15	61	59	58	58	46	17	13	17	26	27	16	11	18	24	21	21	22	23	26	24	37	38	32	32	39	49	35	33	61	7:15	11	32	61
7:30	60	59	58	57	53	21	14	16	26	25	13	10	18	25	21	15	16	16	23	24	35	38	27	32	45	43	28	33	61	7:30	10	31	61
7:45	61	59	58	57	57	36	11	13	18	16	12	10	17	22	27	28	19	18	24	22	27	35	38	39	34	37	33	34	61	7:45	10	32	61
8:00	61	60	59	57	56	30	14	15	23	22	13	9	17	19	23	23	23	25	24	20	31	34	35	35	32	38	29	33	61	8:00	9	32	61
8:15	61	59	58	57	57	21	12	16	28	27	16	10	21	19	22	22	21	21	23	23	31	30	33	34	28	35	29	34	61	8:15	10	31	61
8:30	60	59	58	57	51	21	14	17	22	21	13	12	20	27	26	25	20	15	23	21	28	31	37	31	31	41	29	33	61	8:30	12	31	61
8:45	60	59	58	56	36	17	14	13	20	20	12	8	16	16	17	16	18	17	25	23	34	37	37	36	34	43	28	33	61	8:45	8	30	61
9:00	60	59	58	57	33	11	11	13	15	16	12	11	18	22	24	23	21	26	31	22	31	32	34	41	39	43	30	34	61	9:00	11	31	61
9:15	61	61	59	58	39	13	14	15	22	23	17	9	19	19	19	18	21	21	27	25	31	35	36	54	39	43	30	33	61	9:15	9	32	61
9:30	62	61	60	59	58	51	24	22	27	33	15	11	21	21	16	20	24	33	27	35	44	34	31	36	42	28	34	61	9:30	11	35	62	
9:45	62	62	61	60	59	60	60	59	56	50	14	13	38	29	41	58	52	44	31	28	38	47	37	48	43	44	29	33	61	9:45	13	45	62
10:00	63	63	61	60	60	60	62	62	61	61	57	33	50	55	48	60	57	54	37	37	40	57	47	59	56	52	39	35	60	10:00	33	53	63
10:15	63	63	62	62	61	62	62	63	61	61	58	62	51	59	59	62	61	59	60	62	58	59	58	59	57	56	55	48	60	10:15	48	59	63
Column Summary																														Overall Row Sum			
Min	57	54	50	27	15	10	11	13	15	16	12	8	16	16	16	15	16	15	23	19	27	30	27	31	28	35	28	33	60	Min	8	30	61
Avg	60	59	58	51	43	31	25	26	32	35	26	22	26	32	31	33	31	31	33	30	36	47	44	48	45	48	42	42	61	Avg	17	39	61
Max	63	63	62	62	61	62	62	63	61	61	58	62	51	59	59	62	61	59	60	62	58	62	60	61	60	59	61	59	62	Max	48	59	63

PARAMICS Metering with Queue Detectors																																	
Time slice end	Section number																													Time	Row Summary		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29		Min	Avg	Max
5:15	60	59	58	57	57	58	59	55	53	57	56	59	51	56	54	58	57	56	56	60	54	61	60	61	60	59	62	59	61	5:15	51	58	62
5:30	57	55	54	53	54	55	42	35	40	54	55	57	42	56	54	58	57	56	55	61	53	61	60	61	59	59	62	59	62	5:30	35	55	62
5:45	58	56	56	46	31	26	19	21	38	50	50	50	36	54	52	57	51	49	51	60	54	61	59	60	59	58	61	59	61	5:45	19	50	61
6:00	59	57	55	25	21	18	18	22	36	44	42	39	32	51	53	54	36	33	49	58	51	61	58	60	57	58	60	58	61	6:00	18	46	61
6:15	59	58	55	27	20	19	18	19	32	38	34	29	31	44	36	43	28	33	50	46	47	59	56	60	57	56	56	55	62	6:15	18	42	62
6:30	61	58	59	39	25	17	15	18	31	37	32	21	25	34	36	46	33	32	35	29	43	59	54	59	56	56	59	55	62	6:30	15	41	62
6:45	60	59	58	56	40	26	20	20	46	49	27	18	25	25	21	20	24	26	27	29	42	49	45	57	52	56	59	50	62	6:45	18	40	62
7:00	61	59	59	57	56	50	16	16	26	28	18	12	20	37	36	34	20	21	31	31	39	35	37	48	40	55	48	37	61	7:00	12	37	61
7:15	61	60	59	58	57	57	26	19	28	23	17	10	16	20	19	18	21	21	27	22	31	41	41	36	43	53	36	35	61	7:15	10	35	61
7:30	61	59	59	57	56	45	13	16	24	24	13	9	17	18	21	20	23	27	26	23	32	36	34	41	42	51	36	34	61	7:30	9	34	61
7:45	61	59	59	58	57	39	12	14	23	27	16	9	23	20	20	18	20	21	29	30	42	45	35	36	37	52	32	34	61	7:45	9	34	61
8:00	61	59	59	58	57	25	11	12	20	20	15	13	21	42	43	46	25	20	19	29	30	37	52	41	49	32	34	61	8:00	11	35	61	
8:15	61	59	59	58	57	44	19	21	32	35	18	9	20	16	15	17	17	31	31	38	40	40	46	42	53	31	34	61	8:15	9	35	61	
8:30	61	60	59	58	58	46	16	15	20	18	16	11	20	31	27	22	23	26	32	27	34	32	42	47	43	51	32	34	61	8:30	11	35	61
8:45	61	59	58	57	56	51	17	16	22	27	17	11	20	23	22	23	26	24	28	33	35	37	39	33	46	54	32	34	61	8:45	11	35	61
9:00	61	59	59	57	57	56	29	20	23	23	15	11	24	28	28	30	28	26	32	26	29	27	37	37	46	53	35	34	61	9:00	11	36	61
9:15	62	60	59	58	58	59	30	22	25	30	27	15	24	34	34	28	21	19	22	20	29	35	42	56	48	50	29	33	61	9:15	15	37	62
9:30	62	62	60	59	58	59	61	59	57	59	55	27	42	23	21	24	25	24	37	31	37	47	43	59	56	54	35	34	61	9:30	21	46	62
9:45	63	62	60	60	60	61	62	62	60	61	57	60	56	58	58	60	59	58	46	30	42	55	45	59	56	55	34	35	61	9:45	30	55	63
10:00	62	63	61	60	59	60	61	62	59	60	57	62	57	59	58	61	61	60	60	62	61	61	59	61	59	58	59	53	62	10:00	53	60	63
10:15	64	64	62	61	60	61	62	62	60	61	58	62	52	59	58	61	59	59	59	61	60	61	60	60	59	58	61	59	61	10:15	52	60	64
Column Summary																														Overall Row Sum			
Min	57	55	54	25	20	17	11	12	20	18	13	9	16	16	15	17	17	20	19	29	27	34	33	37	49	29	33	61	Min	9	34	61	
Avg	61	59	58	53	50	44	30	29	36	39	33	28	31	37	37	38	34	34	38	38	42	47	47	52	50	55	45	44	61	Avg	21	43	61
Max	64	64	62	61	60	61	62	62	60	61	58	62	57	59	58	61	61																

