Title
Bay Area Simulation and Ramp Metering Study - Year 2 Report

Authors
Gardes, Yonnel
Kim, Amy
May, Dolf

Publication Date
2003-03-01

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

Bay Area Simulation and Ramp Metering Study – Year 2 Report

Yonnel Gardes, Amy Kim, Dolf May

California PATH Research Report
UCB-ITS-PRR-2003-9

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

Final Report for TO 4106

March 2003

ISSN 1055-1425

Bay Area Simulation and Ramp Metering Study – Year 2 Report

Yonnel Gardes
California PATH

Amy Kim
UC Berkeley

Adolf D. May
UC Berkeley

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

As part of the California PATH program, the Paramics microscopic traffic simulation model was evaluated through a pilot application to the I-680 freeway corridor, one of the most highly congested facilities in the San Francisco Bay Area. The main objective of the project was to test the capability of the model to serve as a tool for evaluating alternative transportation planning and traffic management scenarios.

HOV lanes were investigated first on a “simple” network, and later on the existing I-680 corridor. An Application Programming Interface (API) “plugin” designed by Quadstone, which influences driver behavior regarding HOV lane use, was utilized in an attempt to improve HOV lane simulation. From the existing freeway model to the freeway with an HOV lane, it was found that the total vehicle hours traveled decreased 28 percent and the overall average speed increased 40 percent. Several scenarios were also developed within the I-680 Paramics model as part of a sensitivity analysis, to assess the effects on the network of altering certain input parameters.

Ramp metering was later tested on the calibrated network with the added HOV lane, using various supporting API modules for Paramics developed at PATH. The local actuated ramp control strategy Alinea was implemented and evaluated. It should be noted that Caltrans does not plan to implement the Alinea strategy as tested in the simulation. The report describes the approach used to fine-tune the control strategy, then presents and discusses the results that were obtained. It was found that the overall system performance did not improve after the implementation of ramp control, because the benefits on the mainline freeway did not outweigh the additional delays experienced on the on-ramps. The report identifies a number of factors that may explain why the benefits of ramp metering could have been underestimated in this particular study.

The Paramics model, together with its supporting modules, was found to be an effective and reliable tool for modeling traffic operations on a large-scale and highly congested freeway corridor. It can be used to evaluate the impact of an HOV lane or investigate ramp control metering strategies, and to undertake sensitivity analyses for the various alternative scenarios in a timely and effective way.

However, a number of limitations and shortcomings have been identified, contributing to a likely underestimation of the ramp metering benefits in this study. The most important factor is the absence of route diversion. Because no parallel surface street was modeled, the model did not capture the spatial diversion that is likely to occur when ramp metering is implemented. Another key issue is the ramp queue control process embedded in the Alinea control strategy: because of high demand levels on many on-ramps, the storage capacity is often reached during the simulation period, resulting in an override of the Alinea-optimized metering rate. This phenomenon prevents ramp control to reach the full potential of mainline freeway improvements. Finally, no modal response was considered in the scenario comparisons, which may have contributed to improving the overall system performance with a higher usage of HOV bypass and mainline lanes. These limitations will be addressed in future applications of Paramics to other Bay Area freeways.

ACKNOWLEDGEMENTS

This research was funded by the California Department of Transportation (Caltrans) through the California Partners for Advanced Transit and Highways (PATH) Program.

Several units of Caltrans Headquarters in Sacramento participated in this project. Larry Jellison (New Technologies and Research), Mary Rose Repine and Leo Gallagher (Transportation Systems Information) and Steve Hague (Traffic Operations) provided much valuable time and input into 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, Adrian Levy, Rod Oto and Ray Ovaici were actively involved in the project.

Scott Aitken and Ewan Speirs, from Quadstone in Scotland, provided technical support in applying the Paramics model as well as supporting APIs.

The authors would also like to specially thank the PATH researchers from UC Irvine, Lianyu Chu and Henry Liu, who shared the Paramics APIs they had developed and provided continuous collaboration in applying them to the I-680 project. Finally, Garett Smith, a student working for Caltrans Headquarters, developed and shared the "Report Analyzer" tool used in analyzing the ramp metering results.

CHAPTER 1: INTRODUCTION

1.1 Project scope and objectives

This report describes the second phase of an ongoing research project carried out as part of the California PATH program. The project aims towards developing and applying advanced simulation tools to investigate the effectiveness of traffic management strategies in improving transportation network performance. The particular focus of this research is on modeling freeway operation with the Paramics microsimulation core model and its supporting modules (APIs).

The research has multiple objectives, which includes obtaining an in-depth knowledge of the Paramics core model, testing supporting modules specifically developed for modeling freeway operation, developing and evaluating a calibration process, and assessing the model's ability to serve as a tool for evaluating freeway improvement strategies.

The modeling tool was applied in a pilot study on the I-680 freeway in the San Francisco Bay Area, which provided a case study to test the model and the supporting APIs in a real life environment. A nineteen-mile section of the Interstate 680 (southbound direction) in the San Francisco Bay Area was coded with Paramics. Based on actual traffic counts collected over three days in October 2001, the demand was estimated for the morning peak period. The model was calibrated to replicate the heavy congestion experienced daily on this freeway section, one of the most congested in the Bay Area.

The alternative scenarios that were simulated included adding an HOV lane and implementing a ramp metering scheme. In both cases, the simulation tool required supporting plugins (or APIs) to be used in conjunction with the main Paramics model. The process of calibrating and optimizing the APIs is documented in this report, and the results of the different scenarios are presented and discussed.

1.2 Organization of the report

The first chapters of this report describe the process of collecting the traffic data needed to calibrate and validate the model against current typical traffic conditions. Chapters 2 through 4 cover these initial steps, resulting in a model calibrated for the base traffic conditions.

Alternative scenario investigations started with the addition of an HOV lane. Chapter 5 describes the API that was used on a simple test, while Chapter 6 presents the I-680 investigations. Ramp metering was later added to the network. The process of implementing a particular ramp control strategy (ALINEA) through the use of APIs is described (Chapter 7). Finally, results are presented for the scenario combining an added HOV lane and ramp control (Chapter 8).

CHAPTER 2: DATA COLLECTION ON I-680

2.1 Introduction

One of the major requirements for a simulation study is a reliable and complete dataset covering not only the supply side (network design information), but also the demand side (traffic demand information), and actual traffic performance data. It is only when a complete set of traffic data is available that a model can be calibrated and validated against real-life traffic conditions.

The I-680 network had been previously simulated and calibrated against 1997 data, as described in the first year research report (Reference 1). A number of limitations had been identified during the course of the first year effort. One major issue with the dataset that had been used previously was that the demand information (counts) and traffic performance data had not been collected on the same days. Another problem was that this dataset, dating back to 1997, was outdated and did not reflect current traffic conditions anymore.

The new data needs were discussed with Caltrans District 4, who was to provide most of the resources required to gather the new dataset. In the fall of 2001, Caltrans Headquarters and District 4 decided to embark on an extensive data collection campaign for the purposes of the I-680 simulation project.

The aim was to gather the necessary information required to revisit the earlier calibration of the I-680 Paramics model with a comprehensive new dataset reflecting the most recent traffic conditions on the southbound I-680 during morning peak hours. It was agreed that the various data would be collected simultaneously, which is a critical requirement for simulation purposes.

2.2 Study area

The freeway study site is the southbound I-680 from the I-580 freeway to Route 237 in Milpitas, as shown in Figure 1. The I-680 is a primary north-south transportation corridor for local and inter-regional traffic between Alameda and Santa Clara counties. Over the past several years, traffic congestion has significantly increased during the weekday morning peak commute hours. The I-680 freeway is the only major route that links Silicon Valley with areas farther to the north (Reference 2). On a typical weekday, the congestion spans about 15 miles (24 kilometers) between the cities of Pleasanton and Fremont; this segment of the I-680 was ranked in 1998 as the most congested freeway in the San Francisco Bay Area (Reference 3).

The directional freeway has three lanes, except on a number of sections with an added fourth lane: truck lane from Andrade on to downstream of Sheridan on; collector lane at the Mission 262 interchange; added lane downstream of the Calaveras/237 interchange. Over a distance of nineteen miles, the site includes sixteen on-ramps and fourteen off-

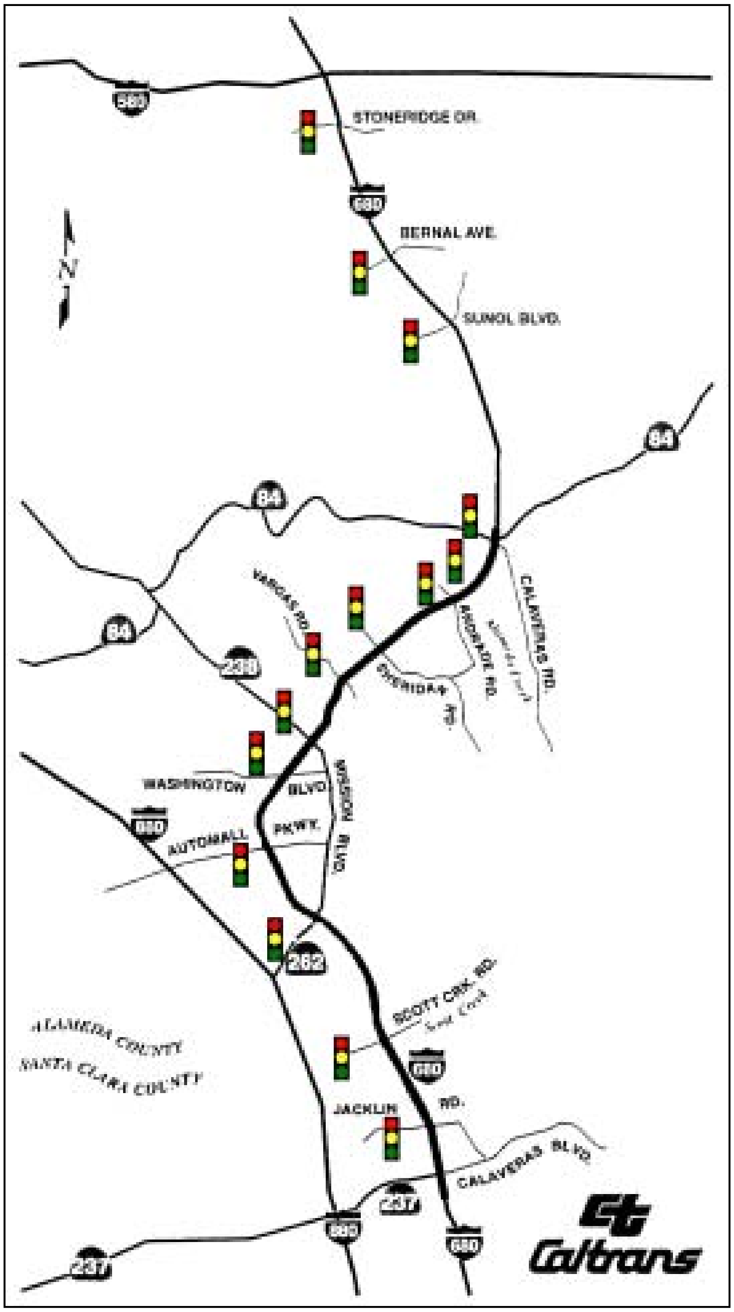

Figure 1: I-680 Site Map

ramps. The study period includes the morning peak period, and extends from 4:30 to 11:15 am. The study was limited to the southbound direction of the freeway and the morning peak period. This selection of spatial and temporal boundaries encompassed the current congested portions of the freeway.

More details on the freeway and interchange geometry are shown in Figure 2.

2.3 Additional data needed

A number of model inputs were already available from the first year effort. In particular, on the supply side, most of the required information had already been gathered and coded within the Paramics model. Some of this information was checked during the new calibration phase, as will be described in Section 3.2.

The additional required data focused on the demand side (counts) and traffic performance information.

2.3.1 Count data

On the demand side, the goal was to gather the information needed to develop a new set of 15-minute origin/destination matrices. As the coded network was limited to the freeway (no parallel surface streets were considered), the demand information to be collected on the I-680 southbound direction included traffic counts at each ramp entrance and exit, and at the freeway mainline origin and destination.

Since the simulation covered the extended morning peak period, it was decided to collect the counts from 5 am to 11 am. In order to capture the variations within the study period, each origin/destination table covered a 15-minute interval, and therefore the counts were also taken at 15-minute intervals.

In addition to the mainline origin and destination counts, additional mainline counts along the freeway section, which would be used in the calibration and validation process, were also undertaken.

2.3.2 Speed data

With regards to the traffic performance information, the main focus was to collect speed data through a series of tachograph runs. Vehicles equipped with the on-board system were driven through the study section, collecting travel times at specific locations, or flag points. From the accurate departure time and time at which the vehicle reaches each flag point, it was possible to plot trajectory graphs and to construct speed contour maps on a

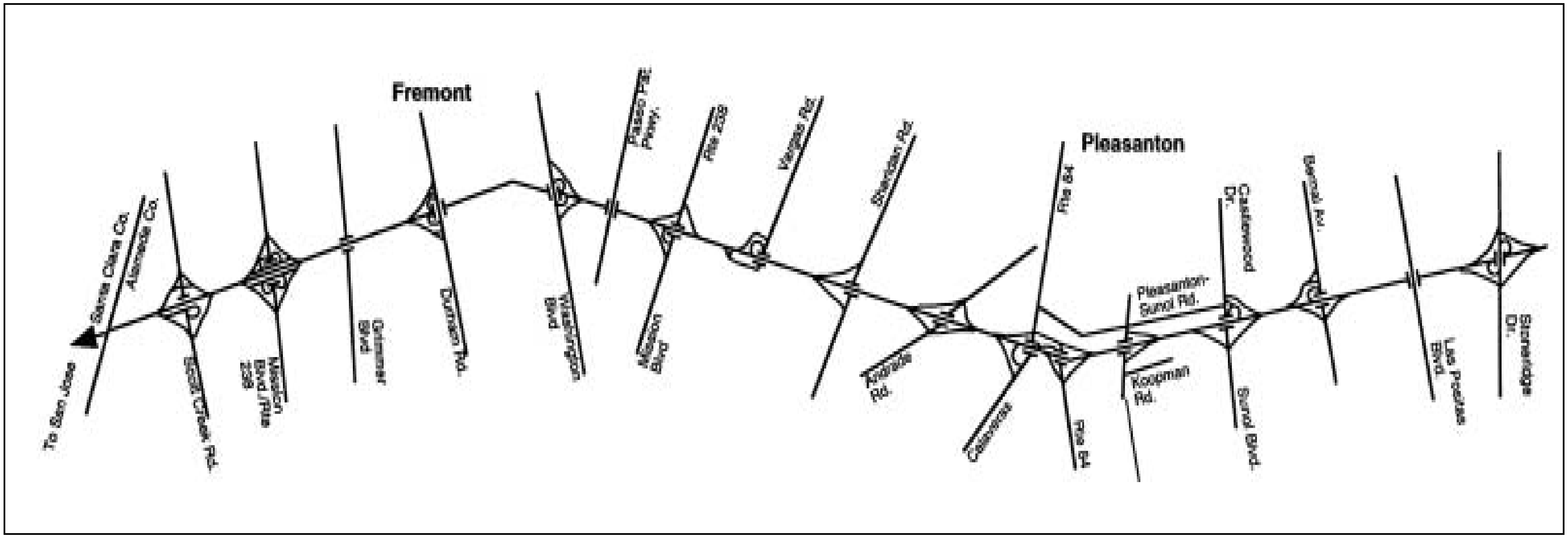

Figure 2: Freeway Section Geometry

time-space diagram. It was identified that tach runs start at 15-minute intervals from 5 am to 10:30 am, and cover the entire study section.

2.3.3 Occupancy data

Passenger occupancy information is important, particularly when investigating the impacts of an added HOV-lane and for studying priority entry control. Therefore, the data collection effort encompassed manual observations of passenger occupancy, allowing for an occupancy distribution analysis for typical days.

2.3.4 Three days of data

In order to obtain typical weekday traffic condition information, data was to be collected over three days, ensuring that at least one day would represent typical traffic conditions.

Given the various requirements and resources available, it was decided to collect the data over three days during the first week of October 2001: the selected days were Tuesday, Wednesday and Thursday, October 2-3-4.

2.4 Organization and resources

The Traffic Operations division of Caltrans District 4 coordinated the data collection effort. The following personnel and equipment resources were used:

- **Tach runs** at 15-minute intervals every day: 6 personnel daily

- **Manual mainline counts** daily at Calaveras (mainline destination): 2 personnel daily

- **Manual mainline occupancy counts** on Tuesday, after Andrade on: 4 personnel (Tuesday only)

- **Manual on-ramp occupancy counts** on Wednesday and Thursday, at selected ramps: 2 personnel daily (Wednesday and Thursday)

- **Automatic mainline counts** daily using monitoring stations/detector loops at Stoneridge (mainline origin), Mission St. and Scott Creek

- **Automatic ramp counts** daily at all on and off-ramps using portable traffic counters.

The portable traffic counters uses Vehicle Magnetic Imaging to record the volume, speed and length classification of vehicles, plus road surface temperature, wet/dry surface conditions, vehicle presence and roadway occupancy. These counters were designed to be adhered to the roadway surface, and did not require any external sensors, loops or tubes. The traffic counter is protected by a due-cast aluminum case that is constructed to withstand the impact of heavy vehicles, and is impervious to oil, fuel, and other chemicals. The portable counters used on the I-680 project are manufactured by Nu-Metrics. Caltrans Headquarters Traffic Operations Division owns a set of counters that can be used upon request by local districts.

2.5 Data collection events

The data collection went as planned. Tuesday and Thursday (October 2 and 4) were relatively incident-free, but there was an accident causing significant congestion on Wednesday on I-580 (east/west freeway intersecting I-680 just north of the study area) that might have affected the study. A summary of the incidents identified by the California Highway Patrol for the three days was obtained.

The portable counters used for collecting ramp counts worked fine, except at two locations: at the Vargas off-ramp, the counter was dislodged and found on the side of the road. Also, at the Route 84 Eastbound on-ramp, the original numbers were suspiciously low; it looked like many vehicles were using the shoulder on this ramp as they rounded the curve. The counter was reinstalled at a better location. For these ramps, the counters were reinstalled and the data was collected again the following week, on October 11 and 12, 2001.

2.6 Preliminary data processing

The data from the portable counters, monitoring stations and loop detectors was initially downloaded and processed by Caltrans District 4 staff. All the 15-minute counts were gathered on a spreadsheet. No further data processing was required, as this spreadsheet could be used directly to prepare the input files needed for the simulation.

Caltrans first plotted the tach runs using the CLOG2 program. CLOG stands for Congestion Location Output Graphics. CLOG2 is a Microsoft Excel spreadsheet with Visual Basic for Applications (VBA) extensions. The program reads the raw data collected by the on-board equipment, and produces the Tachograph plot of the vehicle instantaneous speed along the freeway segment. The link summary information presents travel times and speeds at particular locations called flags. Flag locations (post-miles) are normally generated prior to data collection and they are not modified during data collection.

In the initial data collection, a total of 15 flags, including the origin and destination were included. Caltrans had set the flag locations at each on-ramp in the southbound direction.

Subsection	From	To
2	Stoneridge Loop	Stoneridge Diag On
3	Stoneridge Diag On	Split 1
4	Split 1	Bernal Off
5	Bernal Off	Bernal On
6	Bernal On	Sunol Off
7	Sunol Off	Castlewood On
8	Castlewood On	Split 2
9	Split 2	Koopman Off
10	Koopman Off	Route 84 EB Off
11	Route 84 EB Off	Route 84 EB On
12	Route 84 EB On	Calaveras On
13	Calaveras On	Andrade Off
14	Andrade Off	Andrade On
15	Andrade On	Split 3
16	Split 3	Sheridan On
17	Sheridan On	lane drop
18	lane drop	Vargas Off
19	Vargas Off	Vargas On
20	Vargas On	Mission 238 Off
21	Mission 238 Off	Mission 238 On
22	Mission 238 On	Washington Off
23	Washington Off	Washington On
24	Washington On	Durham Off
25	Durham Off	Durham On
26	Durham On	Mission 262 SB Off
27	Mission 262 SB Off	Mission 262 SB On
28	Mission 262 SB On	Mission 262 NB Off
29	Mission 262 NB Off	Mission 262 NB On
30	Mission 262 NB On	lane drop
31	lane drop	Split 4
32	Split 4	Scott Creek Off
33	Scott Creek Off	Scott Creek On
34	Scott Creek On	Split 5
35	Split 5	Jacklin Off
36	Jacklin Off	Jacklin On
37	Jacklin On	Calaveras Rd Off

Table 1: Subsection Numbering System

Location	Date	5:00	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30
M/L after Stoneridge off	10/2/01	832	932	909	957	978	998	1078	1040	1011	1051	980	883	856	896	786	742	923	961	872	852	814	805	788
Stoneridge Loop On	10/2/01	90	114	69	60	31	39	34	37	32	32	37	41	46	46	33	36	35	32	34	27	37	28	30
Stoneridge Diag On	10/2/01	52	48	29	21	29	35	38	36	32	52	53	93	108	92	66	53	33	44	35	31	35	54	41
Bernal Ave Loop Off	10/2/01	13	36	18	35	40	76	139	123	119	167	202	220	217	195	180	172	188	165	160	138	116	143	126
Bernal Ave Diag On	10/2/01	57	74	59	59	75	80	93	127	153	105	124	130	116	117	105	77	52	68	62	137	152	132	61
Castlewood/Sunol Off	10/2/01	16	30	25	30	47	87	88	156	140	184	118	112	93	91	76	58	52	59	56	137	153	143	39
Castlewood/Sunol On	10/2/01	143	181	153	161	184	201	182	186	205	182	181	139	168	144	147	108	105	74	60	62	54	64	72
Sunol Rd/Koopman Off	10/2/01	24	31	27	58	57	49	43	34	29	26	36	59	85	81	104	107	57	102	96	38	34	41	36
Rte 84 Off	10/2/01	16	37	91	74	107	76	68	75	74	80	116	92	98	96	118	90	82	81	73	94	44	36	28
EB Rte 84 On	10/10/01	335	312	299	281	279	286	312	294	285	264	311	266	241	210	214	215	210	143	137	155	126	146	125
Rte 84/Calaveras On	10/2/01	15	48	146	155	145	132	123	112	132	95	115	120	106	87	75	73	69	72	62	43	30	11	19
Andrade Off	10/2/01	10	12	24	29	29	34	65	66	72	100	141	183	182	236	208	192	173	172	152	123	99	94	37
Andrade On	10/2/01	4	6	6	6	6	6	7	7	12	17	18	16	25	31	16	16	21	18	13	16	15	14	16
Sheridan On	10/2/01	2	6	15	10	16	17	44	45	35	53	96	121	128	168	155	156	125	117	98	93	71	76	7
Vargas Rd Loop Off	10/10/01	2	1	1	4	2	1	2	1	6	2	5	0	2	4	3	6	2	1	2	2	3	3	1
Vargas Rd On	10/2/01	1	2	2	3	4	5	5	10	10	7	11	13	11	4	5	10	12	3	7	7	5	9	14
Mission/Rte238 Off	10/2/01	37	42	68	66	75	69	103	126	141	147	186	174	196	172	203	229	234	176	171	166	145	157	163
Mission/Rte238 On	10/2/01	29	68	79	108	118	159	175	172	169	151	126	142	140	143	120	159	163	154	141	111	95	97	94
Washington Off	10/2/01	32	22	20	38	31	39	38	44	50	65	63	66	59	64	38	41	48	46	38	51	38	59	55
Washington Loop On	10/2/01	19	26	35	51	75	85	107	112	135	143	205	169	176	192	210	179	177	137	105	100	78	81	78
Durham Loop Off	10/2/01	194	191	210	137	106	108	129	138	109	135	102	94	122	93	93	98	85	89	91	84	83	120	126
Durham Diag On	10/2/01	71	51	57	75	116	179	205	261	233	313	345	335	330	340	356	343	326	314	307	267	219	184	162
Mission/Rte262 Diag Off	10/2/01	372	392	381	314	296	236	241	232	251	227	197	231	248	211	209	223	204	220	181	238	259	266	305
Mission/Rte262 Loop Off	10/2/01	1	3	1	0	0	0	1	27	27	55	41	39	27	25	44	44	34	34	70	39	40	18	11
M/L before Rte262 On	10/2/01	673	811	968	1137	1167	1338	1337	1220	1246	1165	1220	1209	1234	1223	1205	1233	1181	1206	1145	1091	1124		
Mission/Rte262 Collector On	10/2/01	9	8	24	36	55	61	101	157	192	188	256	256	230	231	248	211	224	227	210	197	158	108	52
Mission/Rte262 Diag On	10/2/01	39	37	67	93	109	105	117	108	122	124	101	106	101	105	101	106	90	112	115	122	130	169	170
Scott Creek Off	10/2/01	34	42	62	75	98	107	133	113	125	109	112	113	152	138	135	149	127	142	119	109	72	77	88
M/L before Scott Creek On	10/2/01	649	797	904	1161	1172	1385	1406	1317	1402	1380	1431	1476	1395	1410	1395	1438	1370	1367	1326	1304	1361		
Scott Creek On	10/2/01	12	15	14	36	38	27	61	80	59	89	103	119	109	97	99	98	79	71	87	76	74	59	74
Jacklin Rd Off	10/2/01	26	33	36	38	43	43	53	67	52	70	63	68	84	106	98	112	142	119	95	96	91	57	59
Jacklin Rd On	10/2/01	19	28	42	50	46	54	73	118	131	119	188	236	180	136	146	115	85	101	103	105	98	77	84
Rte237/Calaveras Off	10/2/01	181	218	244	333	272	312	332	281	272	295	299	365	291	312	293	264	255	236	218	221	229	211	240
Mainline after Rte237 Off	10/2/01	448	573	569	673	879	1048	981	1066	1176	1238	1240	1230	1246	1241	1113	1148	1114	1154	1089	991	1059	998	887