Ramp Block Analysis - No Metering																	
Time slice end	Ramp number														Row summary		Overall
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Min	Max	
5:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6:00	0	0	13	85	0	0	0	0	0	0	0	0	0	0	0	85	
6:15	0	0	135	133	0	0	0	0	0	0	0	0	0	0	0	135	
6:30	0	0	141	143	0	0	0	13	0	0	0	0	0	0	0	143	
6:45	0	0	31	0	0	0	0	72	0	0	1	0	0	0	0	72	
7:00	0	0	67	28	0	0	0	19	0	0	0	0	0	0	0	67	
7:15	0	0	133	0	0	37	0	0	0	12	0	0	0	37	0	133	
7:30	0	0	47	0	0	23	0	27	28	85	0	0	98	0	0	98	
7:45	0	0	18	0	0	54	0	0	83	231	29	0	121	0	0	231	
8:00	0	0	46	0	0	67	0	0	0	69	69	0	86	2	0	86	
8:15	0	0	0	0	0	21	0	0	0	78	0	0	97	0	0	97	
8:30	0	0	20	0	0	0	0	0	24	136	41	0	91	0	0	136	
8:45	0	0	0	0	0	25	0	3	0	45	81	0	69	0	0	81	
9:00	0	0	0	0	0	71	0	0	23	21	21	0	107	0	0	107	
9:15	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	24	
9:30	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	
9:45	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	24	
10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	0	0	141	143	0	71	0	72	83	231	81	0	121	2	0	231	
Overall	0	0	651	389	0	298	0	157	135	741	242	0	759	2	0	1524	

Ramp Block Analysis - Metering with Queue Detectors																	
Time slice end	Ramp number														Row summary		Overall
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Min	Max	
5:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:45	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	
6:00	0	0	39	46	0	0	0	0	0	0	0	0	0	0	0	46	
6:15	0	0	47	146	0	0	0	0	0	0	0	0	0	0	0	146	
6:30	0	0	10	138	0	0	0	0	0	0	76	0	0	0	0	138	
6:45	0	0	0	68	0	3	0	0	0	0	144	0	0	0	0	144	
7:00	0	0	0	33	0	8	0	0	0	47	112	0	0	0	0	112	
7:15	0	0	0	0	0	23	0	0	12	28	95	0	0	0	0	95	
7:30	0	0	0	0	0	0	0	0	0	79	83	0	94	0	0	94	
7:45	0	0	11	0	0	56	0	0	22	112	125	0	48	38	0	125	
8:00	0	0	19	0	0	9	0	0	0	107	153	0	85	30	0	153	
8:15	0	0	0	0	0	39	0	0	0	50	134	0	47	18	0	134	
8:30	0	0	0	0	0	19	0	0	0	57	118	0	70	30	0	118	
8:45	0	0	0	0	0	0	0	0	0	41	67	0	53	0	0	67	
9:00	0	0	0	0	0	5	0	0	0	24	118	0	55	15	0	118	
9:15	0	0	0	0	0	0	7	0	0	0	19	0	17	0	0	19	
9:30	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	
9:45	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	
10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	0	0	47	146	0	56	7	0	22	112	153	0	94	38	0	153	
Overall	0	0	126	434	0	162	10	0	34	545	1244	0	469	131	0	1515	