Table 2a: Tuesday Ramp and Mainline Counts

Location	Date	5:00	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30
M/L after Stoneridge off	10/3/01	720	830	698	663	768	904	1012	1007	1028	1003	967	867	785	740	915	853	890	830	805	825	823	916	816
Stoneridge Loop On	10/3/01	66	127	93	70	53	63	40	46	41	42	35	37	48	47	31	44	40	42	32	31	28	39	39
Stoneridge Diag On	10/3/01	35	20	13	11	16	23	26	34	35	48	63	95	78	83	77	73	44	28	40	38	38	30	33
Bernal Ave Loop Off	10/3/01	10	38	25	31	31	75	127	125	127	158	197	229	237	226	223	208	194	167	146	154	134	117	125
Bernal Ave Diag On	10/3/01	61	83	74	65	86	91	107	133	145	121	109	133	138	129	95	88	103	88	66	81	68	77	56
Castlewood/Sunol Off	10/3/01	11	38	22	22	34	52	70	68	106	88	102	112	75	73	74	71	55	46	46	43	46	36	43
Castlewood/Sunol On	10/3/01	142	185	176	184	188	218	214	258	231	237	207	172	177	167	135	101	101	119	101	72	73	77	76
Sunol Rd/Koopman Off	10/3/01	25	18	33	19	25	31	34	26	41	36	43	40	54	32	39	51	55	63	56	54	45	50	49
Rte 84 Off	10/3/01	19	34	58	32	43	37	57	79	88	73	52	60	81	67	49	95	87	98	117	113	58	36	46
EB Rte 84 On	10/10/01	335	312	299	281	279	286	312	294	285	264	311	266	241	210	214	215	210	143	137	155	126	146	125
Rte 84/Calaveras On	10/3/01	16	55	81	65	80	55	62	73	82	60	52	63	55	48	36	46	51	58	69	61	25	24	26
Andrade Off	10/3/01	7	8	18	11	8	16	45	33	35	47	32	41	83	156	146	201	180	153	155	162	113	82	64
Andrade On	10/3/01	3	6	1	11	9	4	11	4	8	13	7	8	19	11	9	14	11	15	16	12	6	6	16
Sheridan On	10/3/01	2	0	5	6	4	7	23	17	18	25	18	16	51	80	137	143	131	107	119	88	79	51	34
Vargas Rd Loop Off	10/10/01	2	1	1	4	2	1	2	1	6	2	5	0	2	4	3	6	2	1	2	2	3	3	1
Vargas Rd On	10/3/01	0	1	2	2	2	3	5	9	12	9	7	8	7	11	5	5	4	2	7	3	8	7	6
Mission/Rte238 Off	10/3/01	38	54	59	63	77	100	131	145	151	160	173	197	190	215	224	233	212	170	194	173	161	147	138
Mission/Rte238 On	10/3/01	40	59	77	92	112	137	169	163	143	143	126	167	136	124	133	143	188	137	97	93	88	85	78
Washington Off	10/3/01	22	33	34	25	32	43	44	57	65	67	66	64	41	45	46	51	45	46	47	37	60	55	59
Washington Loop On	10/3/01	15	27	41	50	66	78	124	108	131	186	175	198	130	219	204	175	161	142	123	79	115	74	89
Durham Loop Off	10/3/01	197	208	181	138	125	112	117	139	130	152	137	122	116	89	81	75	89	87	99	105	115	122	119
Durham Diag On	10/3/01	58	50	77	90	126	154	220	228	253	298	352	322	281	343	354	362	360	317	288	270	254	190	161
Mission/Rte262 Diag Off	10/3/01	390	364	376	335	233	260	222	256	265	277	230	236	215	216	182	218	211	185	206	235	270	86	71
Mission/Rte262 Loop Off	10/3/01	1	2	2	0	1	2	3	19	5	24	66	50	38	20	30	38	34	35	40	40	26	28	10
M/L before Rte262 On	10/3/01	659	811	1017	1115	1219	1246	1409	1313	1376	1238	1225	1169	1078	1054	1182	1212	1198	1207	1143	1103	1158		
Mission/Rte262 Collector On	10/3/01	4	14	25	37	53	80	87	175	160	211	220	241	189	204	253	268	269	226	216	177	154	111	65
Mission/Rte262 Diag On	10/3/01	36	41	60	67	115	111	120	102	122	112	116	98	95	139	125	121	110	101	131	130	167	128	174
Scott Creek Off	10/3/01	30	45	61	75	87	134	126	151	126	122	133	126	109	114	133	143	112	129	117	86	101	78	78
M/L before Scott Creek On	10/3/01	614	800	972	1124	1200	1323	1427	1445	1482	1404	1442	1378	1262	1240	1408	1436	1416	1403	1412	1317	1351		
Scott Creek On	10/3/01	13	12	27	29	44	42	63	81	70	87	119	123	112	113	96	95	99	75	80	71	89	58	70
Jacklin Rd Off	10/3/01	19	29	34	48	41	45	54	69	62	77	61	85	74	85	107	128	162	113	97	102	79	70	60
Jacklin Rd On	10/3/01	25	30	50	48	57	50	95	89	112	129	175	233	167	161	128	129	104	90	95	91	99	86	79
Rte237/Calaveras Off	10/3/01	171	238	287	282	303	314	286	331	298	287	318	363	326	282	286	280	288	251	245	216	240	216	192
Mainline after Rte237 Off	10/3/01	433	549	641	803	881	984	1173	1243	1228	1225	1300	1230	1074	1073	1175	1170	1083	1103	1210	1061	1109	998	887

Table 2b: Wednesday Ramp and Mainline Counts

Location	Date	5:00	5:15	5:30	5:45	6:00	6:15	6:30	6:45	7:00	7:15	7:30	7:45	8:00	8:15	8:30	8:45	9:00	9:15	9:30	9:45	10:00	10:15	10:30
M/L after Stoneridge off	10/4/01	831	892	880	912	944	1022	1025	1036	991	1002	980	930	823	876	885	833	938	969	982	878	861	882	858
Stoneridge Loop On	10/4/01	96	96	60	51	44	24	32	20	32	36	31	28	41	46	35	29	24	28	28	27	30	28	30
Stoneridge Diag On	10/4/01	57	42	20	16	28	22	25	36	32	44	60	91	83	81	67	46	37	31	37	40	31	28	39
Bernal Ave Loop Off	10/4/01	10	40	23	30	34	91	141	124	137	146	231	284	202	202	192	180	202	165	152	161	145	143	126
Bernal Ave Diag On	10/4/01	56	80	61	66	80	94	92	126	132	124	125	128	110	120	100	78	76	64	65	73	64	132	61
Castlewood/Sunol Off	10/4/01	8	26	20	31	40	54	59	78	81	100	95	76	73	68	66	42	61	44	55	59	43	143	39
Castlewood/Sunol On	10/4/01	137	170	183	155	194	206	216	209	224	221	222	173	136	159	145	111	96	89	58	72	76	64	72
Sunol Rd/Koopman Off	10/4/01	20	19	31	30	31	49	66	59	34	53	44	30	45	60	49	52	54	69	98	59	34	41	36
Rte 84 Off	10/4/01	22	22	80	70	105	81	93	79	105	95	114	74	80	61	115	69	90	99	102	99	81	36	28
EB Rte 84 On	10/11/01	287	309	268	274	256	292	298	320	306	267	323	294	273	246	255	205	170	154	189	129	120	108	96
Rte 84/Calaveras On	10/4/01	11	39	100	92	126	116	112	85	78	70	103	57	69	43	73	56	46	61	54	62	34	11	19
Andrade Off	10/4/01	14	12	5	28	24	33	32	32	40	47	93	162	174	212	211	200	156	158	145	151	111	94	37
Andrade On	10/4/01	4	7	10	15	18	3	23	14	8	16	15	15	17	10	23	13	19	12	12	24	16	14	16
Sheridan On	10/4/01	1	4	5	12	9	8	19	14	16	13	38	95	106	133	142	136	116	94	95	91	78	76	7
Vargas Rd Loop Off	10/11/01	3	1	1	1	3	2	3	3	2	1	0	3	2	2	1	4	4	0	8	3	5	3	1
Vargas Rd On	10/4/01	2	0	1	1	4	3	5	7	13	8	10	5	10	8	6	13	11	8	6	6	8	9	14
Mission/Rte238 Off	10/4/01	35	61	66	63	68	98	121	138	163	181	186	186	202	195	218	210	213	171	163	163	164	157	163
Mission/Rte238 On	10/4/01	37	72	80	90	112	140	143	171	158	139	135	146	137	137	152	158	158	155	87	119	98	97	94
Washington Off	10/4/01	24	35	22	28	37	38	48	67	61	64	69	58	50	52	42	39	52	45	37	38	43	59	55
Washington Loop On	10/4/01	10	32	38	43	73	72	105	110	147	193	195	164	183	202	175	206	154	139	119	97	71	81	78
Durham Loop Off	10/4/01	181	235	198	148	111	98	104	141	133	110	113	113	94	116	83	86	78	71	70	103	94	120	126
Durham Diag On	10/4/01	58	59	65	104	137	163	252	260	254	299	337	359	302	344	368	353	361	326	287	242	214	184	162
Mission/Rte262 Diag Off	10/4/01	341	397	376	338	264	243	226	248	266	242	215	237	244	221	210	196	200	207	180	218	277	249	222
Mission/Rte262 Loop Off	10/4/01	1	1	2	1	0	3	5	13	38	39	46	37	23	39	47	30	47	35	32	30	40	18	11
M/L before Rte262 On	10/4/01	579	914	1014	1139	1248	1343	1356	1326	1265	1229	1247	1155	1258	1214	1232	1216	1258	1198	1141	1187	1164		
Mission/Rte262 Collector On	10/4/01	5	11	28	32	55	69	103	157	192	230	230	231	223	251	259	246	243	226	213	161	141	108	52
Mission/Rte262 Diag On	10/4/01	39	43	87	79	108	130	119	123	103	119	105	98	105	114	95	105	111	97	133	133	141	169	170
Scott Creek Off	10/4/01	24	52	61	95	91	107	119	132	141	119	124	111	130	150	132	148	122	128	125	95	85	77	88
M/L before Scott Creek On	10/4/01	559	857	962	1134	1320	1339	1438	1456	1383	1449	1426	1394	1427	1430	1438	1431	1455	1404	1338	1381	1328		
Scott Creek On	10/4/01	7	17	21	21	43	48	58	87	62	83	132	114	102	95	96	82	77	67	70	76	80	59	74
Jacklin Rd Off	10/4/01	21	35	34	29	58	54	43	51	54	64	70	71	100	108	111	128	153	96	99	88	74	57	59
Jacklin Rd On	10/4/01	19	24	42	46	60	47	78	105	120	121	182	231	155	169	133	114	96	96	88	104	89	77	84
Rte237/Calaveras Off	10/4/01	162	242	264	275	291	308	314	296	276	310	311	363	311	332	308	293	272	255	250	248	248	223	198
Mainline after Rte237 Off	10/4/01	394	536	636	811	944	1026	1110	1274	1126	1208	1336	1236	1180	1193	1180	1424	1165	1156	975	1203	1106	998	887

Table 2c: Thursday Ramp and Mainline Counts

The resulting link summary information contained 14 freeway sections for which travel times and speeds were available.

However, a problem was identified with this approach. The resulting link-by-link speed information derived from the tach runs was not accurate enough to allow for a comparison with the speed data gathered by the simulation model. Both simulation models to be used in this study, FREQ and Paramics, use link subsections that are more disaggregate than the on-ramp to on-ramp pattern initially used in the tach runs. FREQ uses a different subsection at each on or off-ramp, or changes in the design features such as lane additions or drops. Paramics uses an even more disaggregate structure, with additional nodes and links required at each change in curvature, in addition to changes in the design features.

In order to ensure consistency between the different approaches for aggregating speed data, it was decided to use the FREQ definition for construction the subsection breakdown. As a result, a total of 37 subsections were used, as shown in Table 1.

A new tach run analysis with CLOG2 was necessary. In order to match the new subsection structure, the additional flag points were coded, and new tach plots and link summary tables were produced.

2.7 Analysis of count data

The fifteen-minute counts gathered at each on and off ramps from 5 AM to 11 AM, and at four locations around the mainline freeway are presented on Tables 2a through 2c.

One way of analyzing the dataset is to compare the total number of vehicles entering the system (at mainline origin and all on-ramps) with the total number of vehicles leaving the system (at mainline destination and all off-ramps). This analysis was performed for the three days, for the period from 5 AM to 11 AM.

The following table, Table 3, presents the results.

	Total input flows (veh)	Total output flows (veh)	Difference OUTS-INS (veh)	Ratio diff/INS (%)
Tuesday, 10/02	60,582	57,992	-2,590	-4.3
Wednesday, 10/03	58,432	56,541	-1,891	-3.2
Thursday, 10/04	60,059	58,241	-1,818	-3.0

Table 3: Analysis of Total Number of Vehicles Counted

One reason that can explain why the total OUTS-INS have an apparent “error”é the greater vehicle density at 11AM compared to 5AM. An increase in approximately 30 veh/m/l density would explain the difference.

Another interesting analysis consists in plotting the total number of vehicles passing through a given freeway location, for the different days. Figure 3 shows the graph representing the total number of vehicles counted at the four mainline count locations. It confirms that similar patterns were observed for the three days, in terms of total number of vehicles. Wednesday is shown to have slightly lower flows at three locations; however, at the fourth location (mainline destination), flows were lower on Tuesday than Wednesday and Thursday. This could be due to minor incidents in the downstream part of the study area on Tuesday that would have delayed vehicles. Another reason for the sum of inputs to be greater than the sum of outputs is counter errors.

2.8 Tach runs analysis

2.8.1 Speed contour maps

Speed contour maps were constructed using the information gathered from the tach runs, which were initiated every 15 minutes from 5 AM to 11 AM. Time slices were set at minute intervals on the vertical axis of the time-space diagram. The 37 freeway subsections on the horizontal axis were determined based on the approach described in Section 2.6 and shown in Table 1. Speeds for a given subsection at a given time were entered into the appropriate box in the time-space diagram. After all available tach run data was entered into the matrix, blank boxes were filled using the average of the previous and following time period’s speed.

The resulting 15-minute speed contour maps for the three days of tach run measurements are shown in Figures 4a, 4b and 4c. Three levels of speed are identified on the figures: the unshaded regions represent speeds greater than 50 mph; speeds from 40 to 49 mph are shaded in light gray, and speeds lower than 40 mph are shaded in dark gray.

2.8.2 Total trip time

Another way to look at the tach run data is to compute and plot the total travel time required to traverse the entire freeway section, from the Stoneridge loop on-ramp to the Calaveras off-ramp. Figure 5 presents the results of this analysis, for the three days of tach run measurements available.

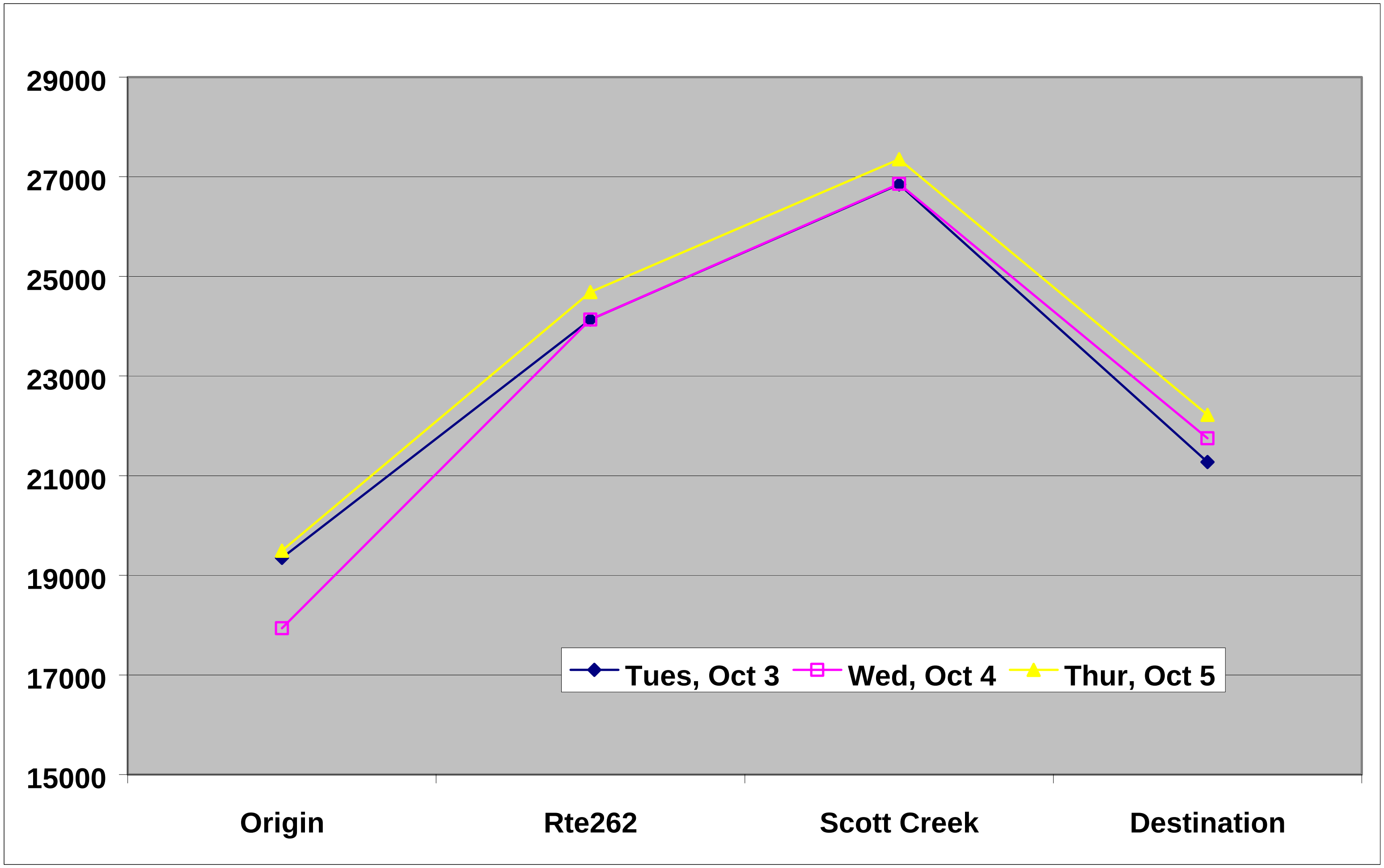

Figure 3: Mainline Counts - Overall Number of Vehicles per Day

I-680 SB — **TACH RUNS SPEED CONTOUR MAP** — **October 2 (Tuesday)**

Interval Start	0	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	30	31	32	33	34	35	36	37	Row Summary Min	Avg	Max
	Section number																																								
5:00			49	61	65	65	63	68	60	66	64	66	60	59	61	58	46	47	28	48	56	59	61	59	62	61	62	63	64	64	62	64	65	64	64	62	60	62	28	60	68
5:15			42	65	65	63	61	66	61	63	55	59	62	56	38	39	18	36	39	44	45	56	59	59	62	61	62	63	64	64	62	64	65	64	64	62	60	62	18	56	66
5:30			50	65	66	66	66	66	66	62	43	12	11	26	51	51	49	43	48	43	53	53	56	58	58	57	60	63	65	65	63	61	62	61	69	72	63	41	11	55	72
5:45			51	61	61	59	60	61	55	24	27	22	34	34	41	44	33	27	33	51	50	53	53	58	58	61	65	65	65	65	65	65	65	65	32	58	55	49	22	51	65
6:00			50	64	64	65	64	65	44	36	23	22	28	30	46	41	31	24	28	45	46	52	56	59	56	53	59	61	61	61	59	58	61	57	58	57	54	56	22	50	65
6:15			63	64	64	64	64	29	34	20	19	21	22	26	51	37	29	22	22	39	52	53	50	57	53	54	57	60	60	59	59	59	62	59	60	60	59	54	19	48	64
6:30			51	65	65	66	65	48	29	21	21	19	35	28	44	23	32	23	31	39	35	46	48	51	48	57	60	61	58	56	55	60	64	60	62	63	64	53	19	47	66
6:45			46	62	62	63	61	42	18	33	14	17	28	35	31	36	19	19	25	38	47	40	41	48	35	45	44	40	44	45	42	50	59	64	64	64	63	53	14	43	64
7:00			51	65	66	66	65	47	17	35	17	25	34	31	36	27	29	26	30	47	17	25	31	37	27	39	27	19	29	34	28	40	62	57	58	55	48	48	17	39	66
7:15			51	63	63	53	31	49	22	32	15	17	24	34	46	39	11	25	27	24	39	10	36	48	24	34	24	26	22	25	31	46	62	63	61	65	63	48	10	38	65
7:30			53	65	64	60	47	53	26	36	16	10	28	37	48	13	13	14	12	31	14	11	26	30	23	30	15	21	21	23	33	33	62	65	58	55	55	53	10	35	65
7:45			55	66	66	66	64	57	30	39	17	13	23	26	33	11	11	13	15	21	17	11	16	12	23	24	18	25	24	24	25	40	62	63	60	56	53	41	11	34	66
8:00			48	63	63	65	64	64	59	37	10	16	17	14	19	9	8	13	15	21	17	13	18	11	22	21	19	21	22	21	26	34	58	62	60	57	55	48	8	33	65
8:15			46	63	65	63	63	63	58	21	14	10	13	20	25	11	7	12	18	11	21	14	20	11	21	21	19	21	22	21	26	34	58	62	60	57	55	48	7	33	65
8:30			47	65	65	65	65	66	49	28	17	7	22	22	11	13	8	15	22	34	17	14	12	25	16	18	20	17	19	18	26	27	54	60	60	59	57	55	7	33	66
8:45			48	63	64	64	62	63	62	25	18	11	5	24	20	9	10	8	18	39	19	11	15	12	23	17	17	21	28	26	24	38	59	57	60	62	60	53	5	34	64
9:00			47	63	65	65	65	65	65	65	19	12	10	17	16	7	9	13	26	8	21	15	17	18	16	25	20	18	23	22	36	45	61	66	57	60	54	40	7	35	66
9:15			58	65	66	67	66	67	66	61	16	13	16	15	10	11	13	10	21	20	21	10	17	29	16	20	19	22	17	26	21	30	60	64	62	67	67	66	10	36	67
9:30			50	65	65	66	65	64	65	60	35	9	21	28	31	8	11	7	17	8	24	16	15	27	18	25	19	30	35	23	30	42	61	62	63	63	57	49	7	37	66
9:45			44	64	67	58	63	63	63	65	32	17	31	17	28	10	18	8	8	26	38	26	4	31	21	30	16	21	16	20	30	36	59	59	60	64	65	65	4	37	67
10:00			49	65	66	66	65	66	66	66	65	45	28	23	25	18	14	22	14	18	21	23	20	15	26	18	20	22	26	16	28	28	51	62	55	64	64	60	14	39	66
10:15			43	61	62	62	61	62	62	62	64	64	63	37	25	13	14	20	28	35	26	30	35	34	31	30	27	25	14	21	28	44	68	60	61	60	55	48	13	43	68
10:30			50	61	65	65	64	65	65	65	64	51	46	44	45	40	36	42	40	42	33	45	38	26	23	48	31	31	29	25	37	45	59	60	62	61	60	57	23	48	65
10:45			48	63	64	63	63	63	63	64	64	56	64	65	64	62	58	63	65	67	44	21	37	56	47	49	51	28	42	39	28	42	61	59	64	63	58	53	21	54	67
11:00			52	66	65	65	65	65	65	65	65	66	70	66	66	63	60	64	66	68	67	67	67	67	63	64	64	62	61	62	63	62	66	65	66	67	60	58	52	64	70
Column Summary																																							Overall Row Summary		
Min			42	61	61	53	31	29	17	20	10	7	5	14	10	7	7	7	8	8	14	10	4	11	16	17	15	17	14	16	21	27	51	57	32	55	48	40	Min 4	24	61
Avg			50	64	65	64	62	59	51	46	33	27	32	33	37	28	23	25	28	35	34	31	34	37	35	39	36	36	37	37	39	46	61	62	60	61	58	53	Avg 23	43	65
Max			63	66	67	67	66	68	66	66	65	66	70	66	66	63	60	64	66	68	67	67	67	67	63	64	65	65	65	65	65	65	68	66	69	72	67	66	Max 60	66	72

Figure 4a: Tuesday Tach Run Speed Contour Map

I-680 SB					TACH RUNS SPEED CONTOUR MAP																																			October 3 (Wednesday)		
	Section number																																							Row Summary		
Interval Start	0	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	30	31	32	33	34	35	36	37		Min	Avg	Max
5:00			49	65	66	66	66	66	64	66	66	65	66	66	66	63	48	53	59	65	64	57	65	66	60	58	65	66	66	66	66	66	66	66	66	66	66	66		48	63	66
5:15			46	63	64	62	62	65	63	64	60	60	56	54	57	51	47	55	56	59	53	56	63	66	63	62	63	64	62	65	66	64	64	64	66	66	66	66		46	61	66
5:30			54	63	64	65	64	65	63	65	61	40	32	42	50	50	42	51	55	55	55	57	61	61	58	59	62	59	59	61	64	63	63	62	64	62	61	63		32	58	65
5:45			51	64	64	63	64	66	63	63	63	63	63	49	56	50	38	48	53	52	57	57	59	56	53	57	60	55	55	57	62	63	64	64	64	64	64	55		38	58	66
6:00			56	62	65	62	62	64	62	62	63	63	62	55	57	48	42	48	48	42	49	40	54	65	54	56	59	65	64	64	64	64	63	65	64	65	64	65		40	58	65
6:15			53	63	63	64	64	70	66	71	62	62	62	60	58	45	45	47	43	47	38	38	47	59	59	61	64	63	63	62	62	61	66	65	65	65	64	62		38	59	71
6:30			52	67	67	67	67	68	67	64	66	61	64	48	28	44	34	50	53	42	36	43	37	48	57	52	62	57	61	55	46	51	61	57	61	60	51	43		28	54	68
6:45			50	64	63	64	63	62	62	63	45	32	37	42	52	41	29	45	34	42	32	38	26	47	44	43	58	39	37	44	42	53	57	64	63	67	67	67		26	49	67
7:00			48	63	64	64	63	65	64	64	38	16	22	38	56	51	39	49	29	33	27	33	38	39	29	55	57	53	55	60	62	58	63	63	61	58	56	60		16	50	65
7:15			52	62	64	64	64	62	59	17	55	55	38	34	59	60	48	53	24	24	18	46	26	39	31	57	43	33	40	20	44	49	62	64	60	57	59	61		17	47	64
7:30			51	66	67	65	65	60	19	21	57	62	64	38	52	57	35	33	23	20	25	46	21	46	26	28	31	24	31	20	27	40	61	64	60	57	61	62		19	44	67
7:45			49	64	65	63	63	55	18	22	58	61	57	64	61	62	20	26	27	30	22	18	13	25	21	22	20	15	22	20	28	27	47	66	60	65	65	65		13	41	66
8:00			55	64	65	65	65	66	30	34	49	51	29	37	55	57	32	15	11	20	23	10	17	8	17	17	19	16	16	14	19	29	63	62	65	65	60	59		8	38	66
8:15			51	63	63	63	62	64	61	62	62	57	35	43	30	12	11	10	18	14	11	8	13	10	9	26	27	16	27	19	32	49	60	61	60	57	64	45		8	38	64
8:30			43	63	64	65	64	65	64	65	64	65	65	58	19	9	6	6	25	24	17	16	9	12	19	12	18	17	19	17	13	39	58	60	59	59	64	54		6	39	65
8:45			51	64	63	63	63	64	63	63	63	12	13	21	8	7	10	6	19	25	18	12	11	11	14	18	17	19	26	29	17	29	55	58	57	61	64	62		6	35	64
9:00			50	65	66	65	66	63	64	65	63	16	12	24	44	12	8	7	13	27	19	8	10	31	16	22	16	23	30	26	20	36	60	58	61	58	54	55		7	37	66
9:15			45	65	65	64	64	64	64	67	55	10	11	13	18	5	10	9	26	10	24	27	10	27	18	25	14	26	35	24	22	44	56	45	55	58	56	46		5	35	67
9:30			55	67	67	67	67	67	67	67	31	12	10	14	22	7	11	18	17	17	23	22	16	14	23	19	22	17	36	18	26	31	56	61	56	60	61	59		7	36	67
9:45			49	63	63	62	61	64	63	63	30	13	21	28	21	19	11	11	18	10	30	15	19	33	23	15	20	20	16	18	21	41	59	61	63	62	55	51		10	36	64
10:00			46	63	65	65	65	65	65	65	35	54	55	31	23	12	12	20	25	12	25	49	20	31	27	23	25	32	10	26	26	41	61	62	60	61	66	59		10	41	66
10:15			53	66	66	64	64	66	64	66	65	65	65	61	25	52	14	17	22	33	14	28	31	34	28	29	22	32	37	46	33	44	61	62	60	57	49	54		14	46	66
10:30			53	66	66	65	65	64	65	65	64	66	67	65	47	24	29	22	26	39	52	43	25	52	47	42	50	29	17	31	48	43	57	58	63	65	65	64		17	50	67
10:45			43	66	64	64	67	65	61	63	61	64	61	57	58	55	58	64	69	70	27	52	44	58	42	53	51	54	56	47	40	33	59	62	59	58	59	57		27	56	70
11:00			43	66	64	64	67	65	61	63	61	64	61	57	58	55	58	64	69	70	66	70	64	66	64	64	64	65	66	67	67	59	64	69	66	62	72	55		43	63	72
Column Summary																																							Overall Row Summary			
Min			43	62	63	62	61	55	18	17	30	10	10	13	8	5	6	6	11	10	11	8	9	8	9	12	14	15	10	14	13	27	47	45	55	57	49	43	Min	5	26	63
Avg			50	64	65	64	64	64	58	58	56	48	45	44	43	38	29	33	35	35	33	36	32	40	36	39	40	38	40	39	41	47	60	62	61	61	61	58	Avg	29	48	65
Max			56	67	67	67	67	70	67	71	66	66	67	66	66	63	58	64	69	70	66	70	65	66	64	64	65	66	66	67	67	66	66	69	66	67	72	67	Max	56	66	72

Figure 4b: Wednesday Tach Run Speed Contour Map

I-680 SB — TACH RUNS SPEED CONTOUR MAP — October 4 (Thursday)

Section number

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Row Summary Avg	Row Summary Max
5:00			48	63	60	57	58	59	59	63	57	59	61	61	61	52	50	41	30	49	57	59	52	60	54	55	62	54	50	60	64	63	64	64	63	63	59	57		30	57	64
5:15			49	63	63	61	61	63	63	63	47	41	43	54	55	52	50	41	30	49	57	59	52	60	54	55	62	54	50	60	64	63	64	64	63	63	59	57		30	56	64
5:30			50	63	65	66	64	67	66	63	36	23	25	47	48	45	42	50	53	53	51	44	55	60	56	58	62	59	57	62	64	63	65	63	61	61	58	57		23	55	67
5:45			53	67	68	68	67	71	68	62	38	31	36	44	40	54	55	52	57	47	38	46	58	60	58	61	63	65	64	64	64	63	65	61	59	59	57	57		31	57	71
6:00			51	66	66	66	65	57	62	63	40	21	15	35	24	48	45	44	42	49	47	47	57	56	54	58	59	60	60	62	59	59	60	59	58	69	55	45		15	52	69
6:15			46	62	63	62	61	60	60	61	23	17	12	39	53	51	48	41	41	52	51	40	42	45	42	44	47	42	52	56	61	63	57	59	57	60	61	55		12	50	63
6:30			48	64	64	65	64	65	60	41	23	17	27	41	53	47	43	42	41	48	47	37	38	38	37	51	57	57	58	50	38	43	53	59	61	58	55	49		17	48	65
6:45			53	65	65	66	66	67	64	50	34	20	18	42	53	43	38	42	41	45	42	34	34	30	31	45	46	48	49	50	53	45	53	54	60	60	62	52		18	48	67
7:00			50	65	66	66	66	66	65	47	31	16	18	29	54	56	50	21	23	31	29	19	31	55	39	35	32	16	38	28	25	33	52	64	63	55	58	57		16	43	66
7:15			48	63	60	59	59	62	58	62	22	20	29	31	60	58	27	19	25	38	29	27	22	17	23	28	18	19	27	33	29	41	61	61	48	59	61	54		17	41	63
7:30			43	66	67	67	67	67	65	67	37	13	16	33	48	36	14	26	32	28	15	35	17	22	22	27	18	17	21	27	31	43	60	59	53	62	60	54		13	40	67
7:45			52	62	64	63	62	63	63	65	37	15	23	34	36	24	13	38	8	10	17	16	20	36	19	22	19	15	16	21	33	46	58	58	58	65	58	55		8	38	65
8:00			48	62	64	64	64	64	62	63	37	17	30	34	23	12	8	15	19	15	19	13	11	19	16	18	18	27	21	22	31	30	51	59	58	60	60	59		8	36	64
8:15			67	67	66	60	66	66	66	66	61	13	21	23	28	11	7	12	23	24	17	17	15	24	26	27	16	23	26	25	24	44	60	62	59	60	59	60		7	39	67
8:30			51	67	67	67	65	64	64	65	26	13	22	15	6	8	16	8	27	33	15	20	18	29	16	18	17	23	21	28	29	40	59	60	61	62	62	62		6	37	67
8:45			49	67	69	69	66	69	63	62	35	15	20	17	35	10	6	14	15	6	17	17	15	18	17	21	17	23	15	32	33	36	59	58	63	64	64	64		6	37	69
9:00			53	66	64	64	65	66	65	67	68	20	18	18	9	9	8	10	14	25	12	23	13	12	17	23	23	42	51	53	55	53	61	59	63	64	56	59		8	40	68
9:15			52	62	60	58	60	63	64	64	55	8	22	20	16	10	7	20	8	14	21	10	23	12	21	28	21	19	23	25	23	43	55	59	62	60	59	55		7	36	64
9:30			48	65	65	65	65	65	65	65	21	12	23	20	17	11	8	22	9	23	21	11	15	36	20	14	19	23	20	25	44	44	55	64	64	69	58	37		8	36	69
9:45			43	66	67	67	67	63	67	67	66	10	22	20	19	13	11	16	11	21	20	19	13	19	25	23	21	20	16	25	27	32	52	62	61	61	62	60		10	37	67
10:00			51	66	64	66	64	64	66	65	63	14	22	18	28	20	7	28	13	19	19	26	32	15	28	31	31	27	26	22	28	36	52	54	64	65	65	63		7	39	66
10:15			44	65	69	70	65	67	64	67	44	43	27	39	36	28	13	22	11	36	46	49	41	54	49	35	29	34	36	22	19	24	52	57	55	60	58	53		11	44	70
10:30			51	65	65	65	62	62	61	66	54	54	46	52	50	14	26	56	63	59	50	43	35	13	35	55	49	31	36	32	31	46	57	60	61	64	60	55		13	50	66
10:45			51	65	65	65	62	62	59	64	64	65	65	65	64	48	26	60	66	66	64	62	65	65	64	65	65	65	65	64	64	61	65	64	62	65	61	57		26	62	66
11:00			51	65	65	65	62	62	59	64	64	65	65	65	64	48	26	60	66	66	64	62	65	65	64	65	65	65	65	64	64	61	65	64	62	65	62	58		26	62	66
Column Summary																																							Overall Row Summary			
Min			43	62	60	57	58	57	58	41	21	8	12	15	6	8	6	8	8	6	12	10	11	12	16	14	16	15	15	21	19	24	51	54	48	55	55	37	Min	6	28	62
Avg			50	65	65	64	64	64	63	62	43	26	29	36	39	32	26	32	31	36	35	33	34	37	35	38	37	37	38	40	42	47	58	60	60	62	60	56	Avg	26	45	65
Max			67	67	69	70	67	71	68	67	68	65	65	65	64	58	55	60	66	66	64	62	65	65	64	65	65	65	65	64	64	63	65	64	64	69	65	64	Max	55	65	71

Figure 4c: Thursday Tach Run Speed Contour Map

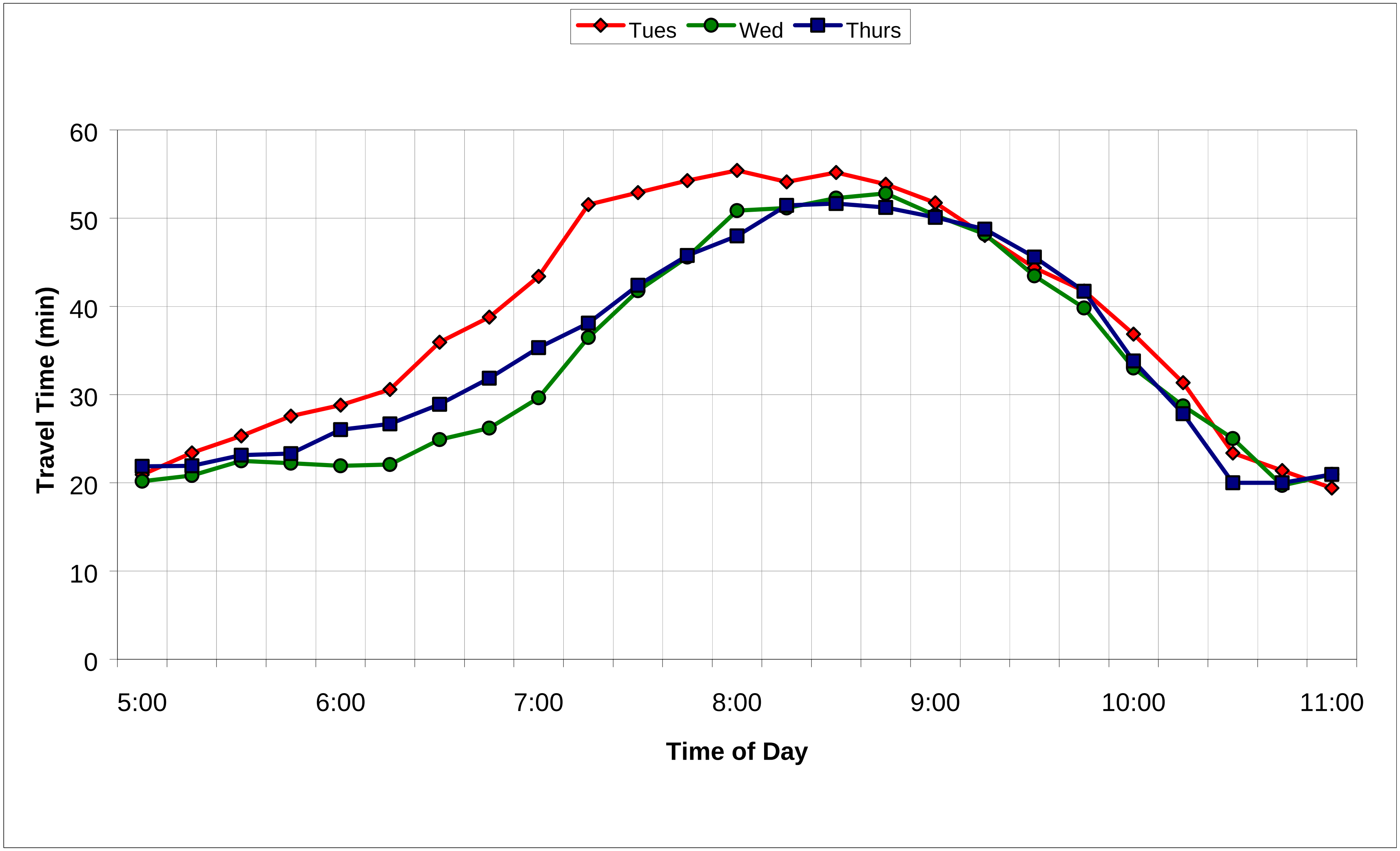

Figure 5: Total Trip Time from Stoneridge to Calaveras

2.9 Occupancy data

Sample occupancy counts were conducted manually on different days and at different places. The following table, Table 4, shows the location and time of the counts, and the results obtained.

Location	Date	Time	Total number of vehicles	% SOV	% 2	% 3+	Truck	Motorcycle
ML after Andrade on	10/2/01	7:00 - 8:45	8371	84%	8%	2%	5%	1%
Mission 262 Diag On	10/3/01	7:00 - 8:30	445	68%	12%	2%	8%	9%
Mission 262 Loop On	10/3/01	7:15 - 8:45	871	91%	7%	1%	1%	0%
Route 84 On	10/3/01	7:30 - 8:45	1658	87%	9%	1%	2%	1%
AutoMall On	10/4/01	7:00 - 8:00	1589	85%	11%	1%	3%	0%
Sheridan On	10/4/01	7:30 - 8:45	889	91%	7%	0%	0%	1%

Table 4: Results of the Sample Occupancy Counts

2.10 Conclusions

The comprehensive dataset collected over three days in October 2001 on the southbound I-680 provided a very solid foundation for the simulation study to be undertaken. All the data necessary for the calibration and validation of the traffic simulation model were available. The three days of data allowed for interesting comparisons between different traffic patterns, as the conditions were different from one day to another.

CHAPTER 3: CALIBRATION OF BASE CONDITIONS

3.1 Introduction

The purpose of the calibration phase is to adjust the general simulation parameters and the various input data files, in order to ensure that the model closely matches traffic conditions as observed in the field. This phase is critical before moving forward to investigate alternative strategies for freeway operations.

The calibration work was largely built upon the work reported in an earlier publication (Reference 1) describing the calibration of the Paramics I-680 model for the 1997 traffic conditions.

For the new phase of the I-680 project, the dataset used for calibration and validation includes counts and speed information collected over three days in October 2001, as described in Chapter 2. The challenge was to fine-tune the model input parameters to replicate real-life conditions for the three days, everything being fixed except the demand information, which varied for each day of simulation.

The calibration encompassed three steps that will be successfully described in this chapter: network geometry refinements; demand estimation and input parameters.

3.2 Network geometry refinements

3.2.1 Reference to earlier work

In terms of network geometry, only minor modifications of the earlier work were required. The network previously modeled in Paramics (Reference 1) covered the entire study section presented on Figure 2, with the exception of the Stoneridge interchange at the northern boundary, which was added in the new network.

In addition, a new auxiliary lane between AutoMall and Mission Route 262 (see Figure 1) had been completed in March 2001 and was added to the modeled network.

3.2.2 Various modifications and checks

The network geometry in Paramics was checked to ensure it reflected field conditions. Link attributes such as the number of lanes and gradients were modified as needed. The network geometry was tested by loading a few vehicles onto the network and observing their behavior. When necessary, the transitions between links were modified to ensure a smooth path for vehicles: curb positions, stopline positions and angles, and the nextlane function were used to achieve this. The curb positions in Paramics define the width of a traveled way, the stoplines specify the entry and exit point of each lane, and nextlane specifies the lane to be used at the start of the downstream link.

Some modifications were made at the zone origins and destinations. When necessary, the zone boundaries and connector links were extended to increase their storage capacity. This was done in an attempt to avoid situations where queued vehicles spillback into the origin zones, preventing new vehicles to be released into the network.

3.3 Demand estimation

The process of synthetic demand estimation converts the traffic count data collected in the field into an origin-destination trip table, which is the input data format used by the Paramics model. As origin-destination data is very difficult and expensive to collect directly, synthetic demand estimation is usually used.

The process was repeated over the three days for which counts were available, to generate three origin-destination tables.

3.3.1 Use of FREQ

The FREQ macroscopic freeway simulation model has a built-in synthetic origin-destination matrix estimation that converts the counts into time slice origin-destination tables. The simulation period covering the extended morning peak-period was divided into 15-minute time slices. The 15-minute counts on the mainline freeway origin, mainline destination and at each on and off-ramp were input into the FREQ model. Once created as text files by FREQ, the origin-destination tables for each time slice were converted into the necessary Paramics format.

The count measurements started at 5:00AM; as a result the first origin-destination matrix computed by FREQ was for the 5:00 to 5:15 AM time slice. In order to avoid collecting statistics on an empty network, the Paramics simulation started with a warm-up period of two time slices: from 4:30 to 4:45 AM and from 4:45 to 5:00 AM. These two initial origin-destination tables were generated with respectively 50 percent and 75 percent of the demand computed for the 5:00 to 5:15 AM time slice.

3.3.2 Vehicle occupancy distribution

The demand information in Paramics also requires a vehicle occupancy distribution to be specified. A typical freeway fleet composition for commute peak periods on US freeways, originally proposed by Dowling in its Paramics Training Course Manual (Reference 4) was used.

It consisted of 84 percent single occupancy vehicles, 15 percent high occupancy vehicles, and 1 percent vans/coaches. Buses were excluded from this population. Of the 84 percent SOVs, 70 percent were vehicles and 14 percent were trucks. Of the 15 percent high occupancy vehicles, 10 percent carried two passengers and five percent carried three or more passengers. The one percent of vans carried an average of 10 passengers. The proportions of vehicle types at all on- and off-ramps in the study corridor were constant at these values.

3.4 Input parameter calibration

The goal of the calibration effort was to identify a set of input parameters that would lead to a close match between simulated and observed traffic performance, for the three days of analysis. Speeds, travel times and count data available from the data collection effort were used to calibrate and validate the model.

With the experience gained from previous calibration work (Reference 5), it was possible to identify the key parameters that would be critical in the calibration of the model. With all else fixed, these key parameters were adjusted one by one to their optimum value.

3.4.1 Overall simulation configuration

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. In 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.

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.

3.4.2 General driving behavior parameters

As identified in previous work (Reference 5), the mean **target headway** and the mean **reaction time** are two user-specified driver behavior parameters that strongly influence Paramics output performances.

Three basic models are implemented within Paramics to control the movement of individual vehicles: the vehicle following, gap acceptance and lane changing models. These three models are sensitive to the mean target headway and mean reaction time values.

It is generally believed that the default values (one second for each parameter) calibrated under UK traffic conditions do not well-represent typical US freeway traffic performance. Several calibration studies carried out in California have recommended that these values be decreased, suggesting that drivers on US freeways tend to accept smaller gaps and have lower reaction times than drivers on UK freeways. The first series of investigations carried out on I-680 (Reference 1) featured 1-second mean target headway and 0.6-second mean reaction time values.

Acceptable results were produced using the previous values with the October 2001 dataset. However, performance was further improved by slightly lowering the target headway. Optimal performance was obtained with 0.98 seconds as the mean target headway and 0.6 seconds as the mean reaction time.

3.4.3 Ramp merge parameters

These parameters were introduced in the updated version of Paramics released in August 2001, version 3.0 Build 7, (REF: V3.0 Build 7) to improve the flexibility of the model in simulating ramp merging areas.

The **ramp headway factor** is applied as a link headway factor, to adjust the headway that drivers wishing to merge on the mainline will accept. Reducing the value from the default of 1.0 allows vehicles to accept smaller gaps. The headway factor was set to 0.33.

The **minimum ramp time** allows vehicles to merge from the ramp to the mainline at a faster rate. In this study, the minimum ramp time was adjusted to 1 second.

The **ramp awareness distance** defines how far upstream the vehicles on the mainline freeway will be warned of an approaching ramp. Downstream of this warning, mainline vehicles will make lane change attempts to create a gap for ramp vehicles to merge. On the I-680 network, the ramp awareness distance was set to a value between 150 and 250 meters, depending on the ramp geometry configuration.

3.4.4 Link headway factors

The Paramics model offers the flexibility of allowing the headway to be changed on a link-by-link basis, in addition to the mean target headway specification that applies to the overall network. This can be useful in calibrating the capacity of a bottleneck section, and adjusting the timing and severity of the resulting congestion conditions. In the main bottleneck section of the I-680 network (at the Mission 262 interchange), the link headway factor was increased to 1.5.

3.4.5 Signposting

Signposts, also called hazards in Paramics, are associated with lane additions, lane drops, and on- and off-ramps. Signposting provides drivers with information in advance of the hazard so that they have time to react and change lanes. Two numbers specify the signposting: the first represents the signpost location, and the second represents the distance along the link that vehicles can react to the hazard in selecting an appropriate lane to switch to.

In previous calibration efforts, it was recommended that the freeway signposting distance be increased from the default value. The signposting of one particular off-ramp (Jacklin) was found to be highly sensitive as it influenced traffic performance in the main bottleneck section. Specific adjustment was required for that signpost, and a signpost distance of 5000 feet was finally used.

CHAPTER 4: VALIDATION OF CALIBRATED RUNS

4.1 Introduction

The calibrated parameters presented in the previous chapter were applied to the refined I-680 network, with the three origin-destination tables derived from the counts obtained in the morning peak periods of Tuesday, Wednesday and Thursday, October 2 to 4, 2001.