Figure 20: Metering with queue detectors – Vehicles blocked at on-ramp origins

BASE RUN SPEED CONTOUR MAP																																	
Section number																																	
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																																	
Time slice end																														Time	Row Summary		
	Min	Avg	Max																														
5:15	60	59	58	57	56	59	59	54	52	56	55	55	48	56	52	59	57	56	55	61	50	62	60	60	59	58	61	58	60	5:15	48	57	62
5:30	57	55	52	50	51	53	41	33	45	54	53	58	40	55	53	58	56	56	55	61	50	61	60	61	60	59	61	59	61	5:30	33	54	61
5:45	58	54	56	42	26	33	22	21	39	51	44	46	34	53	48	57	51	47	52	36	31	60	59	60	59	57	59	58	61	5:45	21	47	61
6:00	59	57	50	27	25	20	19	21	28	37	38	36	25	52	42	40	27	27	31	22	30	61	58	60	58	57	58	61	6:00	19	41	61	
6:15	60	59	58	27	22	19	17	20	30	35	25	17	20	20	19	21	25	33	34	24	32	60	57	60	57	56	59	57	62	6:15	17	37	62
6:30	60	57	57	29	15	10	12	15	27	36	29	16	22	25	29	29	24	23	24	19	33	58	55	59	56	55	58	54	61	6:30	10	36	61
6:45	60	58	58	36	19	16	17	17	33	34	19	11	20	28	24	20	18	23	30	23	35	56	49	59	54	49	53	45	61	6:45	11	35	61
7:00	60	59	58	49	24	14	13	15	24	28	20	11	22	18	22	26	26	25	22	38	50	40	54	40	47	43	36	61	7:00	11	33	61	
7:15	61	59	58	58	46	17	13	17	26	27	16	11	18	24	21	21	22	23	26	24	37	38	32	32	39	49	35	33	61	7:15	11	32	61
7:30	60	59	58	57	53	21	14	16	26	25	13	10	18	25	21	15	16	16	23	24	35	38	27	32	45	43	28	33	61	7:30	10	31	61
7:45	61	59	58	57	57	36	11	13	18	16	12	10	17	22	27	28	19	18	24	22	27	35	38	39	34	37	33	34	61	7:45	10	32	61
8:00	61	60	59	57	56	30	14	15	23	22	13	9	17	19	23	23	23	25	24	20	31	34	35	35	32	38	29	33	61	8:00	9	32	61
8:15	61	59	58	57	57	21	12	16	28	27	16	10	21	19	22	22	21	21	23	23	31	30	33	34	28	35	29	34	61	8:15	10	31	61
8:30	60	59	58	57	51	21	14	17	22	21	13	12	20	27	26	25	20	15	23	21	28	31	37	31	31	41	29	33	61	8:30	12	31	61
8:45	60	59	58	56	36	17	14	13	20	20	12	8	16	16	17	16	18	17	25	23	34	37	37	36	34	43	28	33	61	8:45	8	30	61
9:00	60	59	58	57	33	11	11	13	15	16	12	11	18	22	24	23	21	26	31	22	31	32	34	41	39	43	30	34	61	9:00	11	31	61
9:15	61	61	59	58	39	13	14	15	22	23	17	9	19	19	19	18	21	21	27	25	31	35	36	54	39	43	30	33	61	9:15	9	32	61
9:30	62	61	60	59	58	51	24	22	27	33	15	11	21	21	16	16	20	24	33	27	35	44	34	31	36	42	28	34	61	9:30	11	35	62
9:45	62	62	61	60	59	60	59	56	50	14	13	38	29	41	58	52	44	31	28	38	47	37	48	43	44	29	33	61	9:45	13	45	62	
10:00	63	63	61	60	60	60	62	62	61	61	57	33	50	55	48	60	57	54	37	37	40	57	47	59	56	52	39	35	60	10:00	33	53	63
10:15	63	63	62	62	61	62	62	63	61	61	58	62	51	59	59	62	61	59	60	62	58	59	58	59	57	56	55	48	60	10:15	48	59	63
Column Summary																																	
Min	57	54	50	27	15	10	11	13	15	16	12	8	16	16	16	15	16	15	23	19	27	30	27	31	28	35	28	33	60	Min	8	30	61
Avg	60	59	58	51	43	31	25	26	32	35	26	22	26	32	31	33	31	31	33	30	36	47	44	48	45	48	42	42	61	Avg	17	39	61
Max	63	63	62	62	61	62	62	63	61	61	58	62	51	59	59	62	61	59	60	62	58	62	60	61	60	59	61	59	62	Max	48	59	63