Output statistics gathered by the model were checked for validity, in a qualitative and quantitative way. The simulation runs for the base conditions were first studied at the macroscopic network-wide level: overall simulation statistics were computed, and the relationships between speeds, flows and densities were analyzed.

Further analysis consisted in comparing the model outputs to real-life traffic performance, specifically measured speed and flow data. The same comparisons were performed for the three days of analysis.

4.2 Overall network-wide statistics

The network-wide results of the base runs for the three days are shown in Table 5. The statistics of Table 5 are available from the "general" file, an output of the Paramics model. The day experiencing the most severe conditions for each of the three measures is shaded in gray.

Validation of Base Runs	Tuesday (Oct. 2, 2001)	Wednesday (Oct. 3, 2001)	Thursday (Oct. 4, 2001)
Total Vehicle Count	**62,514**	**59,679**	**61,992**
Total Vehicle Hours Traveled	**21,418**	**20,491**	**20,945**
Overall Average Speed (mph)	**29.9**	**30.4**	**31.0**

Table 5: Paramics Base Conditions Overall Results

"Total Vehicle Count" in Table 5 refers to the number of vehicles actually generated by the simulation model. They are slightly higher than the counts presented in Table 3 because of the added warm-up periods (as described in section 3.3.1).

It can be seen that of the three days modeled, Tuesday experienced the greatest of congestion. It has the highest vehicle demands, the highest total vehicle hours traveled, and the lowest overall average speed. The results presented in Table 5, as outputs of the Paramics model well reflect the count statistics derived from the field measurements and previously shown in Table 3.

4.3 Macroscopic relationships between speeds and flows

As a first check of the quality of the model outputs, the fundamental traffic diagrams were plotted. 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 all links on the mainline freeway. The densities could be derived from speed and flow data.

Figure 6 shows the speed-flow curve derived from the Paramics Tuesday base run. It was constructed by plotting all speed-flow combinations obtained over 15-minute time slices on all freeway mainline links. Not enough data was available to plot a similar chart with field measurements. However, the speed-flow relationship shown on Figure 6 was considered acceptable, as it matches observed data on similar US freeway facilities and typical diagrams from the Highway Capacity Manual (Reference 6). The highest flows around 6200 vehicles per hour for a three-lane freeway falls within the range of expected values. The top part of the curve with freeway sections operating at 60 mph under non-congested conditions is appropriate. The bottom part of the curve, with a high concentration of points around 15-20 mph is typical of congested conditions. Highest flows (over 6000 vph) occur at speeds from 20 to 60 miles per hour.

4.4 Speed analysis

Speed contour maps were created using the empirical freeway traffic data from the tach runs as well as the results of the Paramics model base runs. The speed-contour maps for each day of calibration (Tuesday October 2, Wednesday October 3, and Thursday October 4) are displayed in Figures 7a through 7c.

Vehicle speeds were tabulated at 15-minute time slices for each of 37 freeway sections, from 5:00 to 11:00 am. Each cell represents the average speed of all vehicles over a 15-minute time slice for a given subsection of the freeway. The unshaded regions represent speeds greater than 50 mph; speeds from 40 to 49 mph are shaded in light gray, and speeds lower than 40 mph are shaded in dark gray.

By looking at Figures 7a through 7c, it appears that the time and space boundaries of congestion conditions are fairly close, suggesting that the model was able to properly identify the bottleneck location and represent the extent of queuing. For instance, for the Tuesday demand scenario contained in Figure 7a, the major bottleneck that occurs on this freeway corridor was very closely re-created in Paramics, in terms of location on the corridor as well as the time at which it began and ended. It can be observed, however, that the bottleneck spills back to Section 6 earlier (at about 7:15 am) than is predicted by Paramics (8:00 am).

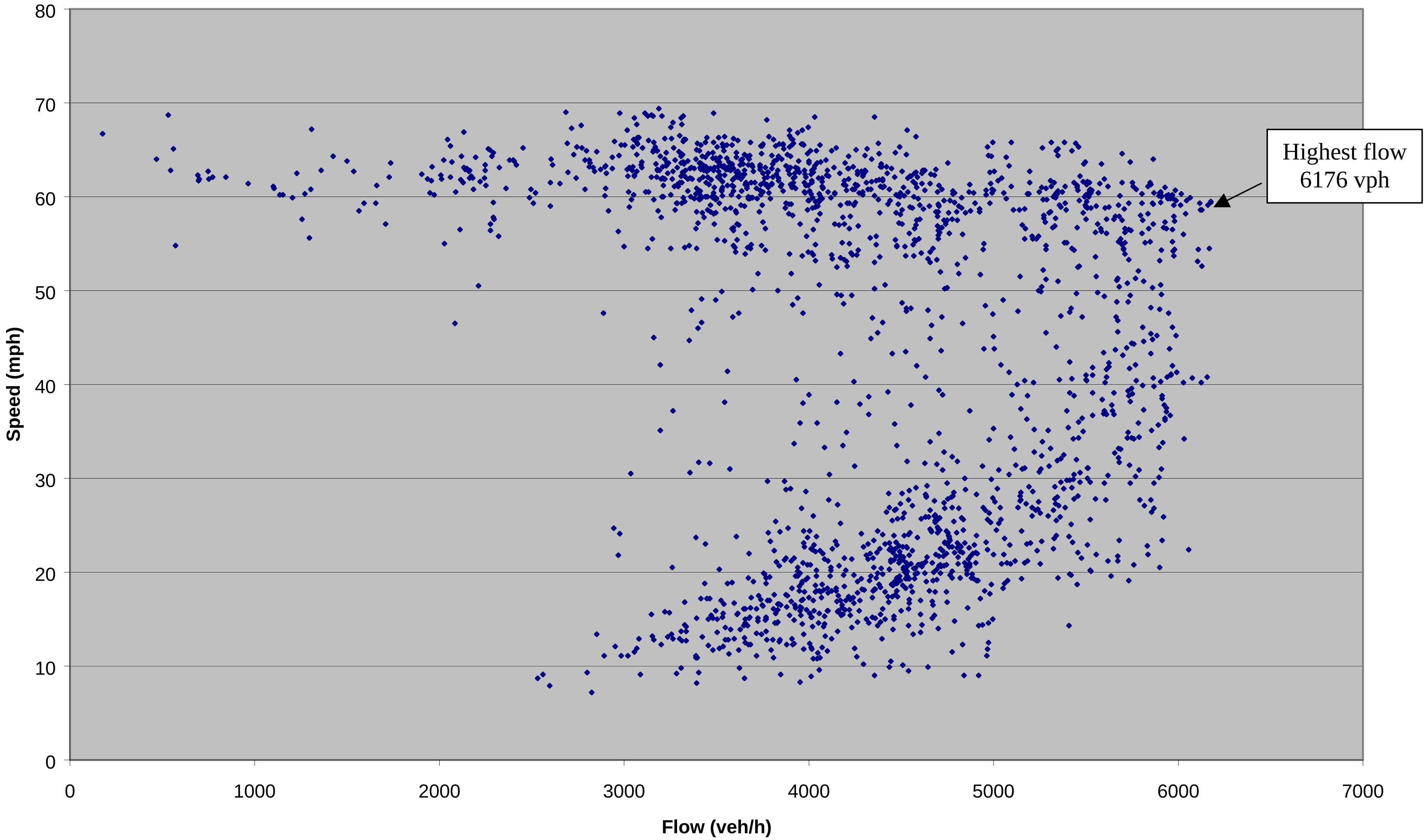

Figure 6: Tuesday Base Run - Speed/Flow Curve

I-680 SB — TACH RUNS SPEED CONTOUR MAP — October 2 (Tuesday)

Section number

Interval Start	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5:00			49	61	65	65	63	68	60	66	64	66	60	59	61	58	46	47	28	48	56
5:15			42	65	65	63	61	66	61	63	55	59	62	56	38	39	18	36	39	44	45
5:30			50	65	66	66	66	66	66	62	43	12	11	26	51	51	49	43	48	43	53
5:45			51	61	61	59	60	61	55	24	27	22	34	34	41	44	33	27	33	51	50
6:00			50	64	64	65	64	65	44	36	23	22	28	30	46	41	31	24	28	45	46
6:15			63	64	64	64	64	29	34	20	19	21	22	26	51	37	29	22	22	39	52
6:30			51	65	65	66	65	48	29	21	21	19	35	28	44	23	32	23	31	39	35
6:45			46	62	62	63	61	42	18	33	14	17	28	35	31	36	19	19	25	38	47
7:00			51	65	66	66	65	47	17	35	17	25	34	31	36	27	29	26	30	47	17
7:15			51	63	63	53	31	49	22	32	15	17	24	34	46	39	11	25	27	24	39
7:30			53	65	64	60	47	53	26	36	16	10	28	37	48	13	13	14	12	31	14
7:45			55	66	66	66	64	57	30	39	17	13	23	26	33	11	11	13	15	21	17
8:00			48	63	63	65	64	64	59	37	10	16	17	14	19	9	8	13	15	21	17
8:15			46	63	65	63	63	63	58	21	14	10	13	20	25	11	7	12	18	11	21
8:30			47	65	65	65	65	66	49	28	17	7	22	22	11	13	8	15	22	34	17
8:45			48	63	64	64	62	63	62	25	18	11	5	24	20	9	10	8	18	39	19
9:00			47	63	65	65	65	65	65	65	19	12	10	17	16	7	9	13	26	8	21
9:15			58	65	66	67	66	67	66	61	16	13	16	15	10	11	13	10	21	20	21
9:30			50	65	65	66	65	64	65	60	35	9	21	28	31	8	11	7	17	8	24
9:45			44	64	67	58	63	63	63	65	32	17	31	17	28	10	18	8	8	26	38
10:00			49	65	66	66	65	66	66	66	65	45	28	23	25	18	14	22	14	18	21
10:15			43	61	62	62	61	62	62	62	64	64	63	37	25	13	14	20	28	35	26
10:30			50	61	65	65	64	65	65	65	64	51	46	44	45	40	36	42	40	42	33
10:45			48	63	64	63	63	63	63	64	64	56	64	65	64	62	58	63	65	67	44
11:00			52	66	65	65	65	65	65	65	65	66	70	66	66	63	60	64	66	68	67
Column Summary																					
Min			42	61	61	53	31	29	17	20	10	7	5	14	10	7	7	7	8	8	14
Avg			50	64	65	64	62	59	51	46	33	27	32	33	37	28	23	25	28	35	34
Max			63	66	67	67	66	68	66	66	65	66	70	66	66	63	60	64	66	68	67

Interval Start	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00	59	61	59	62	61	62	63	64	64	62	64	65	64	64	62	60	62		28	60	68
5:15	56	59	59	62	61	62	63	64	64	62	64	65	64	64	62	60	62		18	56	66
5:30	53	56	58	58	57	60	63	65	65	63	61	62	61	69	72	63	41		11	55	72
5:45	53	53	58	58	61	65	65	65	65	65	65	65	65	32	58	55	49		22	51	65
6:00	52	56	59	56	53	59	61	61	61	59	58	61	57	58	57	54	56		22	50	65
6:15	53	50	57	53	54	57	60	60	59	59	59	62	59	60	60	59	54		19	48	64
6:30	46	48	51	48	57	60	61	58	56	55	60	64	60	62	63	64	53		19	47	66
6:45	40	41	48	35	45	44	40	44	45	42	50	59	64	64	64	63	53		14	43	64
7:00	25	31	37	27	39	27	19	29	34	28	40	62	57	58	55	48	48		17	39	66
7:15	10	36	48	24	34	24	26	22	25	31	46	62	63	61	65	63	48		10	38	65
7:30	11	26	30	23	30	15	21	21	23	33	33	62	65	58	55	55	53		10	35	65
7:45	11	16	12	23	24	18	25	24	24	25	40	62	63	60	56	53	41		11	34	66
8:00	13	18	11	22	21	19	21	22	21	26	34	58	62	60	57	55	48		8	33	65
8:15	14	20	11	21	21	19	21	22	21	26	34	58	62	60	57	55	48		7	33	65
8:30	14	12	25	16	18	20	17	19	18	26	27	54	60	60	59	57	55		7	33	66
8:45	11	15	12	23	17	17	21	28	26	24	38	59	57	60	62	60	53		5	34	64
9:00	15	17	18	16	25	20	18	23	22	36	45	61	66	57	60	54	40		7	35	66
9:15	10	17	29	16	20	19	22	17	26	21	30	60	64	62	67	67	66		10	36	67
9:30	16	15	27	18	25	19	30	35	23	30	42	61	62	63	63	57	49		7	37	66
9:45	26	4	31	21	30	16	21	16	20	30	36	59	59	60	64	65	65		4	37	67
10:00	23	20	15	26	18	20	22	26	16	28	28	51	62	55	64	64	60		14	39	66
10:15	30	35	34	31	30	27	25	14	21	28	44	68	60	61	60	55	48		13	43	68
10:30	45	38	26	23	48	31	31	29	25	37	45	59	60	62	61	60	57		23	48	65
10:45	21	37	56	47	49	51	28	42	39	28	42	61	59	64	63	58	53		21	54	67
11:00	67	67	67	63	64	64	62	61	62	63	62	66	65	66	67	60	58		52	64	70
Column Summary																		Overall Row Summa			
Min	10	4	11	16	17	15	17	14	16	21	27	51	57	32	55	48	40	Min	4	24	61
Avg	31	34	37	35	39	36	36	37	37	39	46	61	62	60	61	58	53	Avg	23	43	65
Max	67	67	67	63	64	65	65	65	65	65	65	68	66	69	72	67	66	Max	60	66	72

I-680 SB — PARAMICS SPEED CONTOUR MAP — October 2 (Tuesday)

Section number

Interval Start	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5:00			66	63	58	65	62	61	60	57	59	62	62	49	57	62	55	62	53	60	56
5:15			66	62	58	64	60	58	59	54	56	60	39	37	51	46	49	59	45	58	56
5:30			66	63	58	65	60	60	59	55	39	49	26	33	40	30	45	51	35	54	50
5:45			66	63	58	66	62	61	60	54	56	47	19	32	49	42	39	38	32	54	48
6:00			65	62	57	65	60	60	60	57	60	59	35	36	51	37	36	34	31	44	35
6:15			65	63	57	65	61	60	60	57	59	45	28	31	40	33	34	31	24	28	29
6:30			65	62	56	66	60	61	60	56	52	31	18	30	37	27	24	15	21	23	22
6:45			65	63	57	65	57	61	61	45	29	16	16	25	33	32	24	13	17	20	20
7:00			65	62	57	65	58	63	63	33	18	16	15	22	24	18	14	12	20	19	19
7:15			65	63	57	66	57	62	47	18	18	13	14	22	27	23	13	10	15	21	17
7:30			65	63	57	67	60	54	25	15	15	13	11	16	16	13	12	9	17	19	20
7:45			66	63	56	67	58	30	13	14	16	14	16	22	23	14	12	9	16	15	12
8:00			66	64	57	68	42	25	20	15	13	8	10	16	20	18	11	9	17	23	29
8:15			66	63	57	67	36	14	15	18	18	17	18	24	22	16	11	8	16	17	16
8:30			66	63	58	67	55	50	21	18	15	11	12	20	22	16	12	11	20	23	20
8:45			66	64	59	67	62	57	26	28	27	21	17	22	20	16	13	10	18	22	23
9:00			66	63	58	67	63	63	63	61	55	21	19	30	25	16	14	11	20	18	17
9:15			66	64	58	68	63	62	62	60	61	42	15	19	23	17	12	9	17	22	27
9:30			65	63	57	67	63	62	63	61	61	35	21	32	39	21	15	12	19	21	26
9:45			66	64	59	68	62	64	64	62	62	64	54	39	37	30	18	10	16	19	20
10:00			66	63	58	66	60	62	63	61	61	64	66	62	64	52	26	14	22	27	30
10:15			66	64	58	67	60	63	63	60	60	63	65	60	61	64	55	61	52	54	53
10:30			66	64	59	67	63	63	63	61	60	63	65	60	61	64	56	63	57	62	57
10:45			66	63	58	66	63	62	63	61	60	62	65	60	61	65	56	63	55	62	55
11:00			67	64	59	67	62	62	62	61	60	62	64	60	60	63	56	63	56	61	58
Column Summary																					
Min			65	62	56	64	36	14	13	14	13	8	10	16	16	13	11	8	15	15	12
Avg			66	63	58	66	59	56	51	46	44	38	32	34	39	33	28	27	28	34	33
Max			67	64	59	68	63	64	64	62	62	64	66	62	64	65	56	63	57	62	58

Interval Start	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00	62	61	60	60	65	60	63	65	65	62	64	65	65	64	63	63	65		49	61	66
5:15	62	60	59	58	65	58	64	65	65	62	64	65	65	64	62	62	64		37	58	66
5:30	62	55	54	56	61	51	64	65	64	62	63	64	64	63	61	62	64		26	55	66
5:45	60	39	33	52	64	55	63	65	64	60	62	64	64	63	60	61	63		19	54	66
6:00	34	30	34	43	37	48	63	64	62	50	60	63	64	63	61	61	61		30	51	65
6:15	30	26	26	24	22	48	63	64	61	40	58	63	64	63	60	61	63		22	47	65
6:30	19	24	29	27	27	44	60	56	39	26	55	62	63	62	58	60	62		15	43	66
6:45	18	23	24	28	28	31	27	26	26	23	55	62	63	60	54	60	56		13	38	65
7:00	18	22	27	21	19	27	23	21	22	21	55	62	63	62	57	60	55		12	36	65
7:15	13	15	16	25	22	32	33	23	23	21	54	61	63	62	57	60	51		10	35	66
7:30	18	21	19	24	23	35	32	23	22	21	54	61	63	52	56	58	52		9	33	67
7:45	12	18	21	22	20	37	32	26	24	20	54	60	57	37	57	60	37		9	31	67
8:00	23	22	17	20	20	29	26	21	21	20	54	60	56	36	50	53	37		8	30	68
8:15	13	17	21	24	21	27	23	22	23	21	55	60	60	45	56	57	40		8	31	67
8:30	16	17	19	24	20	31	27	22	23	19	54	59	63	61	56	58	47		11	33	67
8:45	21	21	21	27	24	30	26	24	23	20	54	59	62	58	54	58	42		10	35	67
9:00	13	17	18	19	18	37	47	32	26	21	53	59	63	61	57	60	48		11	39	67
9:15	25	20	21	22	18	31	25	23	23	21	54	60	63	61	57	58	52		9	39	68
9:30	22	22	25	24	18	29	24	22	23	21	53	60	63	60	56	61	51		12	40	67
9:45	17	17	16	22	21	33	24	23	24	22	54	61	62	59	55	57	50		10	41	68
10:00	31	28	28	25	24	32	27	22	23	23	54	61	63	61	56	59	52		14	46	66
10:15	59	47	37	27	22	38	48	28	25	22	54	62	64	62	58	60	48		22	53	67
10:30	65	63	62	61	47	47	63	65	61	46	59	63	64	62	59	60	46		46	60	67
10:45	65	63	62	62	66	62	63	64	63	59	62	63	64	63	60	61	55		55	62	66
11:00	63	61	60	60	64	60	62	63	62	60	62	63	64	63	61	62	56		56	61	67
Column Summary																		Overall Row Summary			
Min	12	15	16	19	18	27	23	21	21	19	53	59	56	36	50	53	37	Min	8	28	65
Avg	34	32	32	34	33	40	43	40	38	34	57	62	63	58	57	59	52	Avg	27	45	66
Max	65	63	62	62	66	62	64	65	65	62	64	65	65	64	62	62	64	Max	56	63	68

Figure 7a: Tuesday Speed Contour Maps - Paramics and Tach Runs

I-680 SB — **TACH RUNS SPEED CONTOUR MAP** — **October 3 (Wednesday)**

Interval Start	0	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	30	31	32	33	34	35	36	37	Row Summary Min	Avg	Max
5:00			49	65	66	66	66	66	64	66	66	65	66	66	66	63	48	53	59	65	64	57	65	66	60	58	65	66	66	66	66	66	66	66	66	66	66	66	48	63	66
5:15			46	63	64	62	62	65	63	64	60	60	56	54	57	51	47	55	56	59	53	56	63	66	63	62	63	64	62	65	66	64	64	64	66	66	66	66	46	61	66
5:30			54	63	64	65	64	65	63	65	61	40	32	42	50	50	42	51	55	55	55	57	61	61	58	59	62	59	59	61	64	63	63	62	64	62	61	63	32	58	65
5:45			51	64	64	63	64	66	63	63	63	63	63	49	56	50	38	48	53	52	57	57	59	56	53	57	60	55	55	57	62	63	64	64	64	64	64	55	38	58	66
6:00			56	62	65	62	62	64	62	62	63	63	62	55	57	48	42	48	48	42	49	40	54	65	54	56	59	65	64	64	64	64	63	65	64	65	64	65	40	58	65
6:15			53	63	63	64	64	70	66	71	62	62	62	60	58	45	45	47	43	47	38	38	47	59	59	61	64	63	63	62	62	61	66	65	65	65	64	62	38	59	71
6:30			52	67	67	67	67	68	67	64	66	61	64	48	28	44	34	50	53	42	36	43	37	48	57	52	62	57	61	55	46	51	61	57	61	60	51	43	28	54	68
6:45			50	64	63	64	63	62	62	63	45	32	37	42	52	41	29	45	34	42	32	38	26	47	44	43	58	39	37	44	42	53	57	64	63	67	67	67	26	49	67
7:00			48	63	64	64	63	65	64	64	38	16	22	38	56	51	39	49	29	33	27	33	38	39	29	55	57	53	55	60	62	58	63	63	61	58	56	60	16	50	65
7:15			52	62	64	64	64	62	59	17	55	55	38	34	59	60	48	53	24	24	18	46	26	39	31	57	43	33	40	20	44	49	62	64	60	57	59	61	17	47	64
7:30			51	66	67	65	65	60	19	21	57	62	64	38	52	57	35	33	23	20	25	46	21	46	26	28	31	24	31	20	27	40	61	64	60	57	61	62	19	44	67
7:45			49	64	65	63	63	55	18	22	58	61	57	64	61	62	20	26	27	30	22	18	13	25	21	22	20	15	22	20	28	27	47	66	60	65	65	65	13	41	66
8:00			55	64	65	65	65	66	30	34	49	51	29	37	55	57	32	15	11	20	23	10	17	8	17	17	19	16	16	14	19	29	63	62	65	65	60	59	8	38	66
8:15			51	63	63	63	62	64	61	62	62	57	35	43	30	12	11	10	18	14	11	8	13	10	9	26	27	16	27	19	32	49	60	61	60	57	64	45	8	38	64
8:30			43	63	64	65	64	65	64	65	64	65	65	58	19	9	6	6	25	24	17	16	9	12	19	12	18	17	19	17	13	39	58	60	59	59	64	54	6	39	65
8:45			51	64	63	63	63	64	63	63	63	12	13	21	8	7	10	6	19	25	18	12	11	11	14	18	17	19	26	29	17	29	55	58	57	61	64	62	6	35	64
9:00			50	65	66	65	66	63	64	65	63	16	12	24	44	12	8	7	13	27	19	8	10	31	16	22	16	23	30	26	20	36	60	58	61	58	54	55	7	37	66
9:15			45	65	65	64	64	64	64	67	55	10	11	13	18	5	10	9	26	10	24	27	10	27	18	25	14	26	35	24	22	44	56	45	55	58	56	46	5	35	67
9:30			55	67	67	67	67	67	67	67	31	12	10	14	22	7	11	18	17	17	23	22	16	14	23	19	22	17	36	18	26	31	56	61	56	60	61	59	7	36	67
9:45			49	63	63	62	61	64	63	63	30	13	21	28	21	19	11	11	18	10	30	15	19	33	23	15	20	20	16	18	21	41	59	61	63	62	55	51	10	36	64
10:00			46	63	65	65	65	65	65	65	35	54	55	31	23	12	12	20	25	12	25	49	20	31	27	23	25	32	10	26	26	41	61	62	60	61	66	59	10	41	66
10:15			53	66	66	64	64	66	64	66	65	65	65	61	25	52	14	17	22	33	14	28	31	34	28	29	22	32	37	46	33	44	61	62	60	57	49	54	14	46	66
10:30			53	66	66	65	65	64	65	65	64	66	67	65	47	24	29	22	26	39	52	43	25	52	47	42	50	29	17	31	48	43	57	58	63	65	65	64	17	50	67
10:45			43	66	64	64	67	65	61	63	61	64	61	57	58	55	58	64	69	70	27	52	44	58	42	53	51	54	56	47	40	33	59	62	59	58	59	57	27	56	70
11:00			43	66	64	64	67	65	61	63	61	64	61	57	58	55	58	64	69	70	66	70	64	66	64	64	64	65	66	67	67	59	64	69	66	62	72	55	43	63	72
Column Summary																																							**Overall Row Summary**		
Min			43	62	63	62	61	55	18	17	30	10	10	13	8	5	6	6	11	10	11	8	9	8	9	12	14	15	10	14	13	27	47	45	55	57	49	43	Min: 5	26	63
Avg			50	64	65	64	64	64	58	58	56	48	45	44	43	38	29	33	35	35	33	36	32	40	36	39	40	38	40	39	41	47	60	62	61	61	61	58	Avg: 29	48	65
Max			56	67	67	67	67	70	67	71	66	66	67	66	66	63	58	64	69	70	66	70	65	66	64	64	65	66	66	67	67	66	66	69	66	67	72	67	Max: 56	66	72

I-680 SB — **PARAMICS SPEED CONTOUR MAP** — **October 3 (Wednesday)**

Interval Start	0	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	30	31	32	33	34	35	36	37	Row Summary Min	Avg	Max
5:00			68	66	61	69	66	64	65	62	62	65	66	61	63	65	56	64	55	62	58	63	62	61	60	66	62	64	66	65	62	63	64	65	63	62	62	66	55	63	69
5:15			66	63	58	65	62	60	61	61	62	64	64	53	58	64	56	62	54	62	58	63	62	61	61	66	64	64	65	64	63	64	65	65	65	62	63	65	53	62	66
5:30			66	64	59	66	62	61	60	53	56	60	45	37	54	53	52	62	51	59	56	62	58	59	57	65	62	63	64	63	60	62	64	64	63	61	62	65	37	59	66
5:45			67	64	59	67	63	62	63	60	61	63	64	52	54	52	52	60	45	57	56	62	59	58	58	64	57	62	63	60	52	60	63	64	62	59	60	63	45	60	67
6:00			66	64	60	67	63	62	62	60	61	63	62	51	56	63	55	61	52	59	54	62	58	55	53	46	47	62	62	56	35	57	62	64	62	59	61	62	35	58	67
6:15			66	64	59	67	61	62	61	56	59	62	58	42	53	49	53	63	52	59	55	63	60	59	45	33	44	49	35	30	25	56	62	64	62	58	60	63	25	55	67
6:30			65	63	57	66	60	61	61	59	59	62	39	33	52	47	44	50	36	56	56	62	43	35	33	28	28	25	24	25	23	56	61	63	62	58	58	59	23	49	66
6:45			66	63	58	66	62	60	58	57	59	56	30	36	44	34	32	40	29	31	26	24	21	22	24	19	27	25	23	23	22	55	61	63	61	56	59	57	19	43	66
7:00			65	62	57	65	58	61	61	55	55	25	18	22	28	27	19	16	20	23	23	20	20	20	24	22	26	23	22	23	20	54	61	63	60	55	53	52	16	38	65
7:15			65	62	56	66	57	62	61	37	25	22	18	21	26	21	17	11	16	16	15	10	16	17	24	21	25	27	23	22	20	53	61	59	42	55	57	50	10	35	66
7:30			66	63	57	66	61	61	58	25	20	13	13	16	20	16	13	9	16	14	12	17	19	20	23	19	26	22	21	22	19	53	60	51	32	55	58	48	9	33	66
7:45			66	63	57	67	61	62	35	15	12	10	13	22	27	20	10	8	13	17	21	17	18	18	19	16	23	23	23	22	19	53	59	36	31	48	60	46	8	31	67
8:00			66	64	58	68	63	60	27	14	14	13	15	19	19	15	12	9	12	13	14	15	20	18	21	20	31	26	22	21	21	54	59	32	31	46	46	47	9	31	68
8:15			67	64	57	68	63	64	40	17	15	12	13	18	20	16	11	9	21	24	24	18	14	14	27	22	25	23	23	23	20	52	53	39	32	48	58	44	9	32	68
8:30			65	63	57	67	62	63	59	18	14	14	15	19	17	13	12	10	16	16	14	12	16	16	19	17	26	24	22	22	20	52	60	49	36	55	58	53	10	33	67
8:45			66	63	57	67	62	63	60	20	21	14	14	22	28	20	11	9	16	17	19	13	13	14	18	15	23	29	26	23	19	53	61	62	49	57	61	49	9	34	67
9:00			66	64	57	67	62	62	63	60	41	19	15	20	18	13	10	9	14	13	13	13	19	20	20	19	29	26	23	23	20	54	60	64	62	57	60	52	9	36	67
9:15			66	64	58	68	63	62	63	61	61	28	15	23	27	17	10	9	16	24	27	20	15	14	23	20	28	28	27	26	19	54	61	63	59	54	59	52	9	38	68
9:30			66	63	58	67	62	62	62	60	61	54	20	26	25	16	13	11	19	20	24	18	17	18	23	18	25	27	24	22	19	52	60	62	59	55	59	44	11	39	67
9:45			66	64	58	68	63	62	62	60	61	56	20	23	23	18	20	12	19	22	20	21	24	24	23	18	20	20	20	21	19	52	60	61	58	56	59	44	12	39	68
10:00			66	63	58	67	63	62	63	61	62	64	66	63	55	49	31	14	24	25	29	25	20	17	19	16	22	22	21	20	18	52	60	62	59	55	58	43	14	44	67
10:15			66	63	58	67	63	61	61	59	61	63	65	59	62	65	56	64	56	56	41	23	24	24	26	19	24	21	21	22	20	54	60	63	60	55	57	45	19	49	67
10:30			66	64	59	68	63	63	64	61	62	64	66	60	62	64	56	63	55	61	58	64	62	59	31	18	22	22	22	24	21	55	61	63	57	54	60	40	18	53	68
10:45			66	64	58	68	64	63	63	60	61	63	66	62	62	64	56	64	56	62	58	65	64	62	63	49	28	32	27	24	22	56	62	64	62	56	60	47	22	56	68
11:00			65	63	58	67	63	63	63	62	60	62	64	61	61	65	57	63	55	61	55	64	62	61	62	66	64	62	64	64	61	63	65	65	63	60	62	58	55	62	67
Column Summary																																							**Overall Row Summary**		
Min			65	62	56	65	57	60	27	14	12	10	13	16	17	13	10	8	12	13	12	10	13	14	18	15	20	20	20	20	18	52	53	32	31	46	46	40	Min: 8	28	65
Avg			66	64	58	67	62	62	58	49	47	44	38	37	41	38	33	34	33	37	35	36	35	34	34	31	34	35	33	32	29	56	61	59	54	56	59	52	Avg: 29	45	67
Max			68	66	61	69	66	64	65	62	62	65	66	63	63	65	57	64	56	62	58	65	64	62	63	66	64	64	66	65	63	64	65	65	65	62	63	65	Max: 56	64	69

Figure 7b: Wednesday Speed Contour Maps - Paramics and Tach Runs

I-680 SB — TACH RUNS SPEED CONTOUR MAP — October 4 (Thursday)

Section number

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Row Summary Avg	Row Summary Max
5:00			48	63	60	57	58	59	59	63	57	59	61	61	61	52	50	41	30	49	57	59	52	60	54	55	62	54	50	60	64	63	64	64	63	63	59	57		30	57	64
5:15			49	63	63	61	61	63	63	63	47	41	43	54	55	52	50	41	30	49	57	59	52	60	54	55	62	54	50	60	64	63	64	64	63	63	59	57		30	56	64
5:30			50	63	65	66	64	67	66	63	36	23	25	47	48	45	42	50	53	53	51	44	55	60	56	58	62	59	57	62	64	63	65	63	61	61	58	57		23	55	67
5:45			53	67	68	68	67	71	68	62	38	31	36	44	40	54	55	52	57	47	38	46	58	60	58	61	63	65	64	64	64	63	65	61	59	59	57	57		31	57	71
6:00			51	66	66	66	65	57	62	63	40	21	15	35	24	48	45	44	42	49	47	47	57	56	54	58	59	60	60	62	59	59	60	59	58	69	55	45		15	52	69
6:15			46	62	63	62	61	60	60	61	23	17	12	39	53	51	48	41	41	52	51	40	42	45	42	44	47	42	52	56	61	63	57	59	57	60	61	55		12	50	63
6:30			48	64	64	65	64	65	60	41	23	17	27	41	53	47	43	42	41	48	47	37	38	38	37	51	57	57	58	50	38	43	53	59	61	58	55	49		17	48	65
6:45			53	65	65	66	66	67	64	50	34	20	18	42	53	43	38	42	41	45	42	34	34	30	31	45	46	48	49	50	53	45	53	54	60	60	62	52		18	48	67
7:00			50	65	66	66	66	66	65	47	31	16	18	29	54	56	50	21	23	31	29	19	31	55	39	35	32	16	38	28	25	33	52	64	63	55	58	57		16	43	66
7:15			48	63	60	59	59	62	58	62	22	20	29	31	60	58	27	19	25	38	29	27	22	17	23	28	18	19	27	33	29	41	61	61	48	59	61	54		17	41	63
7:30			43	66	67	67	67	67	65	67	37	13	16	33	48	36	14	26	32	28	15	35	17	22	22	27	18	17	21	27	31	43	60	59	53	62	60	54		13	40	67
7:45			52	62	64	63	62	63	63	65	37	15	23	34	36	24	13	38	8	10	17	16	20	36	19	22	19	15	16	21	33	46	58	58	58	65	58	55		8	38	65
8:00			48	62	64	64	64	64	62	63	37	17	30	34	23	12	8	15	19	15	19	13	11	19	16	18	18	27	21	22	31	30	51	59	58	60	60	59		8	36	64
8:15			67	67	66	60	66	66	66	66	61	13	21	23	28	11	7	12	23	24	17	17	15	24	26	27	16	23	26	25	24	44	60	62	59	60	59	60		7	39	67
8:30			51	67	67	67	65	64	64	65	26	13	22	15	6	8	16	8	27	33	15	20	18	29	16	18	17	23	21	28	29	40	59	60	61	62	62	62		6	37	67
8:45			49	67	69	69	66	69	63	62	35	15	20	17	35	10	6	14	15	6	17	17	15	18	17	21	17	23	15	32	33	36	59	58	63	64	64	64		6	37	69
9:00			53	66	64	64	65	66	65	67	68	20	18	18	9	9	8	10	14	25	12	23	13	12	17	23	23	42	51	53	55	53	61	59	63	64	56	59		8	40	68
9:15			52	62	60	58	60	63	64	64	55	8	22	20	16	10	7	20	8	14	21	10	23	12	21	28	21	19	23	25	23	43	55	59	62	60	59	55		7	36	64
9:30			48	65	65	65	65	65	65	65	21	12	23	20	17	11	8	22	9	23	21	11	15	36	20	14	19	23	20	25	44	44	55	64	64	69	58	37		8	36	69
9:45			43	66	67	67	67	63	67	67	66	10	22	20	19	13	11	16	11	21	20	19	13	19	25	23	21	20	16	25	27	32	52	62	61	61	62	60		10	37	67
10:00			51	66	64	66	64	64	66	65	63	14	22	18	28	20	7	28	13	19	19	26	32	15	28	31	31	27	26	22	28	36	52	54	64	65	65	63		7	39	66
10:15			44	65	69	70	65	67	64	67	44	43	27	39	36	28	13	22	11	36	46	49	41	54	49	35	29	34	36	22	19	24	52	57	55	60	58	53		11	44	70
10:30			51	65	65	65	62	62	61	66	54	54	46	52	50	14	26	56	63	59	50	43	35	13	35	55	49	31	36	32	31	46	57	60	61	64	60	55		13	50	66
10:45			51	65	65	65	62	62	59	64	64	65	65	65	64	48	26	60	66	66	64	62	65	65	64	65	65	65	65	64	64	61	65	64	62	65	61	57		26	62	66
11:00			51	65	65	65	62	62	59	64	64	65	65	65	64	48	26	60	66	66	64	62	65	65	64	65	65	65	65	64	64	61	65	64	62	65	62	58		26	62	66
Column Summary																																							Overall Row Summary			
Min			43	62	60	57	58	57	58	41	21	8	12	15	6	8	6	8	8	6	12	10	11	12	16	14	16	15	15	21	19	24	51	54	48	55	55	37	Min	6	28	62
Avg			50	65	65	64	64	64	63	62	43	26	29	36	39	32	26	32	31	36	35	33	34	37	35	38	37	37	38	40	42	47	58	60	60	62	60	56	Avg	26	45	65
Max			67	67	69	70	67	71	68	67	68	65	65	65	64	58	55	60	66	66	64	62	65	65	64	65	65	65	65	64	64	63	65	64	64	69	65	64	Max	55	65	71

I-680 SB — PARAMICS SPEED CONTOUR MAP — October 4 (Thursday)

Section number

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Row Summary Avg	Row Summary Max
5:00			66	64	59	65	63	58	60	59	59	62	65	58	60	64	55	63	54	60	56	62	60	60	58	65	62	64	65	64	63	64	65	65	64	62	62	64		54	62	66
5:15			66	63	58	65	62	60	60	59	60	58	34	38	54	52	48	62	48	59	57	62	60	60	58	65	58	65	66	65	63	64	64	64	63	61	61	64		34	59	66
5:30			66	64	59	66	62	60	60	58	58	53	25	36	51	34	45	46	35	54	55	62	58	57	57	64	57	64	65	64	62	63	65	65	64	62	63	64		25	57	66
5:45			65	63	58	65	62	60	61	58	60	56	29	33	39	33	45	42	34	52	47	62	58	55	54	54	47	64	65	64	60	62	64	64	63	61	62	64		29	55	65
6:00			66	63	58	66	61	60	60	58	60	62	40	33	37	38	44	44	34	50	51	57	37	32	33	27	47	63	64	61	51	60	63	64	63	60	61	64		27	53	66
6:15			65	63	57	66	60	61	61	57	59	58	30	30	43	37	38	42	33	45	42	42	31	32	32	28	41	62	63	55	33	56	62	64	61	58	61	64		28	50	66
6:30			65	63	57	66	61	61	61	59	59	51	25	31	42	31	26	23	23	26	23	19	22	23	27	27	45	57	46	35	26	56	62	63	60	57	57	58		19	44	66
6:45			65	62	56	66	59	62	61	57	59	40	19	21	25	21	20	14	19	21	19	19	22	30	27	23	38	28	23	24	22	56	62	62	58	57	59	50		14	40	66
7:00			65	62	57	66	59	60	45	33	27	15	13	18	26	24	21	14	16	17	19	16	22	24	23	20	29	30	23	23	21	54	61	61	49	54	57	52		13	35	66
7:15			65	62	57	66	59	58	34	19	15	14	17	20	27	23	17	13	17	16	16	18	20	19	21	20	25	21	21	22	21	54	61	63	61	56	59	46		13	34	66
7:30			65	63	57	67	59	51	20	16	17	11	13	25	28	19	13	9	16	20	20	13	14	14	24	23	30	29	23	23	20	54	60	60	45	54	59	47		9	33	67
7:45			65	63	55	68	60	33	18	17	16	14	14	15	18	14	10	9	16	20	19	27	26	19	21	19	31	31	22	22	21	54	61	59	38	55	58	38		9	32	68
8:00			66	64	58	68	62	45	14	15	15	12	13	23	25	18	13	10	18	19	17	17	25	24	25	20	37	29	22	23	21	54	61	59	44	55	58	50		10	33	68
8:15			66	63	57	67	52	30	19	17	19	14	16	28	36	30	18	12	21	25	26	15	17	15	22	20	28	25	23	24	21	54	60	56	35	50	55	48		12	33	67
8:30			66	63	56	67	51	32	25	25	25	22	17	24	24	14	10	8	14	15	15	14	17	20	24	21	30	34	25	24	20	53	60	49	32	43	50	38		8	31	67
8:45			66	64	58	68	62	62	55	19	19	15	15	19	18	14	11	9	15	18	21	23	20	18	20	17	25	23	22	24	21	54	61	58	39	52	52	38		9	33	68
9:00			66	64	58	68	63	62	62	27	15	12	16	25	23	18	12	9	15	18	18	15	16	13	19	17	30	26	22	22	19	53	60	63	61	57	60	52		9	35	68
9:15			65	64	58	67	63	62	62	49	25	17	16	22	20	13	10	8	13	15	15	13	16	18	23	22	33	28	22	22	20	55	61	63	61	57	60	53		8	36	67
9:30			66	63	57	67	61	61	61	60	45	14	13	18	19	13	12	11	23	27	28	23	19	24	24	20	28	24	22	23	21	54	61	64	62	58	59	46		11	38	67
9:45			66	64	59	68	64	63	63	61	61	35	17	22	23	21	18	12	23	24	25	25	25	23	22	20	30	29	23	23	21	54	61	64	61	57	61	49		12	40	68
10:00			66	64	59	67	63	62	63	61	61	55	23	34	57	37	20	13	25	30	29	30	23	30	24	21	31	22	21	23	21	55	61	64	61	56	60	42		13	43	67
10:15			66	64	59	67	61	62	62	60	61	64	65	57	57	45	36	13	22	26	27	26	27	29	23	21	26	25	26	25	23	55	61	64	62	58	61	54		13	46	67
10:30			66	63	58	67	62	62	62	59	60	62	65	59	62	65	56	63	55	45	36	44	25	26	22	21	42	61	50	36	25	55	61	63	59	56	59	47		21	52	67
10:45			66	63	58	67	62	62	63	60	61	63	65	60	61	65	56	63	55	61	53	64	63	62	51	59	46	63	64	61	48	59	63	64	63	60	58	57		46	60	67
11:00			64	62	57	66	59	61	61	60	60	63	65	60	61	64	57	63	56	61	56	64	62	61	61	65	62	62	64	63	62	63	64	65	63	61	62	60		56	62	66
Column Summary																																							Overall Row Summary			
Min			64	62	55	65	51	30	14	15	15	11	13	15	18	13	10	8	13	15	15	13	14	13	19	17	25	21	21	22	19	53	60	49	32	43	50	38	Min	8	28	65
Avg			65	63	58	66	61	56	51	45	43	38	29	32	37	32	29	27	28	33	32	33	31	31	32	31	38	41	38	37	32	57	62	62	55	56	59	52	Avg	27	44	66
Max			66	64	59	68	64	63	63	61	61	64	65	60	62	65	57	63	56	61	57	64	63	62	61	65	62	65	66	65	63	64	65	65	64	62	63	64	Max	56	63	68

Figure 7c: Thursday Speed Contour Maps - Paramics and Tach Runs

A statistical comparison of the contour maps was also carried out using the chi-square test. The results are shown on Figures 8a through 8c. The largest chi-square values occurred at the upstream end of congestion and in the latter time intervals. Overall, the fit between the target values and the calibrated values was considered good for the three days.

4.5 Trip time analysis

Another analysis carried out as part of the validation was to compare the overall travel times of vehicles on the actual freeway network using the “floating car” tachography runs, to those of vehicles in the Paramics model. Figure 9 shows, for the three days of analysis, the comparison of the actual and model overall trip times to drive over the entire freeway study section (from the mainline origin to the last exit ramp). Trip times in minutes are plotted against time of departure. Field data was available from the tach runs. Modeled data was obtained by averaging the trip times of all vehicles starting the trip within a time slice.

It can be observed that the travel times of vehicles simulated in Paramics follows the same pattern and are of similar magnitude to that of the actual tach runs made. The travel times simulated by Paramics based on Tuesday vehicle demands follow the same pattern and are spread evenly around the tach run travel time curve. Similar boundary conditions (about 20 minutes for free-flow conditions) and peak values of 56-58 minutes occurring in the same time slice are observed. Over most of the study period, modeled trip times were within the +/-10 percent range of the actual travel times.

On Wednesday and Thursday, travel times on the network begin to increase earlier in the Paramics simulations than in the tach runs. The travel times also peak earlier in Paramics than observed on the tach runs on Wednesday and Thursday. Paramics may have been predicting congestion to appear on the freeway network earlier than actually occurred on the two days (Wednesday, October 3rd and Thursday, October 4th) that the data was collected. As discussed in Chapter 3, the calibration of input parameters was set to get a good fit on Tuesday. This may have been done at the expense of the Wednesday and Thursday results.

The main issue raised by the three plots on Figure 9, however, lies in the unexpectedly wide range of travel times predicted by Paramics. For a given starting time, vehicles are shown to experience high differences in performances, with trip times varying between 40 and 80 minutes during the congestion peak. These results were extensively discussed with Caltrans and Quadstone, and additional investigations were performed at the end of the project to try to improve the results. Some suggestions related to changing the method for collecting trip time statistics were tried, but were unsuccessful. The model was also run with a newer version of the Paramics software (Version 4) released in the fall of 2002: trip time results with Paramics Version 4 were found to be less scattered, but the average trip times did not match the tach run data as well as in the Tuesday scenario shown on the top of Figure 9.

I-680 SB — SPEED COMPARISON - CHI SQUARE TEST — October 2 (Tuesday)

Interval Start	0	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	30	31	32	33	34	35	36	37	Row Summary Min	Row Summary Avg	Row Summary Max
5:00			6	0	1	0	0	1	0	1	0	0	0	2	0	0	2	5	23	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	23
5:15			14	0	1	0	0	1	0	1	0	0	8	7	4	1	54	16	1	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	54
5:30			5	0	1	0	0	1	1	1	0	119	22	2	2	8	0	1	4	3	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	13	0	5	119
5:45			4	0	0	1	0	0	0	40	33	28	6	0	1	0	1	5	0	0	0	1	3	11	1	0	1	0	0	0	0	0	0	0	29	0	1	4	0	5	40
6:00			4	0	1	0	0	0	6	12	60	65	2	1	0	0	1	4	0	0	3	6	12	11	3	5	2	0	0	0	1	0	0	1	0	0	1	0	0	6	65
6:15			0	0	1	0	0	34	19	64	87	27	2	1	3	0	1	3	0	3	10	10	12	17	15	18	2	0	0	0	6	0	0	1	0	0	0	1	0	9	87
6:30			4	0	1	0	0	3	35	61	47	7	8	0	1	0	2	3	3	6	5	17	12	10	9	15	5	0	0	5	16	0	0	0	0	0	0	2	0	8	61
6:45			8	0	0	0	0	9	104	4	16	0	5	3	0	0	1	2	3	8	15	12	8	12	1	6	4	4	7	8	8	1	0	0	0	1	0	0	0	7	104
7:00			4	0	1	0	1	5	125	0	0	3	10	3	4	3	7	8	4	17	0	2	2	3	2	10	0	1	2	4	2	6	0	1	0	0	3	1	0	7	125
7:15			4	0	0	3	22	4	26	6	0	1	4	4	8	7	0	10	5	0	12	1	13	21	0	4	3	2	0	0	3	2	0	0	0	1	0	0	0	5	26
7:30			3	0	1	1	3	0	0	12	0	1	11	13	22	0	0	2	2	4	2	5	1	4	0	2	26	6	0	0	5	14	0	0	1	0	0	0	0	4	26
7:45			2	0	1	0	1	13	10	16	0	0	2	0	3	1	0	1	0	2	1	0	0	7	0	1	18	2	0	0	1	5	0	1	9	0	1	0	0	3	18
8:00			7	0	0	0	7	24	26	14	1	4	3	0	0	8	1	1	0	0	8	9	1	2	0	0	6	1	0	0	1	12	0	0	9	1	0	3	0	4	26
8:15			9	0	1	0	11	37	32	0	1	5	2	1	0	2	2	1	0	2	1	0	0	9	0	0	3	0	0	0	1	13	0	0	4	0	0	2	0	4	37
8:30			8	0	1	0	1	4	16	4	0	2	4	0	10	1	2	1	0	4	1	0	2	2	5	0	7	6	0	1	2	26	0	0	0	0	0	1	0	3	26
8:45			7	0	0	0	0	1	21	0	6	9	32	0	0	6	1	0	0	7	1	11	2	8	1	3	9	1	1	0	1	6	0	1	0	1	0	3	0	4	32
9:00			7	0	1	0	0	0	0	0	67	7	7	9	6	11	2	0	1	14	1	0	0	0	1	2	14	44	3	1	6	1	0	0	0	0	1	1	0	6	67
9:15			1	0	1	0	0	0	0	0	134	67	0	1	15	3	0	0	1	0	2	23	0	3	2	0	7	1	2	0	0	19	0	0	0	1	1	3	0	8	134
9:30			5	0	1	0	0	0	0	0	19	77	0	1	2	21	2	3	0	19	0	3	4	0	2	2	5	1	5	0	3	3	0	0	0	1	0	0	0	5	77
9:45			11	0	1	1	0	0	0	0	27	126	16	29	3	39	0	0	9	2	9	4	50	7	0	3	18	0	2	1	2	8	0	0	0	1	1	3	0	10	126
10:00			5	0	1	0	1	0	0	0	0	8	50	65	60	63	10	2	5	5	4	3	3	11	0	2	7	1	0	3	1	25	2	0	1	1	0	1	0	9	65
10:15			12	0	0	0	0	0	0	0	0	0	0	13	50	198	123	84	20	10	27	28	4	0	0	2	4	22	14	1	2	2	1	0	0	0	0	0	0	17	198
10:30			5	0	0	0	0	0	0	0	0	3	8	6	6	15	11	10	7	9	18	9	16	52	67	0	8	34	44	52	2	5	0	0	0	0	0	2	0	11	67
10:45			7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	3	95	19	1	5	5	3	44	12	16	34	10	0	0	0	0	0	0	0	7	95
11:00			4	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	2	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Column Summary																																							**Overall Row Summary**		
Min			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avg			6	0	1	0	2	5	17	10	20	22	8	7	8	16	9	7	4	5	5	10	7	8	5	3	6	7	4	4	4	6	0	0	2	1	0	2	0	6	22
Max			14	0	1	3	22	37	125	64	134	126	50	65	60	198	123	84	23	19	27	95	50	52	67	18	26	44	44	52	34	26	2	1	29	2	3	13	0	48	198