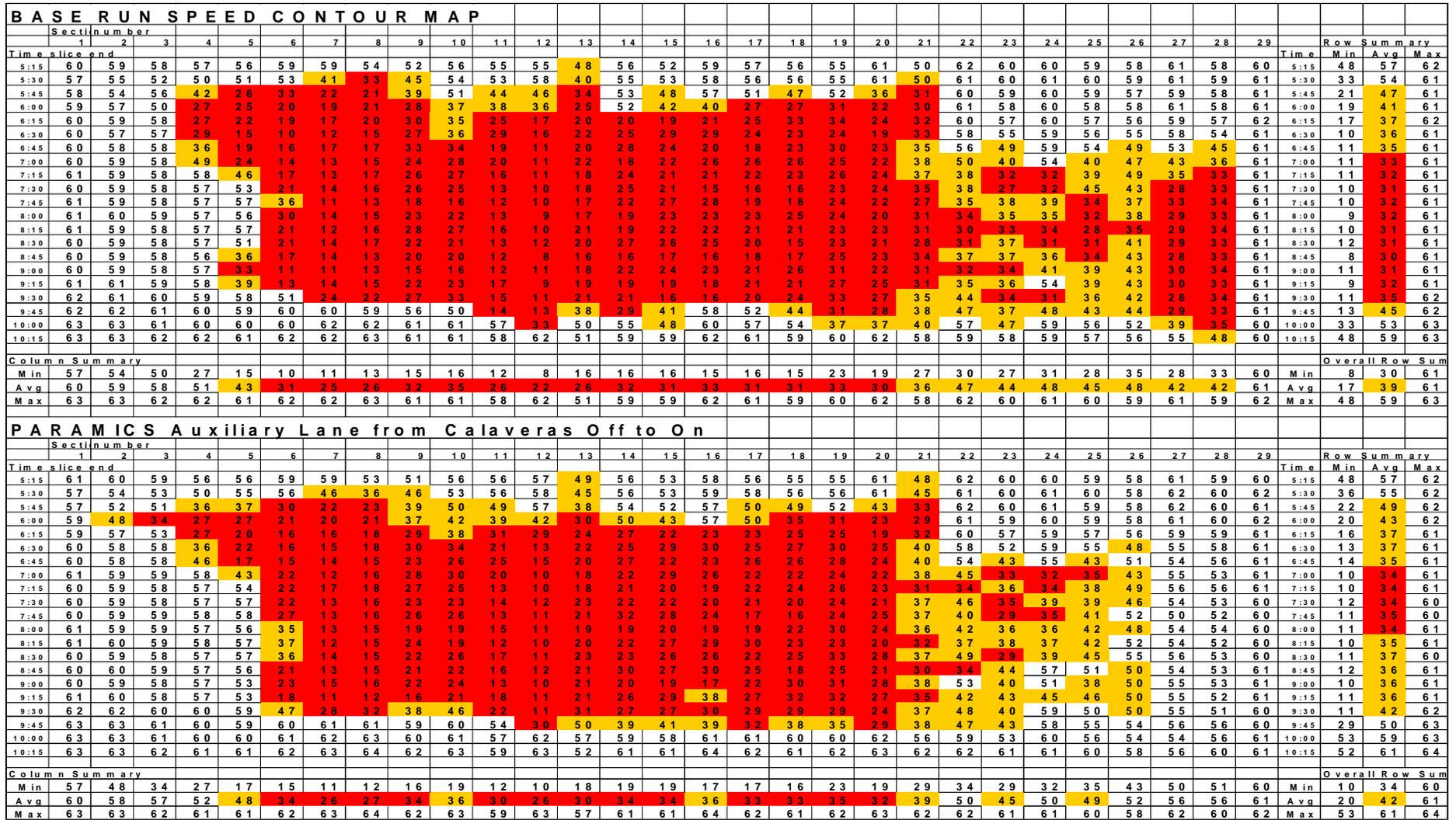
PARAMICS Metering without Queue Detectors																																		
Section number																																		
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																																		
Time slice end																														Time	Row Summary			
	Min	Avg	Max																															
5:15	60	59	58	57	57	59	60	55	52	55	55	59	50	56	54	58	56	56	55	61	56	62	60	61	60	59	62	60	61	5:15	50	58	62	
5:30	58	55	56	53	53	57	48	40	47	54	55	58	42	56	54	58	57	56	56	61	54	61	61	61	60	59	61	59	62	5:30	40	56	62	
5:45	59	57	55	50	40	33	23	22	40	51	45	48	35	52	53	57	50	47	52	58	50	60	58	60	58	58	60	57	61	5:45	22	50	61	
6:00	60	58	57	42	28	23	20	21	37	48	38	37	33	47	46	48	34	35	49	55	44	61	59	60	58	58	60	58	61	6:00	20	46	61	
6:15	60	59	59	49	36	23	18	21	29	34	38	38	33	41	34	46	30	35	48	45	41	60	58	60	59	58	60	58	62	6:15	18	44	62	
6:30	60	58	58	56	56	46	40	30	47	55	42	31	34	36	29	30	28	30	47	36	40	58	53	60	57	57	59	55	62	6:30	28	46	62	
6:45	60	58	58	58	57	59	55	45	48	54	54	37	37	47	48	49	51	38	32	34	33	43	52	44	59	52	57	56	45	62	6:45	32	49	62
7:00	61	59	59	58	57	59	59	52	51	56	56	53	44	54	54	59	58	53	54	38	44	54	45	58	47	54	40	35	62	7:00	35	53	62	
7:15	60	59	58	56	55	58	53	45	51	57	55	53	44	55	54	59	57	56	56	50	46	56	47	59	50	49	32	34	61	7:15	32	53	61	
7:30	61	60	59	59	58	60	59	49	51	56	56	55	45	54	51	60	59	56	55	45	46	53	45	59	53	56	40	34	62	7:30	34	54	62	
7:45	61	60	59	57	57	59	60	56	54	58	56	57	42	55	54	60	58	57	56	52	47	54	47	60	55	56	40	34	62	7:45	34	55	62	
8:00	61	59	59	58	57	59	57	46	51	56	55	45	43	54	54	60	58	57	56	54	49	57	49	60	56	56	37	34	61	8:00	34	54	61	
8:15	61	60	60	59	58	60	59	52	52	56	56	58	45	56	56	60	58	58	57	59	54	56	49	60	55	55	34	34	61	8:15	34	55	61	
8:30	60	59	58	57	57	59	56	43	45	53	56	55	40	55	54	59	58	56	57	54	49	58	49	60	57	57	42	35	61	8:30	35	54	61	
8:45	61	59	59	57	57	59	55	43	49	55	56	47	38	54	54	59	57	56	56	53	48	53	46	59	56	56	41	35	62	8:45	35	53	62	
9:00	60	60	58	57	56	59	53	39	46	53	55	50	39	53	55	59	58	58	56	50	46	58	47	60	55	53	37	35	61	9:00	35	53	61	