Overall sum 5466

Figure 8a: Tuesday Speed Contour Maps - Chi Square Test

I-680 SB — SPEED COMPARISON - CHI SQUARE TEST — October 3 (Wednesday)

Interval Start	0	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	30	31	32	33	34	35	36	37	Row Summary Min	Row Summary Avg	Row Summary Max
5:00			7	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
5:15			9	0	0	0	0	0	0	0	0	0	1	0	0	3	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9
5:30			3	0	0	0	0	0	0	2	0	10	5	0	0	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10
5:45			4	0	0	0	0	0	0	0	0	0	0	0	0	0	5	3	1	0	0	0	0	0	0	1	0	1	1	0	2	0	0	0	0	0	0	1	0	1	5
6:00			2	0	0	0	0	0	0	0	0	0	0	0	0	5	4	4	0	7	1	12	0	1	0	2	2	0	0	1	13	1	0	0	0	1	0	0	0	2	13
6:15			3	0	0	0	0	1	0	3	0	0	0	5	0	0	1	5	2	3	8	16	4	0	3	13	6	3	13	17	23	0	0	0	0	1	0	0	0	4	23
6:30			3	0	1	0	1	1	0	0	1	0	10	4	20	0	3	0	5	4	11	8	1	4	10	11	19	19	23	17	12	1	0	1	0	0	1	6	0	5	23
6:45			5	0	0	0	0	0	0	1	4	19	1	1	1	1	0	1	1	3	1	5	1	13	9	13	16	5	6	9	10	0	0	0	0	2	1	1	0	4	19
7:00			6	0	1	0	0	0	0	1	8	6	1	6	14	12	10	23	3	3	1	5	9	9	1	20	17	17	20	23	28	0	0	0	0	0	0	1	0	7	28
7:15			3	0	1	0	1	0	0	24	16	20	11	5	19	25	20	33	3	3	1	27	4	12	1	22	7	1	7	0	13	0	0	0	5	0	0	2	0	8	33
7:30			4	0	1	0	0	0	78	1	24	39	41	12	20	30	14	18	2	2	7	18	0	15	0	3	1	0	3	0	2	4	0	3	13	0	0	3	0	10	78
7:45			5	0	1	0	0	1	16	2	36	43	34	28	19	28	5	12	7	5	0	0	1	2	0	2	1	3	0	0	3	25	3	13	14	5	0	6	0	9	43
8:00			2	0	1	0	0	0	0	12	26	29	7	9	23	31	12	3	0	2	3	2	0	13	1	1	7	7	3	3	0	21	0	14	18	6	3	3	0	7	31
8:15			5	0	1	0	0	0	7	33	36	36	14	14	3	1	0	0	0	7	15	12	0	2	35	1	0	3	0	1	5	0	1	8	13	1	1	0	0	7	36
8:30			11	0	1	0	0	0	1	33	39	40	38	26	0	2	8	4	4	3	0	1	5	2	0	2	3	3	0	2	3	5	0	2	8	0	1	0	0	7	40
8:45			5	0	1	0	0	0	0	30	29	0	0	0	55	27	0	1	1	3	0	0	0	1	2	0	2	5	0	1	0	21	1	0	1	0	0	3	0	5	55
9:00			5	0	1	0	0	0	0	0	8	0	1	1	15	0	1	0	0	7	2	3	8	4	1	0	12	1	2	0	0	8	0	1	0	0	0	0	0	2	15
9:15			10	0	1	0	0	0	0	1	1	31	1	7	5	26	0	0	4	21	0	2	3	7	1	1	14	0	2	0	0	2	0	7	0	0	0	1	0	4	31
9:30			2	0	1	0	0	0	0	1	30	148	10	10	0	10	1	2	0	1	0	1	0	1	0	0	0	5	4	1	2	15	0	0	0	0	0	4	0	7	148
9:45			6	0	0	1	0	0	0	0	32	137	0	1	0	0	6	0	0	13	3	2	1	2	0	1	0	0	1	1	0	3	0	0	0	1	0	1	0	6	137
10:00			8	0	1	0	0	0	0	0	20	2	2	34	43	114	28	1	0	15	0	12	0	7	3	2	1	3	10	1	3	3	0	0	0	1	1	4	0	9	114
10:15			3	0	1	0	0	0	0	1	0	0	0	0	52	3	124	138	51	17	53	1	1	3	0	3	0	4	7	13	6	2	0	0	0	0	1	1	0	13	138
10:30			3	0	1	0	0	0	0	0	0	0	0	0	5	68	25	76	32	13	1	11	55	1	6	14	15	2	1	2	15	3	0	0	1	2	0	9	0	10	76
10:45			12	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	37	3	9	0	11	0	10	9	15	11	8	16	0	0	0	0	0	2	0	4	37
11:00			11	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	11
Column Summary																																							**Overall Row Summary**		
Min			2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Avg			6	0	1	0	0	0	4	6	12	22	7	7	12	16	11	13	5	5	6	6	4	4	3	5	5	4	5	4	6	5	0	2	3	1	1	2	0	5	22
Max			12	0	1	1	1	1	78	33	39	148	41	34	55	114	124	138	51	21	53	27	55	15	35	22	19	19	23	23	28	25	3	14	18	6	3	9	0	36	148

Overall sum 4827

Figure 8b: Wednesday Speed Contour Maps - Chi Square Test

I-680 SB				SPEED COMPARISON - CHI SQUARE TEST																																						October 4 (Thursday)
	Section number																																							Row Summary		
Interval Start	0	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	30	31	32	33	34	35	36	37		Min	Avg	Max
5:00			6	0	0	1	0	0	0	0	0	0	0	0	0	3	1	11	18	3	0	0	1	0	0	2	0	2	4	0	0	0	0	0	0	0	0	0	1		0	2	18
5:15			6	0	0	0	0	0	0	0	4	7	2	5	0	0	0	10	10	2	0	0	1	0	0	2	0	2	5	0	0	0	0	0	0	0	0	0	1		0	2	10
5:30			5	0	1	0	0	1	1	0	14	38	0	2	0	3	0	0	6	0	0	7	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1		0	2	38
5:45			3	0	2	0	0	2	1	0	12	19	1	3	0	8	2	2	9	1	2	6	0	1	0	1	4	0	0	0	0	0	0	0	0	0	0	0	1		0	2	19
6:00			4	0	1	0	0	0	0	1	10	81	39	0	7	2	0	0	1	0	0	2	7	11	8	16	2	0	0	0	1	0	0	0	0	1	1	8		0	6	81
6:15			7	0	1	0	0	0	0	0	57	94	26	2	2	4	2	0	2	1	2	0	3	4	2	6	1	10	2	0	13	1	0	0	0	0	0	1		0	7	94
6:30			6	0	1	0	0	0	0	8	59	67	0	2	2	5	6	8	8	10	12	9	7	5	2	11	3	0	2	5	4	4	1	0	0	0	0	2		0	7	67
6:45			3	0	1	0	1	0	0	1	18	21	0	10	15	11	8	19	12	13	13	7	5	0	1	11	1	8	14	14	18	2	1	1	0	0	0	0		0	6	21
7:00			4	0	1	0	1	1	6	4	1	0	2	4	15	18	17	3	2	6	4	0	3	17	6	6	0	11	6	1	1	14	2	0	3	0	0	0		0	4	18
7:15			6	0	0	1	0	0	10	30	2	2	5	4	19	21	4	2	3	13	6	3	0	0	0	2	3	0	1	4	3	4	0	0	3	0	0	1		0	4	30
7:30			11	0	2	0	1	4	31	38	10	0	0	2	9	8	0	11	8	2	2	13	1	3	0	0	8	8	0	1	4	2	0	0	1	1	0	1		0	5	38
7:45			4	0	1	0	0	15	33	36	12	0	4	10	9	4	1	22	7	8	0	7	2	8	0	1	7	17	3	0	4	1	0	0	7	1	0	5		0	6	36
8:00			7	0	1	0	0	6	37	37	13	2	9	4	0	2	3	2	0	1	0	1	17	1	5	0	19	0	0	0	4	18	2	0	3	0	0	1		0	5	37
8:15			0	0	1	1	3	20	33	36	29	0	1	1	2	31	15	0	0	0	5	0	0	3	1	2	8	0	0	0	1	3	0	1	10	2	0	3		0	6	36
8:30			5	0	2	0	3	16	24	25	0	6	1	5	54	5	2	0	7	10	0	2	0	3	3	0	11	5	1	1	2	5	0	2	14	6	2	9		0	6	54
8:45			6	0	2	0	0	1	1	30	7	0	1	0	8	1	4	2	0	29	1	2	1	0	1	1	3	0	4	2	4	9	0	0	10	3	2	11		0	4	30
9:00			3	0	0	0	0	0	0	24	42	3	0	2	21	10	2	0	0	2	3	2	1	0	0	2	2	6	16	18	23	0	0	0	0	1	0	1		0	5	42
9:15			4	0	0	1	0	0	0	4	16	10	2	0	1	1	1	7	4	0	1	1	2	3	0	1	7	4	0	0	0	3	1	0	0	0	0	0		0	2	16
9:30			6	0	1	0	0	0	0	0	26	1	4	0	0	1	2	6	20	0	3	13	1	4	1	3	4	0	0	0	12	3	1	0	0	2	0	2		0	3	26
9:45			13	0	1	0	0	0	0	0	0	60	1	0	1	5	4	1	12	0	1	2	11	1	0	0	4	4	3	0	1	16	2	0	0	0	0	2		0	4	60
10:00			4	0	0	0	0	0	0	0	0	118	0	14	32	14	21	9	12	7	6	1	3	15	1	3	0	1	1	0	2	10	2	2	0	1	0	7		0	8	118
10:15			11	0	2	0	0	0	0	1	7	10	54	9	13	11	39	4	11	3	8	11	5	12	14	6	0	2	3	1	1	40	2	1	1	0	0	0		0	8	54
10:30			4	0	1	0	0	0	0	1	1	1	9	1	3	185	35	1	1	3	4	0	3	14	5	21	1	29	5	1	1	2	0	0	0	1	0	1		0	9	185
10:45			4	0	1	0	0	0	0	0	0	0	0	0	0	6	33	0	2	0	2	0	0	0	3	1	5	0	0	0	4	0	0	0	0	0	0	0		0	2	33
11:00			3	0	1	0	0	0	0	0	0	0	0	0	0	5	36	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	36
Column Summary																																							Overall Row Summary			
Min			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Min	0	0	0
Avg			5	0	1	0	0	3	7	11	14	22	6	3	8	15	10	5	6	5	3	4	3	4	2	4	4	4	3	2	4	5	1	0	2	1	0	2	Avg	0	5	22
Max			13	0	2	1	3	20	37	38	59	118	54	14	54	185	39	22	20	29	13	13	17	17	14	21	19	29	16	18	23	40	2	2	14	6	2	11	Max	0	27	185
																																							Overall sum		4258	

Figure 8c: Thursday Speed Contour Maps - Chi Square Test

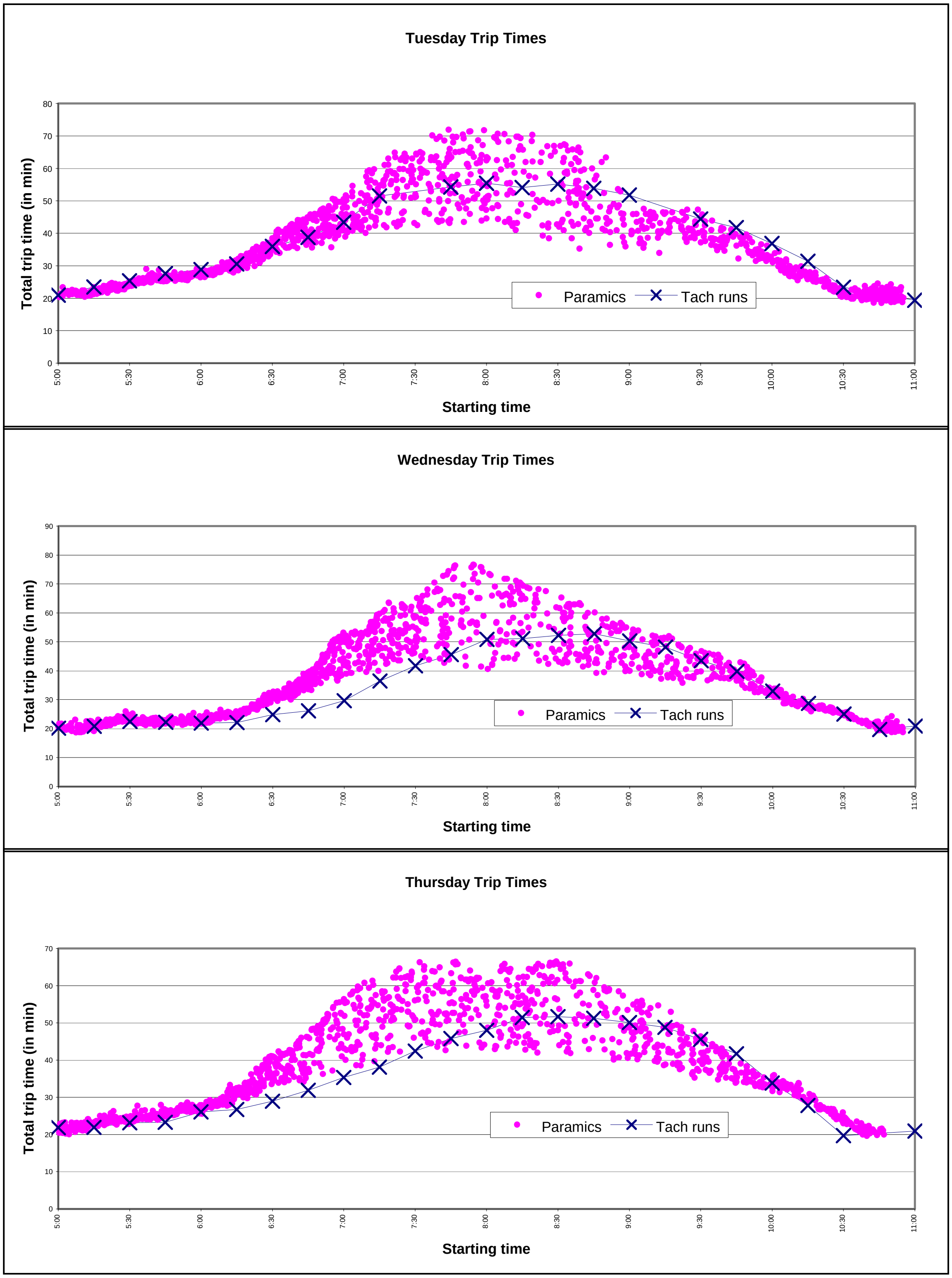

Figure 9: Comparison of Total Trip Times

4.6 Flow analysis

Vehicle volume checks were made at the various locations along the freeway study corridor for which mainline counts were available. In Section 2.4 it was stated that the collected data from the actual I680 freeway corridor included detector volume counts at four locations along the mainline freeway. Detectors were created at identical locations on the freeway network within Paramics, and the counts from each detector location pair were compared.

The results of this analysis, for all three days of traffic data and at the four locations, are displayed in Figure 10a through 10c. It can be observed that Paramics has estimated the number of vehicles to be acceptably close to that counted on the actual freeway. The counts appear to be consistent both in terms of magnitude and pattern.

4.7 Conclusions

The calibrated Paramics model was applied with all parameters and input data being fixed, except the demand information that was changed to represent the day-to-day variations. The outputs of the resulting three base runs (one for each day) were analyzed, and compared to the field measurements.

The network-wide statistics, and macroscopic relationships between speeds and flows derived from the model appeared to be consistent with what was expected based on real-life data and common expert knowledge.

Speeds, travel times and flows predicted by the model compared well with the traffic performances measured on the freeway study site. It was concluded that the calibration work had been successful, and that the model could realistically represent the base traffic conditions. With the base model being validated, it was possible to move forward and apply the model to the various alternative scenarios to be investigated.