9:15	61	60	59	58	58	60	59	49	52	56	55	44	45	50	55	59	58	57	56	58	52	58	49	60	56	56	42	36	62	9:15	36	54	62	
9:30	62	61	60	59	58	59	61	59	56	58	56	58	53	56	55	59	58	57	57	60	56	58	52	60	57	56	49	36	61	9:30	36	57	62	
9:45	62	62	61	60	59	60	61	60	59	59	57	60	56	58	56	60	58	57	58	60	58	59	57	60	58	57	55	44	61	9:45	44	58	62	
10:00	64	64	62	61	60	60	62	62	60	61	58	62	58	59	58	60	59	58	59	61	60	60	59	60	58	58	61	58	61	10:00	58	60	64	
10:15	64	64	63	62	62	63	63	63	61	62	59	62	51	60	60	63	62	60	61	63	61	61	59	61	59	59	62	57	61	10:15	51	61	64	
Column Summary																																		
Min	58	55	55	42	28	23	18	21	29	34	38	31	33	36	29	30	28	30	34	33	40	52	44	58	47	49	32	34	61	Min	18	44	61	
Avg	61	59	59	56	54	54	51	45	49	55	53	51	43	53	52	56	53	52	54	53	50	58	52	60	56	56	49	44	61	Avg	35	53	62	
Max	64	64	63	62	62	63	63	63	61	62	59	62	58	60	60	63	62	60	61	63	61	62	61	61	60	59	62	60	62	Max	58	61	64	

Figure

Ramp Block Analysis - No Metering																	
Time slice end	Ramp number														Row summary		Overall
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Min	Max	
5:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6:00	0	0	13	85	0	0	0	0	0	0	0	0	0	0	0	85	
6:15	0	0	135	133	0	0	0	0	0	0	0	0	0	0	0	135	
6:30	0	0	141	143	0	0	0	13	0	0	0	0	0	0	0	143	
6:45	0	0	31	0	0	0	0	72	0	0	1	0	0	0	0	72	
7:00	0	0	67	28	0	0	0	19	0	64	0	0	0	0	0	67	
7:15	0	0	133	0	0	37	0	0	0	12	0	0	37	0	0	133	
7:30	0	0	47	0	0	23	0	27	28	85	0	0	98	0	0	98	
7:45	0	0	18	0	0	54	0	0	83	231	29	0	121	0	0	231	
8:00	0	0	46	0	0	67	0	0	0	69	69	0	86	2	0	86	
8:15	0	0	0	0	0	21	0	0	0	78	0	0	97	0	0	97	
8:30	0	0	20	0	0	0	0	0	24	136	41	0	91	0	0	136	
8:45	0	0	0	0	0	25	0	3	0	45	81	0	69	0	0	81	
9:00	0	0	0	0	0	71	0	23	0	21	21	0	107	0	0	107	
9:15	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	24	
9:30	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	
9:45	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	24	
10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	0	0	141	143	0	71	0	72	83	231	81	0	121	2	0	231	
Overall	0	0	651	389	0	298	0	157	135	741	242	0	759	2	0	1524	

Ramp Block Analysis - Metering without Queue Detectors																	
Time slice end	Ramp number														Row summary		Overall
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Min	Max	
5:15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5:45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6:00	0	0	0	85	0	0	0	0	0	0	0	0	0	0	0	85	
6:15	0	0	16	365	0	0	0	0	0	0	0	0	0	0	0	365	
6:30	0	0	0	183	0	77	0	30	0	0	47	0	0	0	0	183	
6:45	0	0	0	80	0	42	0	124	23	199	215	0	0	0	0	215	
7:00	0	0	0	30	0	66	0	134	0	186	122	0	0	0	0	186	
7:15	0	0	0	9	0	20	0	140	0	44	70	0	11	0	0	140	
7:30	0	0	0	0	0	14	0	127	0	122	75	0	43	0	0	127	
7:45	0	0	0	0	0	43	0	96	0	90	103	0	96	11	0	103	
8:00	0	0	0	0	0	51	0	135	0	76	110	0	48	17	0	135	
8:15	0	0	0	0	0	19	0	109	0	65	131	0	19	22	0	131	
8:30	0	0	0	0	0	33	0	144	0	97	109	0	14	18	0	144	
8:45	0	0	0	0	0	38	0	103	0	52	165	0	0	0	0	165	
9:00	0	0	0	0	0	71	0	121	0	0	164	0	16	0	0	164	
9:15	0	0	0	0	0	0	0	94	0	0	33	0	0	0	0	94	
9:30	0	0	0	0	0	0	0	61	0	0	0	0	0	0	0	61	
9:45	0	0	0	0	0	0	0	39	0	0	0	0	0	0	0	39	
10:00	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	29	
10:15	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20	
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Max	0	0	16	365	0	77	0	144	23	199	215	0	96	22	0	365	
Overall	0	0	16	1007	0	474	0	1506	23	931	1344	0	247	68	0	2641	

Figure 22: Metering without queue detectors – Vehicles blocked at on-ramp origins



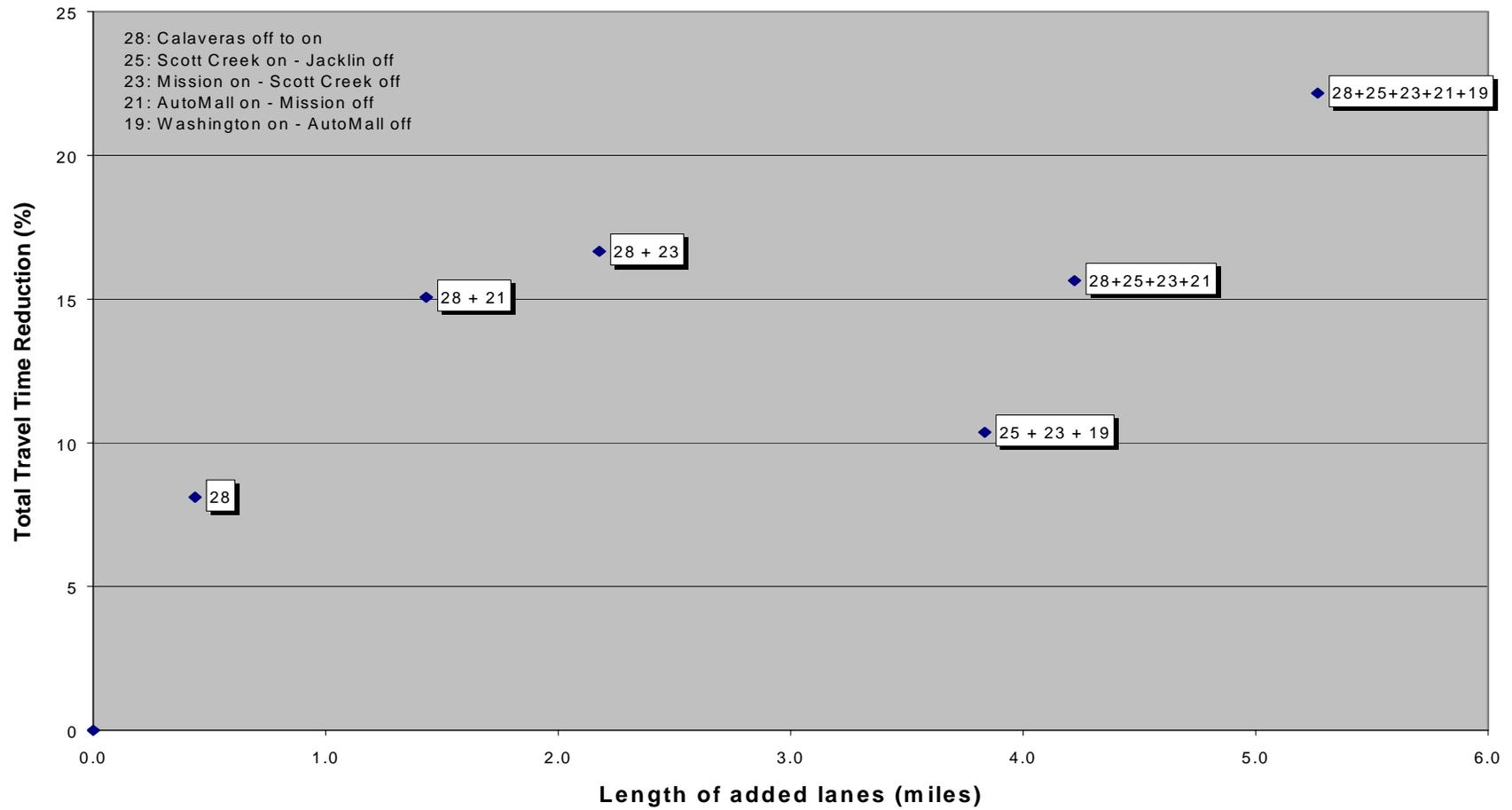
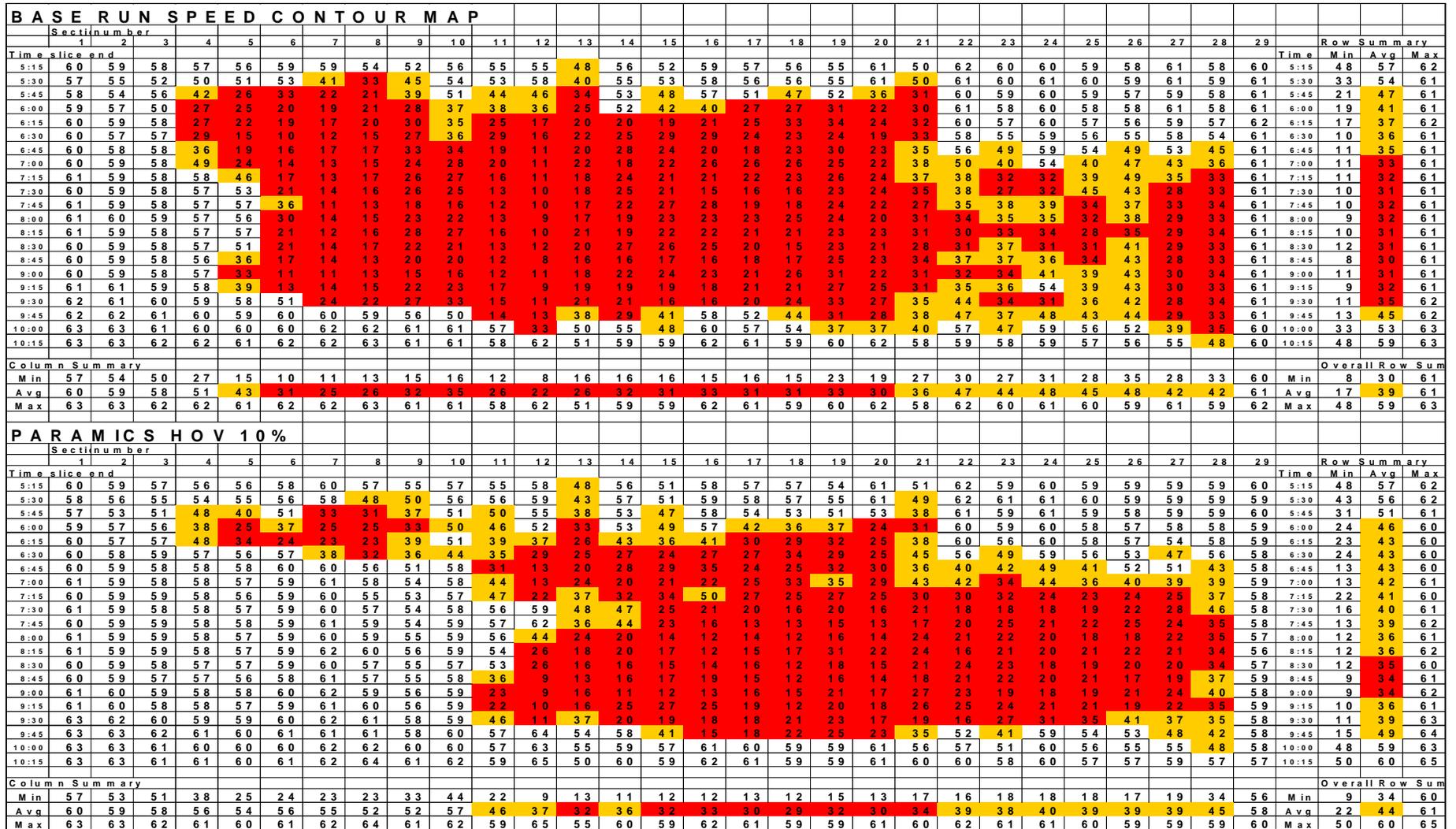