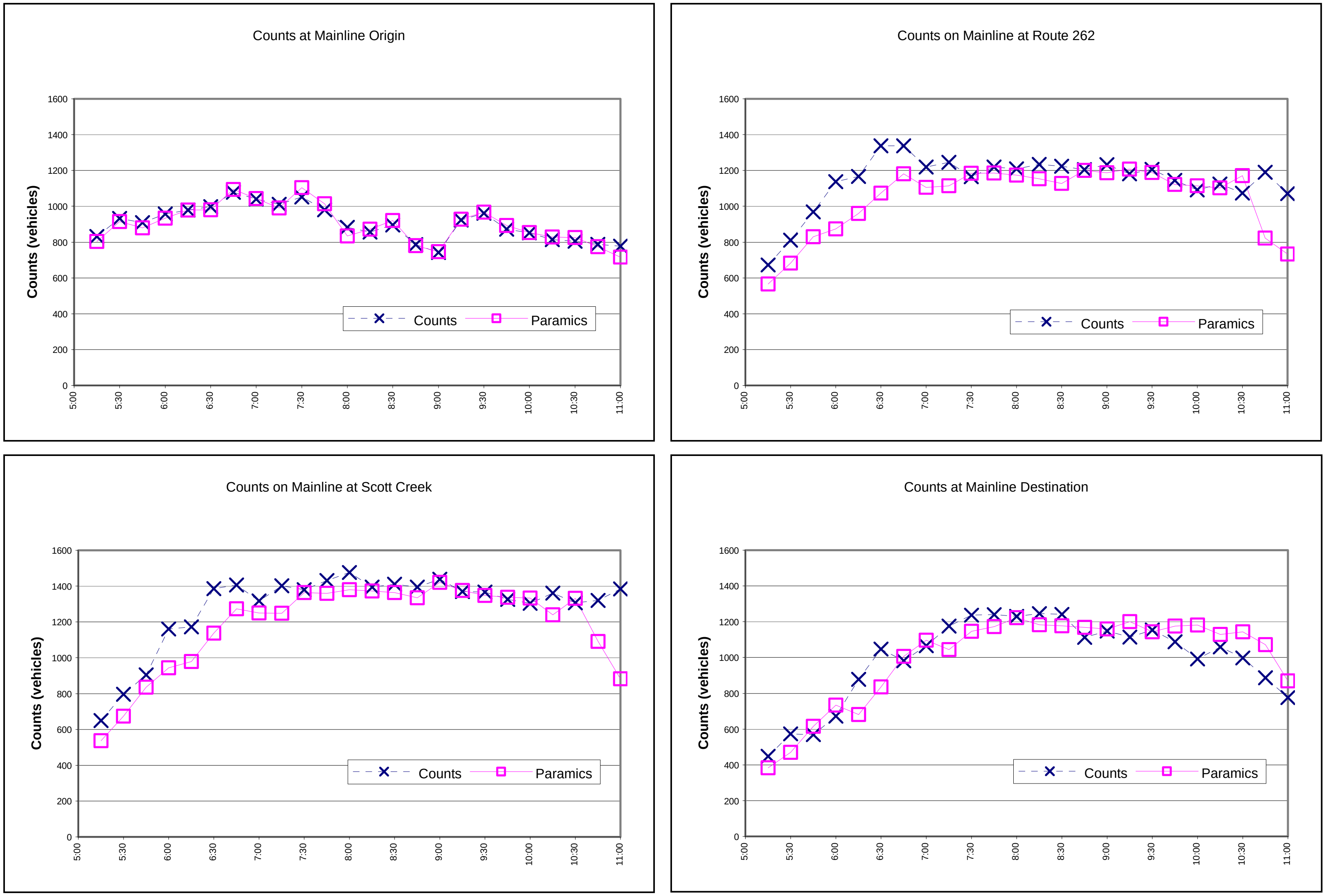

Figure 10a: Tuesday Base Run - Comparison of Actual and Model Counts

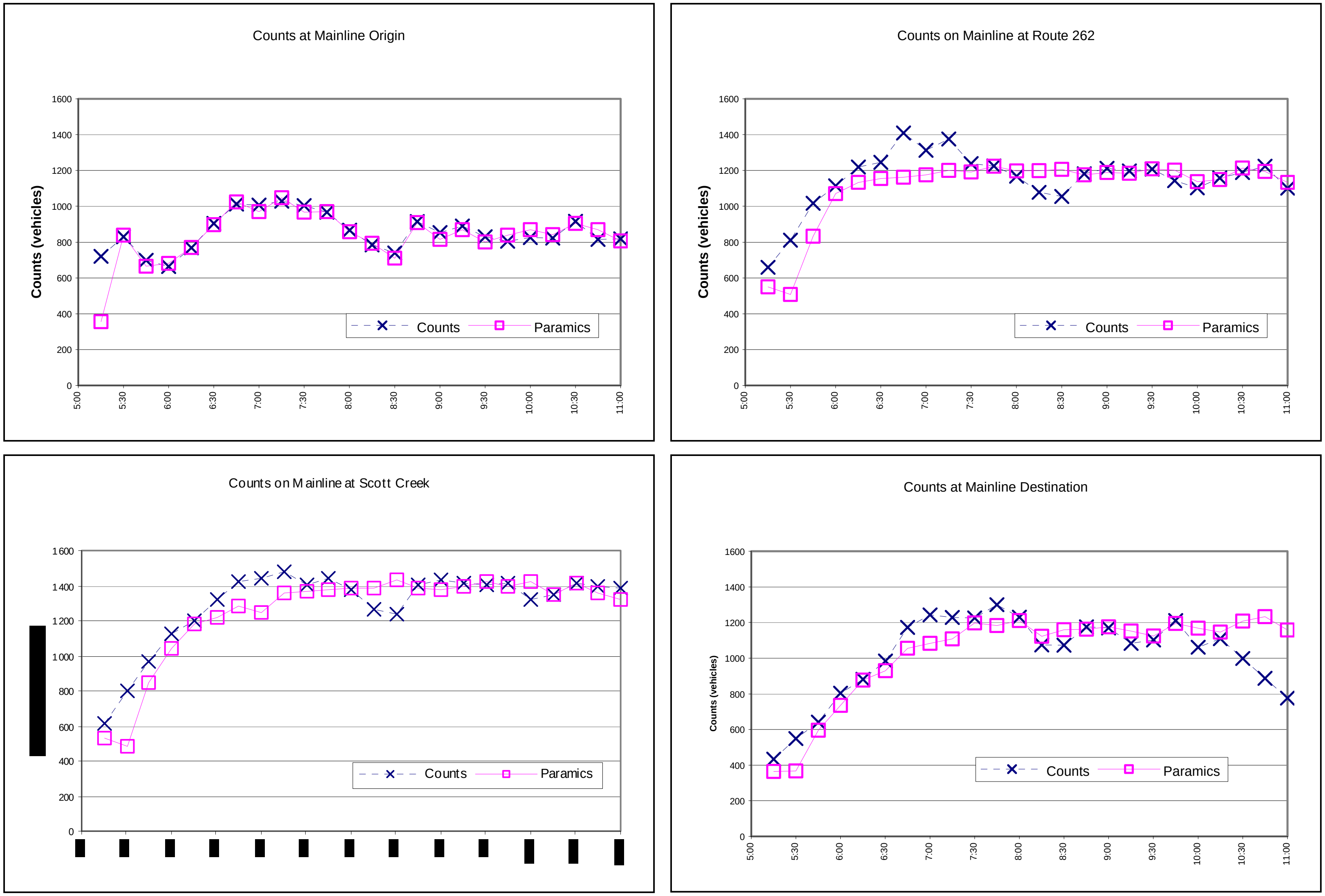

Figure 10b: Wednesday Base Run - Comparison of Actual and Model Counts

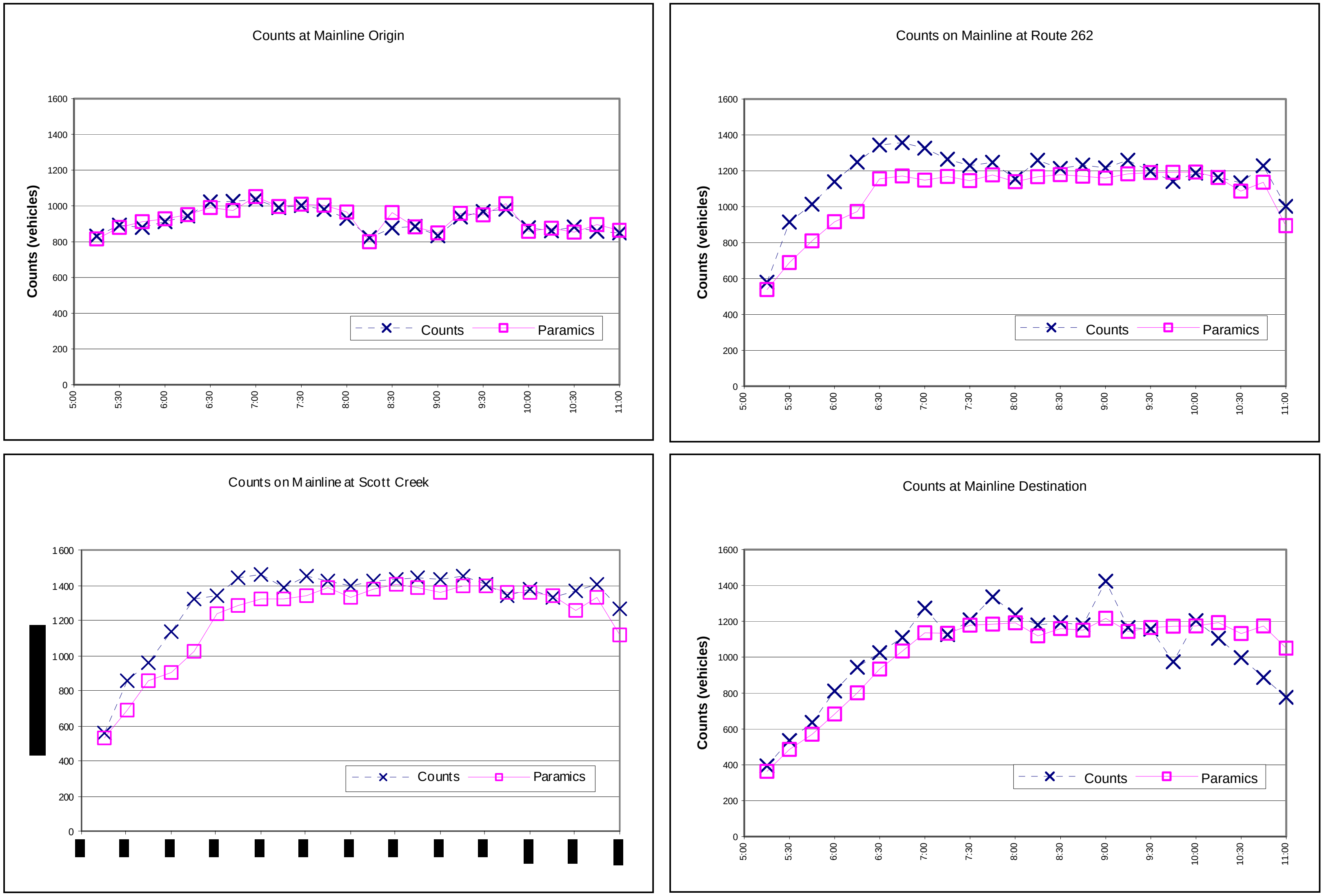

Figure 10c: Thursday Base Run - Comparison of Actual and Model Counts

CHAPTER 5: INITIAL TESTS WITH MODELLING HOV LANES

5.1 Introduction

There are two types of HOV lane configurations commonly used - contiguous and barrier-separated HOV lanes. A contiguous HOV lane is created by placing vehicle restrictions (against all lower-occupancy vehicles) on the lane that is designated for exclusive use by HOV vehicles. Vehicles can move into and out of contiguous lanes at any location along its length. A barrier-separated lane is represented by adding an additional set of links that runs parallel to the mainline freeway. It is connected to the mainline at connector nodes, where eligible vehicles can exit the mainline to enter the HOV lane and vice versa. Intermittent HOV barriers are also becoming common in southern California.

In the first phase of the I-680 project (Reference 1), it was found that Paramics Modeller could realistically simulate a barrier-separated HOV lane, but some difficulties were found when using Modeller alone to simulate contiguous HOV lanes. In order to address these difficulties, a specific "plugin" (or API) was developed by Quadstone to replicate drivers' behavior regarding HOV lane use, particularly that behavior which allows weaving in and out of a contiguous HOV lane.

When this API first became available for the I-680 project, no previous users outside Quadstone had ever used the API; the California PATH project team was the first group outside Quadstone to test this API. A guide to using the API had been written by Quadstone (Reference 7), but it was only an internal document that had not been published.

The API attempts to modify elements of driver behavior such that the simulation of a freeway with a contiguous HOV lane could be improved. It was tested on different networks –on a sample network that was sent by Quadstone along with the API, on a one-directional, straight pipe section with a contiguous HOV lane (referred to as the "simple network" and discussed in Section 5.3), and finally on the I680 freeway study corridor. The methods and inputs required to use the API are discussed in detail in Section 5.2.

5.2 API input data files

5.2.1 API input file 1: "hov-behavior.cfg"

This file specifies various behavior parameters of the HOV vehicles. With the use of the API, HOV vehicles will be able to evaluate link restrictions ahead of time; if a lane is restricted yet still allows HOV vehicles, it is assumed by the HOV driver to be an HOV lane and the driver will tend towards that lane.

The various parameters can be adjusted by the user, by either toggling the command to 'true' or 'false', or setting numerical values:

<u>Lane change accept time</u>: the minimum time that an HOV must receive stimuli before it attempts to lane change towards the HOV lane. (Range 2-10 seconds)
<u>Lane change re-set time</u>: the minimum time that an HOV must wait following a lane change before it attempts another one. (Range 2-20 seconds)
<u>Lookahead</u>: specifies whether HOV or non-HOV vehicles are warned of an upcoming HOV lane restriction on the upstream link. Once an HOV is warned of the restriction ahead, it can start the required lane changing process to get over to the HOV lane.
<u>Lookahead distance</u>: the maximum distance that a vehicle can look ahead for an upcoming HOV lane restriction (range 0–2000 meters). An adjustment range can be specified, to give different drivers different "awareness levels". (Range 0-500 meters)

5.2.2 API input file 2: "hov-types"

This file specifies the number of HOV vehicle types and characteristics of each.

By enabling "**<u>weaving</u>**", HOVs assume that there is no hard barrier separating HOV lanes from the mixed flow lanes, and they are allowed to weave into or out of the HOV lane at any point on the link.

Other parameters to be adjusted include:

<u>Patienc</u>e: how long the HOV will tolerate being held up by a slower HOV while traveling in the HOV lane, before it attempts to overtake. (Default 15 seconds)
<u>Overtake time</u>: how long an HOV will spend trying to overtake a slower HOV before it moves back to the HOV lane. (Default 30 seconds)
<u>Headway factor</u>: defines an HOV's gap acceptance factor, and applies to the HOV's target headway when it is weaving in and out of the HOV lane. (Range 0.1-1.0)

5.3 Test of the API on a simple network

5.3.1 Design of experiment

In order to test the API before applying it to the large I-680 network, a simple network was set up. As shown on Figure 11, the simple network was created especially for this modeling exercise. It consists of a straight, level, one-directional, three-lane freeway section, with lanes 13 feet in width and a free-flow speed of 65 mph. 13-feet wide lanes

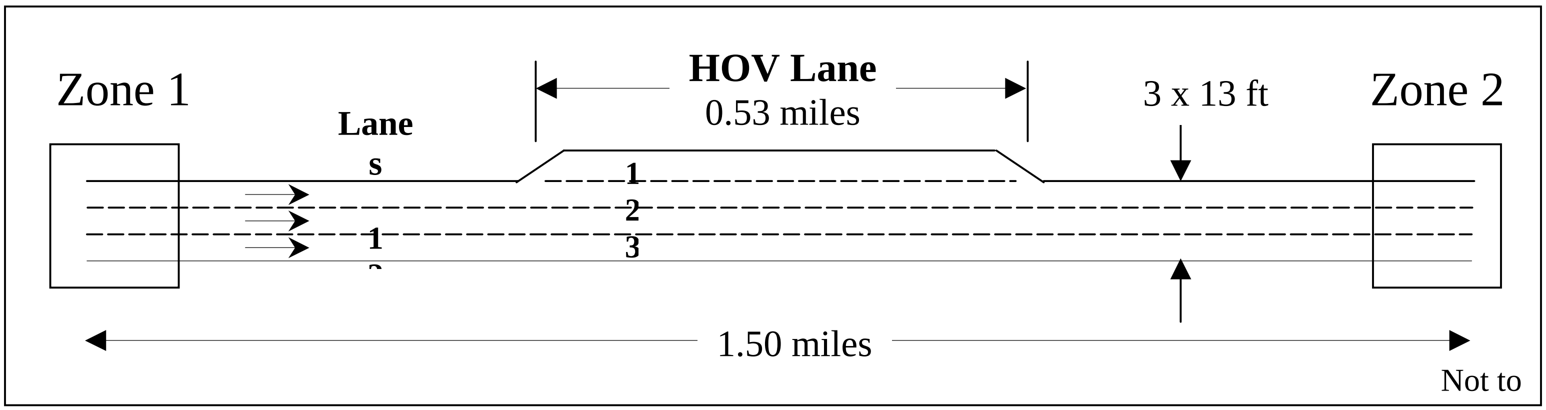

Figure 11: Simple Freeway Network with HOV Lane

are the maximum width specified by Caltrans. Two zones were designated, one at each end of the freeway section, such that the network consists of one origin-destination pair. The freeway network is 1.5 miles (7900 ft) long in total between the origin and destination.

The contiguous HOV lane shown in Figure 11 added an extra lane to the mainline freeway, making it four lanes wide across. It extends for a length of 0.53 miles (2800 ft). Although the lane is very short, it was maintained for simplicity. A quick calculation proves that a vehicle traveling at a speed of 65 mph will traverse the HOV section in approximately 29 seconds, while it will take a vehicle traveling at 20 mph, 1 minute 35 seconds (about a 1-minute addition). This calculation demonstrates that the maximum travel time savings possible on this freeway corridor are small in an absolute sense. The HOV lane is restricted to vehicles carrying two or more persons each.

The API input file parameters are shown on Figure 12. The parameters are extreme values; they have been set such that drivers are as impatient as possible, with the lowest allowed tolerance for delay. This was done to be able to visually observe, as clearly as possible, effects the API may have on the simple network.

"hov-behavior.cfg":	**api coefficients 8** **True "Enable HOV Behaviour"** **True "Force 'This-Link' HOV Decision"** **3 "Lane Change Accept Time" range 2 to 10 precision 0** **5 "Lane Change Re-Set Time" range 2 to 20 precision 0** **True "Force HOV Lookahead Decision"** **True "Force Other Lookahead Decision"** **500 "Lookahead Distance (m)" range 0 to 2000 precision 0** **50 "Lookahead Range (m)" range 0 to 500 precision 0**
"hov-types":	**hov vehicle types 2** **vehicle type 2** **weaving enabled** **patience 00:00:10** **overtake time 00:00:30** **vehicle type 3** **weaving enabled** **patience 00:00:10** **overtake time 00:00:30**

Figure 12: Driver Behavior API Input Files

Vehicle occupancies were specified as follows: 80 percent single occupancy, 15 percent double occupancy, and 5 percent 3+ occupancy. The simulation period was one-hour long. The demand was set at 5500 vehicles per hour over the freeway section.

For analysis purposes detectors were placed at three locations: 340 ft downstream of the beginning of the HOV lane, in the middle of its length (1600 ft downstream of the beginning) and then 100 ft upstream of its termination. From these detectors, measures of speed, flow, delay, occupancy and other parameters could be made on a lane by lane basis, which is important for analysis of HOV lane operations in comparison to the other lanes of the freeway.

5.3.2 Analysis of results

Occupancy values collected from the three detectors were translated into flow and speed values, which are found in the point data files (one file for each detector and each lane; 12 files in total). These values were averaged over the entire simulation hour and tabulated in Table 6.

All figures represent average values over the one-hour simulation period. The *Percent usage* values were calculated from the flow values. Paramics is set up such that the lanes are numbered from the innermost to the outermost. With this convention, the median-side HOV lane is Lane 1.

DETECTOR 1	Lane 4	Lane 3	Lane 2	HOV Lane
Flow (vph)	1946	2315	2078	893
Percent usage	26.9	32.0	28.7	12.3
Speed (mph)	59.1	64.1	71.8	78.0

DETECTOR 2	Lane 4	Lane 3	Lane 2	HOV Lane
Flow (vph)	2177	2607	2468	1051
Percent usage	26.2	31.4	29.7	12.7
Speed (mph)	57.8	63.1	68.9	76.2

DETECTOR 3	Lane 4	Lane 3	Lane 2	HOV Lane
Flow (vph)	2163	2468	2286	1006
Percent usage	27.3	31.2	28.9	12.7
Speed (mph)	50.0	47.0	45.3	51.8

Table 6: Average Flow, Speed, and HOV Lane Usage Values

From Table 6, it can be observed that the actual usage of the HOV lane represents about 12% of the total traffic. As can be expected, average speeds are much higher and vehicle flows much smaller on the HOV lane because of its limited usage. The average speed measured on the HOV lane at Detector 3 is 51.8 mph, lower by about 25 mph than that of the other two detectors.

The low percentage of HOV lane usage could be explained by different factors. It may have occurred because the operating speeds on the mixed-use lanes are high enough such that drivers do not feel the need to weave over to the HOV lane. In addition, the HOV lane is only 0.5 miles in length and vehicles are traveling at freeway speeds. Over this length, vehicles may not find that the travel time savings gained by weaving over to the HOV lane is enough incentive to actually do so. However, this 12% HOV lane usage has to be compared with the proportion of eligible vehicles, i.e. the vehicles that are actually allowed to use the HOV lane. In our scenario, 20 percent of all vehicles (proportion of double and triple+ occupancy vehicles in the vehicle population) can legally use the HOV lane. Overall, the usage of the HOV lane represents about 60% of all the eligible HOV vehicles, which is in the order of what was expected, based on empirical information (Reference 8) and past observations.

It was observed that all HOV vehicles traveling in the innermost lane, upstream of the HOV lane, immediately enter the HOV lane as soon as it begins. However, few HOVs traveling in the two outer lanes upstream of the HOV lane were observed to move into the third lane before the beginning of the HOV lane. If vehicles are traveling on the lane adjacent to the HOV lane, having switched onto it after the HOV lane began (from one of the two outer lanes), they switch lanes again into the HOV lane in the middle of a link if they begin experiencing a large decrease in speed (as compared to free-flow speed). This was found to be a realistic representation of driver behavior, because drivers are generally extremely impatient and, while commuting, will take any opportunity to travel faster if they are at all able.

There were found to be many HOV vehicles traveling in the two outer lanes, despite the fact that they were forewarned of the HOV lane upstream of its beginning. Often times, these HOV vehicles become caught in the congestion on the non-HOV lanes in which they are traveling, and then cannot lane-change over to the HOV lane due to the limited number and size of gaps in traffic.

5.3.3 Conclusions

From the investigations conducted of the simple network and discussed in this section, it can be concluded that the API is working correctly for purposes of modeling vehicle behavior in the presence of HOV lanes. The tests of the driver behavior API on the simple network have provided a satisfactory basis from which to move forward with additional tests of the API.

CHAPTER 6: HOV LANE INVESTIGATIONS ON I-680

6.1 Introduction

This part of the investigations involved modeling the I-680 freeway corridor with an additional contiguous HOV lane. These investigations were based upon the I-680 network previously calibrated and validated, and were using the driver behavior API introduced and discussed in Chapter 5.

6.2 Preparing the input data files

6.2.1 Network geometry specifications

The contiguous HOV lane is to be constructed within the boundaries of Route 84 (Calaveras) in the north to Route 237 (Calaveras) in the south, a total of approximately 13 miles (see Figure 13). These boundaries had been previously specified by Caltrans. In the Paramics model, the HOV lane was coded as an additional contiguous lane. By using lane restrictions, only vehicles carrying two or more passengers are allowed to use this HOV lane

Several geometric refinements and trial runs were necessary before the roadway network and base network were deemed acceptable. Because of the additional lane being created, the network geometry was modified and a number of adjustments were necessary. It is critical that the network's physical characteristics be accurately represented, because the geometry has a substantial effect on vehicle behavior in Paramics.

Geometric refinements included realignment of three on-ramps where they merge with the mainline freeway, realignment of nodes and curb points at fourteen locations on the freeway mainline, increasing the distance of the signed warning upstream of the HOV lane, and improving the alignment of the freeway widening at the beginning of the HOV lane.

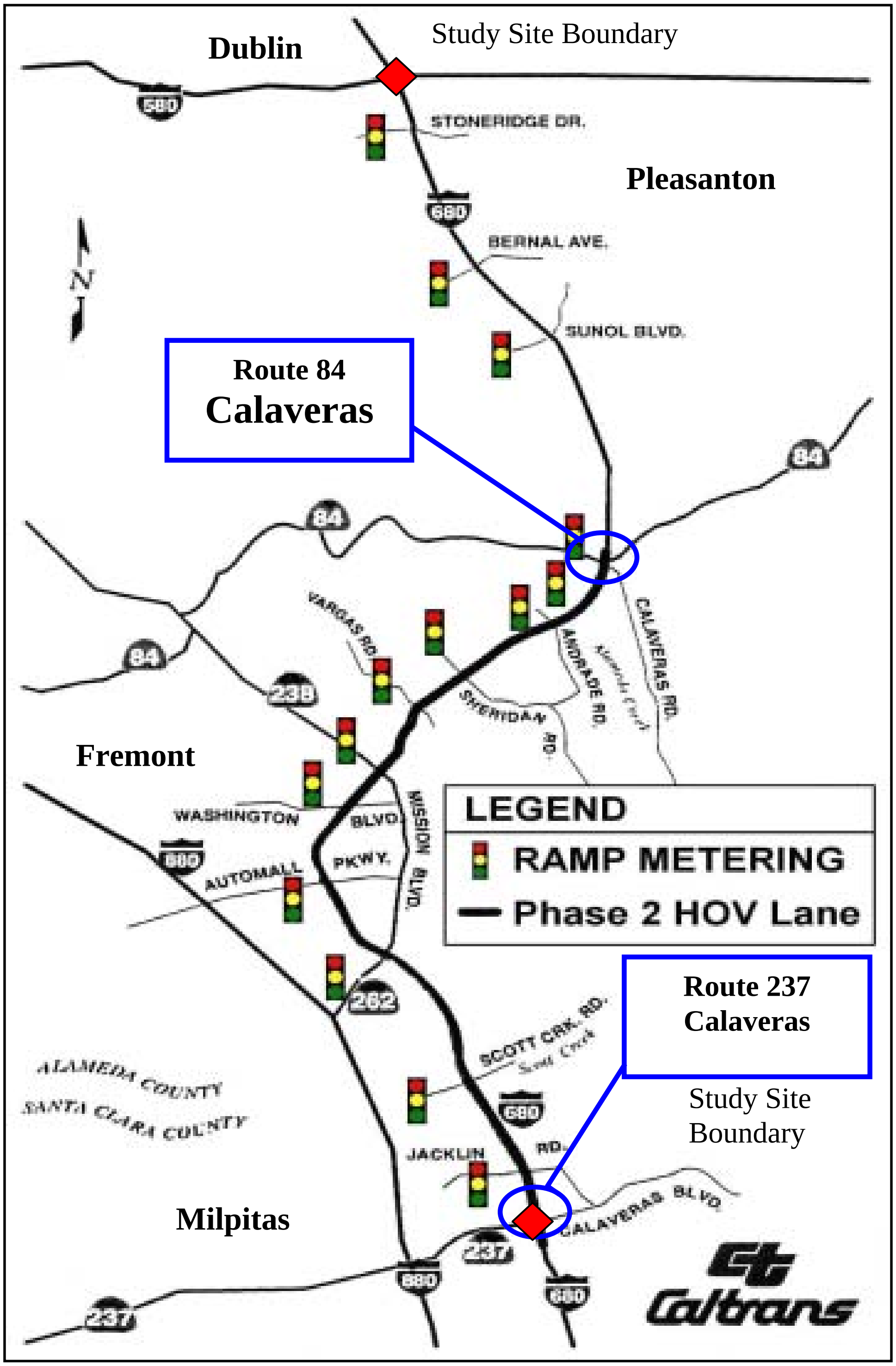

Figure 13: I-680 HOV Lane Limits

6.2.2 Vehicle demands and other traffic-related inputs

Vehicle demands, types and occupancies used in the calibration of the base conditions were initially used in the HOV investigations. This indicates that, at this stage of the study, no modal shift as a result of the HOV lane opening was assumed to occur; however, the phenomenon of modal shift was later investigated as part of the sensitivity analysis (see Section 6.4.2).

The vehicle breakdown is listed in Table 7; it is identical to that described in Section 3.3.2.

Paramics Description		**HOV or SOV**	**Description**	**% Total**
Type 1	Car	SOV	Passenger Vehicle, 1 pax.	70%
Type 2	**Car**	**HOV**	**Passenger Vehicle, 2+ pax.**	**15%**
Type 11	Minibus	HOV	Minibus	Fixed Route
Type 12	LGV	SOV	Light Goods Vehicle (truck)	8%
Type 13	OGV1	SOV	Open Goods Vehicle (truck)	3%
Type 14	OGV2	SOV	Open Goods Vehicle (truck)	2.5%
Type 15	**Coach**	**HOV**	**VANPOOL**	**1%**
Type 16	Bus	HOV	Bus	Fixed Route
Type 17	OGV2	SOV	Open Goods Vehicle (truck)	0.5%

Table 7: Vehicle Breakdown (Initial HOV Run)

Vehicles are distinguished within Paramics by their length, top free-flow speed, and their proportion in the total vehicle traffic. There are no specific vehicle types representing HOV vehicles, but they can be distinguished from single occupancy vehicles by type number.

As only Vehicle Types 2 and Types 15 were allowed onto the restricted HOV lane in the model simulation runs, HOV vehicles make up 16 percent of the total vehicle population. Type 2 vehicles listed in Table 7 include both two-person occupancy and three or more occupancy vehicles, which were grouped into one vehicle type for the analysis.

The Tuesday (October 2nd) demand scenario was modeled in the first Paramics run described in Section 6.3, as well as the ensuing sensitivity analyses reported in Section 6.4. This was done such that some initial statistics could be obtained and experiments performed.

After it was deemed that the objectives of the research had been adequately satisfied with the Tuesday demands and different sensitivity runs, analyses of the Wednesday (October 3rd) and Thursday (October 4th) demand scenarios were performed. The analysis of the Wednesday and Thursday demand scenarios are presented in Section 6.4.4 as part of the sensitivity analysis.

6.3 Results of the "Tuesday" HOV scenario

6.3.1 Network-wide statistics

The first HOV lane simulation results for the Tuesday demand scenario indicated that there were major improvements to the operating conditions of the existing freeway. The same scenario was run seventeen times, varying the random number seed each time, because it was desirable to study the variations in the results due to random variations.

The random number seed in Paramics sets the random number generator starting point, and varying this value will guarantee a different outcome from the simulation each time due to random release of traffic by the program. Paramics users are advised to run the model with different seed values to test its sensitivity and stability.

The average values of the seventeen simulations made with different random numbers for each day are shown in Table 8. All statistics are taken over the simulation period from 4:30 to 11:15 am. The percentage figures in italics are the differences between the Base Case (as presented in Chapter 4) and HOV Case results.

TUESDAY HOV RUNS	**Base Case**	**HOV Case (Average of 17 runs)**	**Percent Change**
Total Vehicle Input (onto freeway)	62,514	62,626	*+0.2%*
Total Vehicle Hours Traveled	21,418	14,201	*-34%*
Total Vehicle Miles Traveled	641,110	642,237	*+0.2%*
Overall Average Speed (includes both mainline and ramps, mph)	29.9	45.3	*+51%*

Table 8: Network-wide Statistics, Base HOV Lane Runs

In the Tuesday traffic demand scenario, it can be observed that the total vehicle hours traveled decreased 34 percent and the overall average speed increased 51 percent from the existing freeway to the freeway with an HOV lane. The total vehicle count (i.e. the total number of vehicles released onto the network) and vehicle miles traveled remain very similar before and after the HOV lane implementation, which indicates consistency in the traffic demand served between the two scenarios.

6.3.2 Lane-by-lane detector statistics

Detector data at one key location - just before the on-ramp at the Scott Creek interchange - was reviewed for analysis. This detector location was chosen because it is located near the midpoint of the study corridor. Table 9 displays the statistics obtained from the first trial run for the Tuesday demand scenario (random number 1245) for the entire simulation period (4:30-11:15 AM).