Figure 24: Auxiliary lanes analysis – Impact on overall travel time



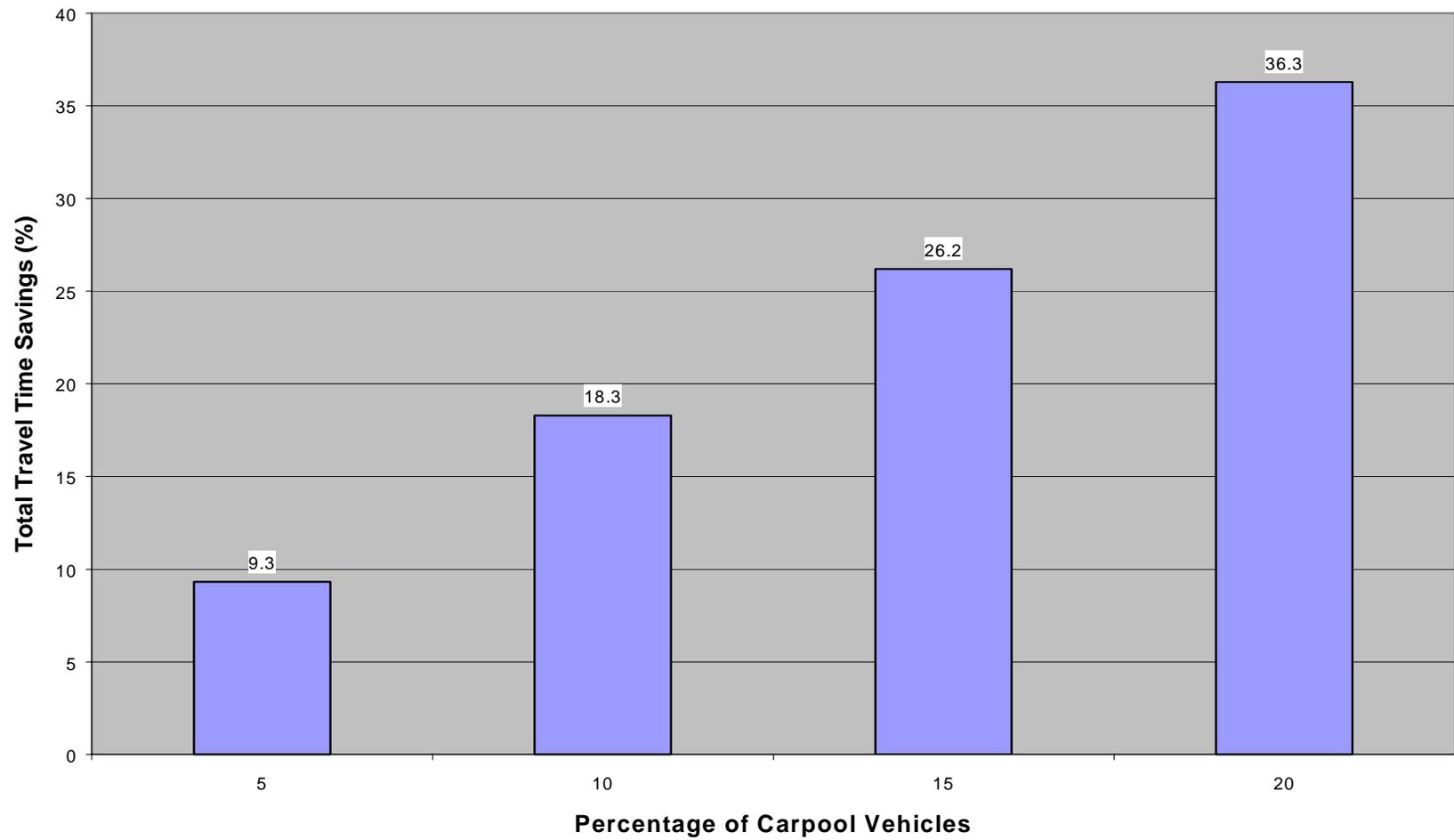


Figure 26: HOV lane analysis – Impact on overall travel time

CHAPTER 10: SUMMARY OF EXPERIMENTS AND FUTURE PLANS

10.1 Summary of Experiments

This research project focused on the investigation of a portion of the southbound morning peak I-680 freeway facility, between I-580 in Pleasanton and SR 237 in San Jose. However, in the initial phase of the project, and prior to the large-scale application, several simple networks were developed to provide the opportunity for conducting some initial experiments with the Paramics model. The intent was to apply the model to very simple situations in which the predicted model results could be compared with known accepted results or observed real-life data. Three test freeway networks were first developed: the lane-drop, ramp merge, and weaving experiments. Another pilot test network was later developed in order to investigate the modeling of ramp metering, including the use of a local traffic-responsive control strategy.

This initial project phase provided not only a valuable learning experience on the model capabilities but also a basis for discussion with a number of partners including Caltrans (Headquarters support team and District 4), Quadstone (Paramics development and support company) and other PATH research teams at UC Irvine and UC Davis working with Paramics.

Once the initial pilot studies had been considered successfully completed, the application to the I-680 network could start. There are three major steps in building a traffic model prior to its use for scenario analysis: data collection, coding input and model calibration.

The work on the I-680 application started with data gathering, which included freeway design features, traffic counts, tachography runs, origin-destination matrices, and FREQ simulation outputs. The modeled network covers 19 miles of I-680 (southbound direction) and includes 15 on-ramps and 12 off-ramps. The study period is the morning peak, from 5 am to 10:15 am.

The network was coded in Paramics to include precise geometric description (curvatures, elevation), allowing the visual aspect of the simulation to be quite realistic. This process involved the use of a network Autocad drawing provided by Caltrans, and its importation into Paramics as an overlay.

The calibration phase of the model was considered critical, as predicted results of uncalibrated models should never be used. As a relatively new tool, few references were available for freeway applications of Paramics. As a result, a process for calibrating Paramics was developed. It consisted in identifying and fine-tuning the key parameters that affect the model outputs, so that the model realistically represents real-life traffic conditions, in terms of predicted flows and speeds.

Finally, once the model was considered calibrated, a number of scenarios were investigated. Improvement options involving the use of ramp metering, added auxiliary lanes or HOV lanes were simulated, and the effects of each strategy could be evaluated.

The I-680 project provided a very useful and timely opportunity for testing the Paramics model capabilities to replicate freeway traffic conditions, and assess to what extent the existing model can simulate various operational strategies such as ramp metering or HOV lane. Existing or potential Paramics model users throughout California will benefit from the lessons learned, especially in the process of calibrating the model to California freeway operations.

However, the final scope of the initial I-680 project was limited due to several external constraints. One limitation had to do with the reference field traffic data set, which was not complete enough to allow for a full comparison between simulated and observed traffic conditions. Another limitation came from the fact that external modules to replicate the effects of HOV lanes and actuated ramp meters were not completed by others and available within the time frame of the initial I-680 project.

10.2 Future Plans

Following up on the initial I-680 study, the research team expects to participate in further applications of Paramics to I-680 and other highly congested corridors in the San Francisco Bay Area. Research such as that presented in this report and planned research will provide Caltrans with tools to evaluate alternatives with a high degree of confidence.

Caltrans District 4 has expressed interest in continuing this investigation on I-680, providing current data and further model testing of freeway improvement alternatives. District 4 staff agreed to collect the necessary traffic data on I-680 for updating the Paramics model. The staff also clearly outlined the freeway development scenarios that they want modeled. Scenario 1 will be the existing conditions. Scenario 2 will add HOV (to existing conditions). Scenario 3 will add ramp metering and new auxiliary lanes.

The new simulation project is a continuation and an extension of the initial Paramics effort. It will serve two purposes in parallel:

- providing an assessment tool for Caltrans District 4 in the development and evaluation of ramp metering and HOV strategies;
- providing a case study for evaluating the standard Paramics model, as well as developing and testing new model functionalities as they become available.

The work on the I-680 network will be extended in several directions, responding to Caltrans' main priorities:

- The calibration will be revisited with a new and more comprehensive data set reflecting recent traffic conditions on I-680. The dataset to be collected includes traffic counts and tach runs.
- The HOV investigations will be further refined by using the newly developed API from Quadstone, which allows to model contiguous HOV lane operation.

- The ramp metering systems to be modeled will reflect more closely the actual operational strategies used by District 4
- Some mixed strategies such as Priority Entry Control combining ramp metering and HOV lanes on I-680 could be tested

District 4 has also identified the I-880 freeway as the second operational site to be modeled. There are several converging reasons for choosing this site. The most important one is that I-880 has been for a number of years among the most congested locations in the Bay Area, providing a real challenge for Caltrans operations engineers. Another reason is that there is a high level of traffic detection equipment in place and a large amount of relevant traffic data already available for this facility. Finally, there is a potential for modifying ramp metering rates if this can be shown to improve the general performance of the freeway corridor. The District 4 staff has requested PATH to use Paramics to model various ramp metering operations strategies.

The new I-880 simulation project will focus on the southbound morning commute, starting before Whipple Road and extending past the Mission Road/Dixon Landing Road bottleneck, which is the section Caltrans district 4 is most interested in.

Reconstruction work on I-880 was completed in December 1998 with the opening of a carpool lane in both directions from Alvarado-Niles Road in Union City to Mission Boulevard in Fremont. The completion of the carpool lane and the activation of ramp metering have helped improve traffic conditions during the morning commute. However, based on the last HICOMP (Highway Congestion Monitoring Program) report issued in 1998, the southbound morning commute on I-880 still ranked number 5 in the Bay Area worst congestion locations. Congestion extends to the Automall Parkway interchange.

Through the simulation analysis, it will be possible to evaluate the impact of the existing ramp metering strategy, evaluating travel times, the reliability of travel times, traffic volumes and throughput, and congestion characteristics. In addition, the model will be very useful in the process of developing and testing new ramp metering strategies, ranging from isolated fixed-time strategies to system-wide coordinated actuated strategies

CHAPTER 11: REFERENCES

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APPENDIX

APPENDIX 1 – PRIORITIES FILE

```
actions 45
phase offset 0.00 sec
phase 1
    0.00
    max 2.00
red phase 0.00
fill
all barred except
from 47 to 44 major
phase 2
    2.00
    max 18.00
red phase 0.00
fill
all barred except
```

APPENDIX 2 – PHASES FILE

```
use plan 1
on node 45 phase 1
with loops
    loop2 lane 1
    loop1 lane 1
    loop1 lane 2
    loop1 lane 3
loop3 lane 1
    loop4 lane 1
loop5 lane 1
```

APPENDIX 3 – PLANS FILE

plan count 1

plan 1 definition

loops 7

line below initialises the signal as variable time

```
if (init) {variable ;}
```

IF statement below implements plan if parameter [1] is greater than 0

```
if ((occupied [1]) or (occupied [7]))  
{
```

```
    if ((occupancy [5]/(occupancy [5]+ gap [5])) < 0.30)
```

```
    {
```

```
        if ((occupancy [6]/(occupancy [6]+ gap [6])) < 0.30)
```

```
        {
```

```
            if (((occupancy [2]/(occupancy [2]+ gap [2])) + (occupancy  
[3]/(occupancy [3]+ gap [3])) + (occupancy [4]/(occupancy [4]+ gap  
[4]))) / 3) < 0.15)
```

```
            {
```

```
                green2 = 2 ; green2 [ + 1 ] = 2 ; report (((occupancy  
[2]/(occupancy [2]+ gap [2])) + (occupancy [3]/(occupancy [3]+ gap  
[3])) + (occupancy [4]/(occupancy [4]+ gap [4]))) / 3);
```

```
                report (occupancy [5]/(occupancy [5]+ gap [5])); report  
(occupancy [6]/(occupancy [6]+ gap [6]));
```

```
            }
```

```
            else if (((((occupancy [2]/(occupancy [2] + gap [2])) + (occupancy  
[3] /((occupancy [3] + gap [3]))+ (occupancy [4]/(occupancy [4] + gap  
[4])))/3) > 0.25)
```

```
            {
```

```
                green2 = 2 ; green2 [ + 1 ] = 18 ; report (((occupancy  
[2]/(occupancy [2]+ gap [2])) + (occupancy [3]/(occupancy [3]+ gap  
[3])) + (occupancy [4]/(occupancy [4]+ gap [4]))) / 3);
```

```
                report (occupancy [5]/(occupancy [5]+ gap [5])); report  
(occupancy [6]/(occupancy [6]+ gap [6]));
```

```
            }
```

```
        else
```

```
        {
```

```
            green2 = 2 ; green2 [ + 1 ] = 2 + 160 *  
(((occupancy[2]/(occupancy [2] + gap [2]))+(occupancy[3]/(occupancy  
[3] + gap [3]))+(occupancy[4]/(occupancy [4]+ gap [4]))/3) - 0.15) ;
```

```
            report (((occupancy [2]/(occupancy [2]+ gap [2])) +  
(occupancy [3]/(occupancy [3]+ gap [3])) + (occupancy [4]/(occupancy  
[4]+ gap [4]))) / 3);
```

```
            report (occupancy [5]/(occupancy [5]+ gap [5])); report  
(occupancy [6]/(occupancy [6]+ gap [6])); }
```

```
        }
```

```
    else
```

```
    {
```

```
        green2 = 0;report (((occupancy [2]/(occupancy [2]+ gap  
[2])) + (occupancy [3]/(occupancy [3]+ gap [3])) + (occupancy  
[4]/(occupancy [4]+ gap [4]))) / 3);
```

```

        report (occupancy [5]/(occupancy [5]+ gap [5])); report
(occupancy [6]/(occupancy [6]+ gap [6]));
    }
}
else
{
    if ((occupancy [6]/(occupancy [6] + gap [6])) < 0.30)
    {
        green2 = 2 ; green2 [ + 1 ] = 2 ; report (((occupancy
[2]/(occupancy [2]+ gap [2])) + (occupancy [3]/(occupancy [3]+ gap
[3])) + (occupancy [4]/(occupancy [4]+ gap [4]))) / 3);
        report (occupancy [5]/(occupancy [5]+ gap [5])); report
(occupancy [6]/(occupancy [6]+ gap [6])); }
    else
    {
        green2 = 0;report (((occupancy [2]/(occupancy [2]+ gap
[2])) + (occupancy [3]/(occupancy [3]+ gap [3])) + (occupancy
[4]/(occupancy [4]+ gap [4]))) / 3);
        report (occupancy [5]/(occupancy [5]+ gap [5])); report
(occupancy [6]/(occupancy [6]+ gap [6]));
    }
}
}
}
else
{
    green2 = 0;report (((occupancy [2]/(occupancy [2]+ gap [2])) +
(occupancy [3]/(occupancy [3]+ gap [3])) + (occupancy [4]/(occupancy
[4]+ gap [4]))) / 3);
    report (occupancy [5]/(occupancy [5]+ gap [5])); report
(occupancy [6]/(occupancy [6]+ gap [6]));
}
}

```