TUESDAY INITIAL HOV RUN	**Lane 4**	**Lane 3**	**Lane 2**	**HOV Lane (1)**	**TOTAL**
Flow (vph)	776	1,479	1,673	**462**	4,390
Speed (mph)	58.7	62.4	64.0	**67.2**	
Total vehicle count	5,239	9,980	11,293	**3,120**	29,632
% Traffic per lane	17.7%	33.7%	38.1%	**10.5%**	

Table 9: HOV Run Lane Statistics, Detector at Scott Creek

In Table 9, average flow is calculated based on the total vehicle count over the simulation period. Average speed is calculated from the average of all counted vehicles' speed in each lane; the percentage total vehicles are found by taking the total vehicle count per lane over the total number of vehicles that traveled over the detector during the simulation.

As shown, 10.5 percent of all vehicles use the HOV lane at this detector location. Vehicles eligible to use the HOV lane make up 16 percent of the total vehicle population; such that (10.5/16)*100 = 66% of all eligible HOV vehicles use the HOV lane. This percentage of HOV lane usage falls within the range of what is expected based on empirical information collected in the field by Caltrans District 4 (Reference 8) and past observations.

6.3.3 Speed contour map

A speed-contour map of the HOV base run results was prepared in order to observe traffic flow improvements within the study corridor, as compared to the Base Case (Figure 14). The speed-contour map results for the HOV lane base run are the composite results of the HOV lane operations and the mixed-flow operations. It would be desirable to present the HOV lane operations and the mixed-flow lane operations separately, but this was a limitation of the model in that it does not disaggregate statistics on a lane-by-lane basis.

The speed-contour maps show a significant decrease in freeway congestion with the HOV lane addition, or substantial increases in vehicle speeds, as evident from the reduced congestion (in both time and space). In the base case, congestion begins at about 5:15 AM on Subsections 12 and 13. Congested conditions are last seen at 10:30 AM on Subsections 25 to 26 and 30. The bottleneck occurs in Subsection 31; at its most severe, the congestion extends from Subsection 31 to upstream to Subsection 6 in the base case.

In the HOV scenario, the congested conditions begin on the freeway at approximately the same time, but end earlier. The average speed on the freeway corridor for the entire simulation period, as computed based on these speed diagrams, has increased from 30 mph to 43 mph.

6.3.4 Average freeway travel times

Average 15-minute interval travel times were also generated through Paramics Analyzer; the travel times shown in Figure 15 are those for the entire length of the freeway section, as computed by Paramics. It can be observed that the travel times for both high occupancy as well as single occupancy vehicles decreases dramatically after the HOV lane addition.

The travel times in the HOV scenario are always lower than the Base Case travel times in the same 15-minute time slice. This indicates that the bottleneck that occurred on the freeway under the base conditions was not as severe after the addition of the HOV lane. Although congested conditions begin at about the same time, in the HOV scenario, the congestion is never as severe as in the Base Case. The congestion also ends about an hour earlier with the HOV lane added.

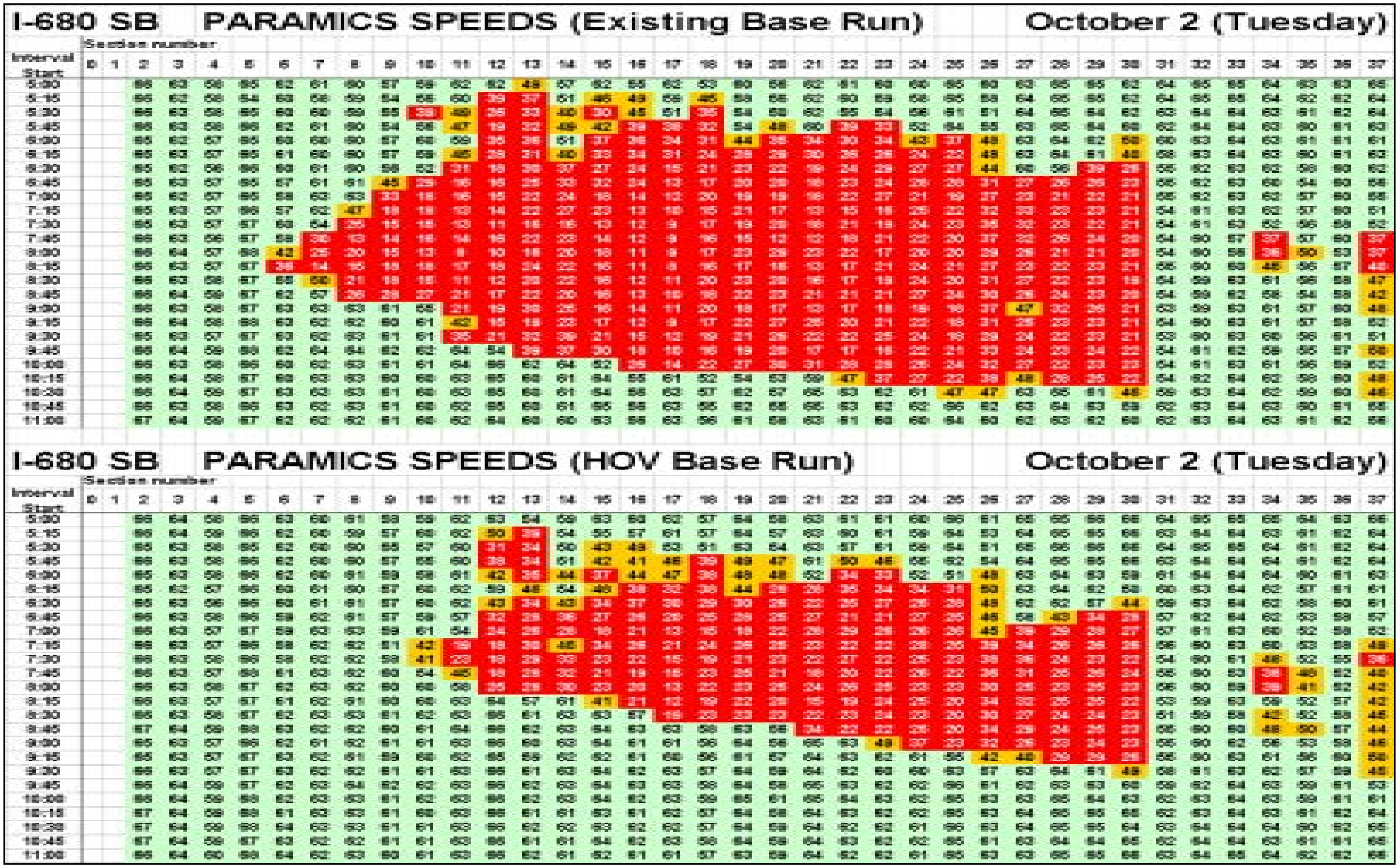

Figure 14: Tuesday Speed Contour Maps - Base Case vs. HOV Case

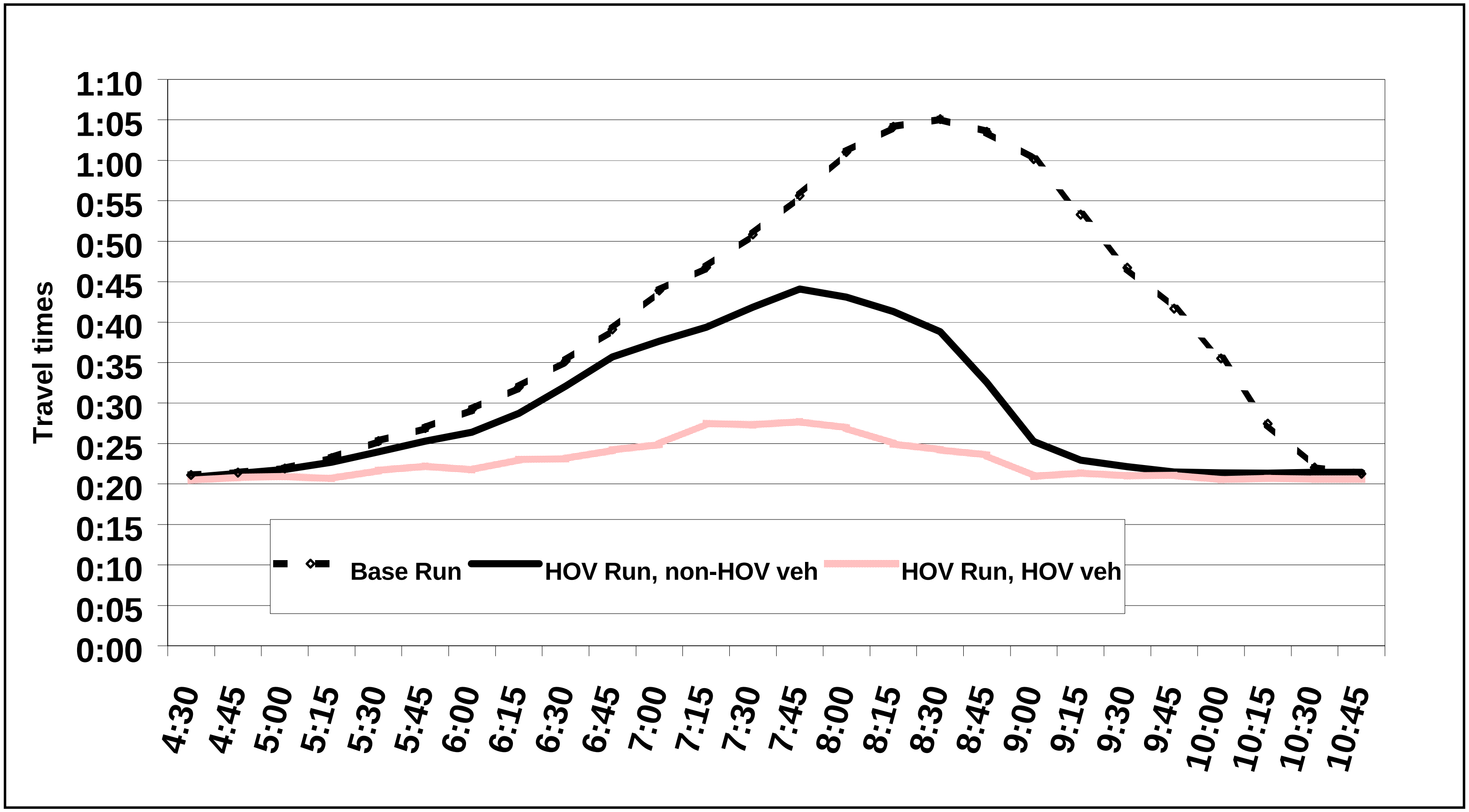

Figure 15: HOV and Base Scenarios - Comparison of Freeway Trip Times

6.4 Sensitivity analysis

Several scenarios were developed within Paramics as part of a sensitivity analysis, to assess the effects on the network of altering certain input parameters that had previously been specified as part of the calibration of base conditions or maintained as defaults from the Paramics model.

The scenarios that were investigated included:

- Varying the HOV lane passenger occupancy cutoff level;
- Testing different vehicle occupancy distributions;
- Applying growth factors to the overall demand;
- Investigating the "Wednesday" and "Thursday" demand scenarios.

6.4.1 HOV lane occupancy restriction

In this scenario, the network was modeled by restricting use of the HOV lane to vehicles with three or more passengers, as opposed to the two or more person occupancy restriction that was previously used for the analysis. In the base HOV run, the HOV lane was used on average by 10.5 % of the overall freeway traffic (see Section 6.3.2, Table 9). If the cutoff level was increased to 3, and the vehicle occupancy distribution remained the same, it was expected that the HOV lane usage would become extremely low, greatly altering the potential benefits of the HOV lane.

Nevertheless, a scenario with a cutoff level of three passengers was modeled for analysis. As expected, this scenario resulted in a very low usage of the HOV lane (3.6% of the overall mainline traffic at the Scott Creek detector). Low utilization of the HOV lane resulted in a significant decrease of the savings associated with the implementation of the HOV lane. Instead of the 45.3 mph overall average speed reported in the previous HOV scenario (see Table 8), the average speed decreased to 34 mph.

The modeling results confirmed that the two or more passenger occupancy lane design adopted by Caltrans for this project is the greatest restriction possible, if HOV lane implementation is to be justified by the improvement of freeway operating conditions. Alternatively, if a three or more passenger occupancy HOV was desired, one might consider implementing a high occupancy toll (HOT) lane option; however, this scenario was beyond the scope of this simulation project.

6.4.2 Alternate vehicle occupancy distributions

The next two scenarios were those in which the vehicle occupancy distributions were changed. As described in Section 6.2.2, the initial HOV run used the vehicle distribution initially developed for the calibrated base run.

Two alternative vehicle occupancy distributions, based on two sets of empirical data, were tested as part of the sensitivity analysis. These data sets included:

- Vehicle occupancy counts taken Tuesday October 2, 2001 on the existing I-680 freeway as part of the data collection effort for this study (as described in Section 2.3.3);

- Data from the existing HOV facility on I-680 just north of the study corridor, collected in 2000, and reported in a statistics report form Caltrans District 4 (Reference 8)

A comparison of the three vehicle occupancy distributions is presented on Table 10.

Vehicle Type	**Occupancy Distributions**		
	Initial	2001 Study Counts	2000 Stat. Report
Single Occupancy Vehicles	84%	89%	81%
Double Occupancy	10%	9.3%	13%
Three or more Occupancy	5%	1.7%	5%
Coaches (vanpool)	1%	-	1%
Total HOV Vehicles	16%	11%	19%

Table 10: Different Vehicle Occupancy Distributions

The initial vehicle occupancy breakdown is assumed to be typical of an average US freeway, without consideration for HOV lanes. The second occupancy distribution is based on observations made on the actual study network, before HOV lane implementation. The low percentage of HOV vehicles (11%) indicates a situation where there is no strong incentive to carpool.

On the other hand, the third vehicle occupancy breakdown is taken from a section of I-680 where the HOV lane is implemented. Therefore, it is likely that some modal shift has gradually occurred, resulting in a higher percentage of HOV vehicles (19%).

Results of the initial and two additional scenarios are presented on Table 11.

HOV RUNS	Occupancy Distributions		
	Initial	2001 Study Counts	2000 Stat. Report
Total Vehicle Count	62,626	62,224	62,645
Total Vehicle Hours Traveled	14,201	15,126	13,145
Overall Average Speed (mph)	45.3	42.3	49.0
% Total Traffic in HOV Lane	10.5%	7.6%	12.7%
% Usage of HOV Lane by HOVs.	66%	69%	67%

Table 11: HOV Runs – Results with different vehicle populations

The initial occupancy distribution represents the base HOV run, with the Tuesday demand scenario and a random number of 1245, as presented in Section 6.3.

When the first alternative vehicle occupancy distribution was modeled, the reduction of HOV vehicles in the vehicle population resulted, as expected, in a reduction of the HOV total lane usage (7.6% of the overall mainline traffic instead of 10.5%). Fewer vehicles using the HOV lane also resulted in a decrease of the overall freeway speed performance (42.3 mph as opposed to 45.3 mph).

The opposite occurred with the second alternative vehicle occupancy distribution, that of the HOV facility upstream of the study corridor, with a larger proportion of HOV vehicles. In this case, the utilization of the HOV lane increased to 12.7% from 10.5% and traffic operations on the freeway improved (i.e. average vehicle speed increased to 49 mph from 45.3 mph).

These results are consistent with the changes made in occupancy proportions. An interesting additional finding was that the percentage of eligible vehicles actually using the HOV lane was fairly stable, varying between 66% and 69%.

6.4.3 Overall demand growth

It is important to consider the phenomenon of demand growth in any investigation that requires vehicle demand input. As part of the sensitivity analysis, the effect of applying a growth factor to vehicle demand was investigated. Demand growth was modeled on both the base existing I-680 freeway as well as the I-680 with the HOV lane, such that comparisons could be made between the two network scenarios in terms of their performance under the increased demands.

A five percent compounded growth factor was applied over four time steps to vehicle demands. Figure 16 presents the results obtained in terms of overall average speed, in the base (no HOV) and HOV scenarios. Adding the HOV lane now results in the largest savings. As expected, the results show that the operating conditions of the existing I-680 network or on the freeway network with the HOV lane would deteriorate with increased demands. In year 4, the scenarios with and without the HOV lane lead to similar overall performance statistics, which is a unique and unexpected situation likely due to the fact that in the simulation, the density on the mixed-flow lanes is so high that the HOV vehicles are prevented from changing lanes to move into the HOV lane.

It was recognized that these results should be taken with caution, as the extreme level of congestion experienced in most of these runs did not allow for all vehicle input demand to be served at the end of the simulation period.

6.4.4 “Wednesday” and “Thursday” demand scenarios

In addition to the Tuesday demand scenario, HOV investigations were also made with the two other sets of demand data developed with counts collected on Wednesday, October 3, 2001 and Thursday, October 4, 2001.

In these two additional scenarios, only the demand Origin-Destination tables were different from the Tuesday HOV scenario previously described in Section 6.3. The network geometric configuration and the vehicle proportions were kept the same than in the Tuesday Base HOV scenario. As explained in 6.3.1 for the Tuesday scenario, each additional demand scenario was also run seventeen times with a different random seed number. The seed numbers were the same in the Tuesday, Wednesday and Thursday scenarios.

As in the Tuesday case, results were analyzed in terms of overall network-wide statistics, vehicle lane distribution, speed contour maps, and entire freeway trip times.

Table 12 presents a comparison of the overall network statistics and HOV lane usage for the three demand scenarios.

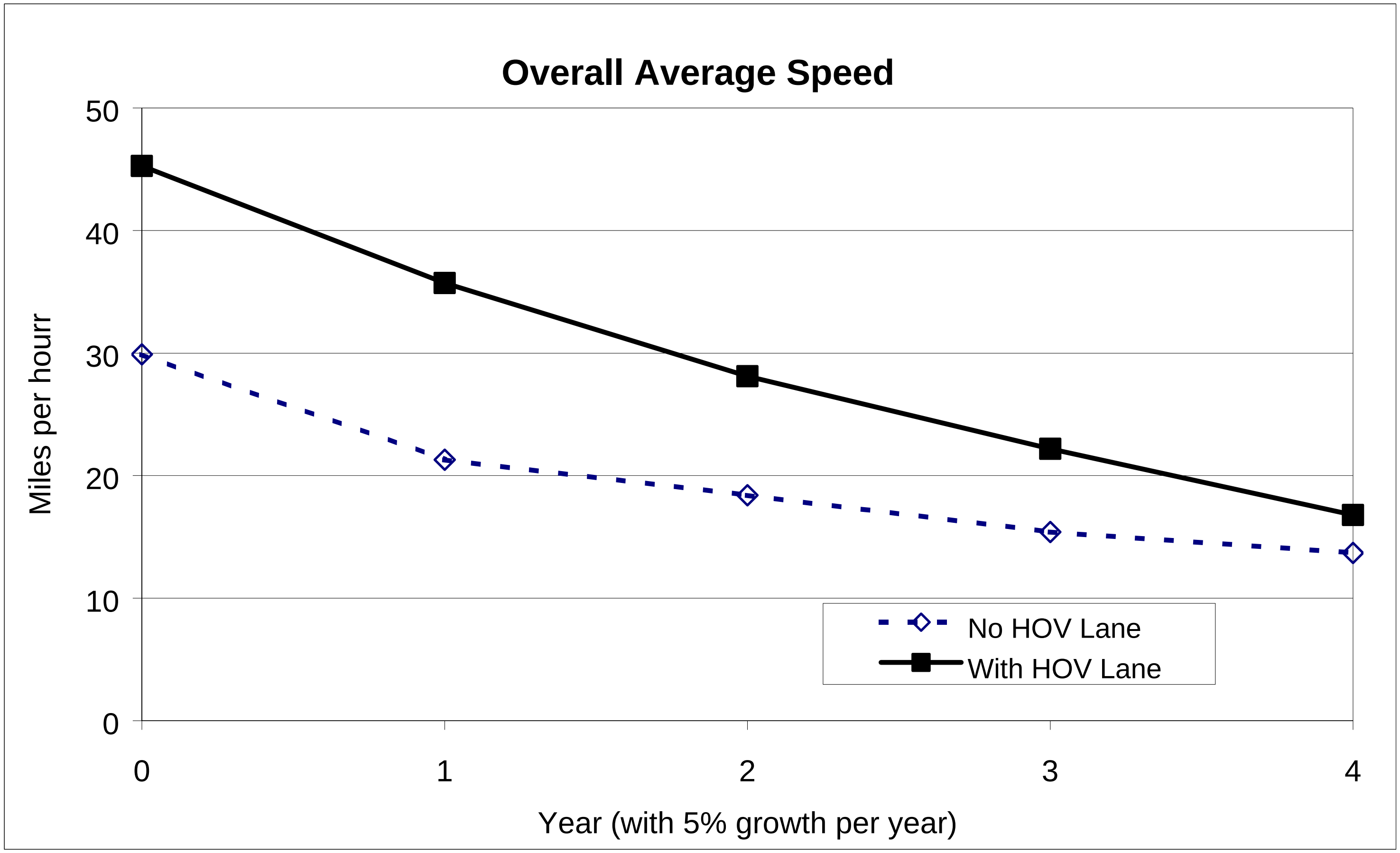

Figure 16: Overall Average Speed - 5% Yearly Growth in Demand

HOV RUNS		TUES	WED	THUR
Total Vehicle Count		62,626	59,488	62,132
Total Vehicle Hours Traveled		14,201	14,663	15,185
Overall Average Speed (mph)		45.3	42.5	43.1
HOV Lane	**% Total Traffic**	10.5%	10.6%	10.2%
	% of HOV veh.	66%	66%	64%

Table 12: HOV Run Results - Comparison of Three Days

The statistics related to overall network on the top of Table 12 represent the average values of the 17 runs made with different random numbers. The statistics in the bottom part, related to HOV lane usage, were obtained with one particular random number (1245) for the entire study time duration from 4:30 to 11:15 AM.

It can be seen on the table that the three days have resulting statistics that are very close from each other. The HOV lane usage, at 10.6% of the total traffic in the Wednesday case and 10.2% in the Thursday case, remained very similar to that of Tuesday (10.5%). The resulting percentage of eligible vehicles actually using the HOV lane is therefore also very stable, around 66%.

The speed contour maps for the Wednesday and Thursday scenarios are presented in Figures 17a and 17b.

I-680 SB — **PARAMICS SPEED CONTOUR - Base Run** — **October 3 (Wednesday)**

Section number

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00			68	66	61	69	66	64	65	62	62	65	66	61	63	65	56	64	55	62	58	63	62	61	60	66	62	64	66	65	62	63	64	65	63	62	62	66		55	63	69
5:15			66	63	58	65	62	60	61	61	62	64	64	53	58	64	56	62	54	62	58	63	62	61	61	66	64	64	65	64	63	64	65	65	65	62	63	65		53	62	66
5:30			66	64	59	66	62	61	60	53	56	60	45	37	54	53	52	62	51	59	56	62	58	59	57	65	62	63	64	63	60	62	64	64	63	61	62	65		37	59	66
5:45			67	64	59	67	63	62	63	60	61	63	64	52	54	52	52	60	45	57	56	62	59	58	58	64	57	62	63	60	52	60	63	64	62	59	60	63		45	60	67
6:00			66	64	60	67	63	62	62	60	61	63	62	51	56	63	55	61	52	59	54	62	58	55	53	46	47	62	62	56	35	57	62	64	62	59	61	62		35	58	67
6:15			66	64	59	67	61	62	61	56	59	62	58	42	53	49	53	63	52	59	55	63	60	59	45	33	44	49	35	30	25	56	62	64	62	58	60	63		25	55	67
6:30			65	63	57	66	60	61	61	59	59	62	39	33	52	47	44	50	36	56	56	62	43	35	33	28	28	25	24	25	23	56	61	63	62	58	58	59		23	49	66
6:45			66	63	58	66	62	60	58	57	59	56	30	36	44	34	32	40	29	31	26	24	21	22	24	19	27	25	23	23	22	55	61	63	61	56	59	57		19	43	66
7:00			65	62	57	65	58	61	61	55	55	25	18	22	28	27	19	16	20	23	23	20	20	20	24	22	26	23	22	23	20	54	61	63	60	55	53	52		16	38	65
7:15			65	62	56	66	57	62	61	37	25	22	18	21	26	21	17	11	16	16	15	10	16	17	24	21	25	27	23	22	20	53	61	59	42	55	57	50		10	35	66
7:30			66	63	57	66	61	61	58	25	20	13	13	16	20	16	13	9	16	14	12	17	19	20	23	19	26	22	21	22	19	53	60	51	32	55	58	48		9	33	66
7:45			66	63	57	67	61	62	35	15	12	10	13	22	27	20	10	8	13	17	21	17	18	18	19	16	23	23	23	22	19	53	59	36	31	48	60	46		8	31	67
8:00			66	64	58	68	63	60	27	14	14	13	15	19	19	15	12	9	12	13	14	15	20	18	21	20	31	26	22	21	21	54	59	32	31	46	46	47		9	31	68
8:15			67	64	57	68	63	64	40	17	15	12	13	18	20	16	11	9	21	24	24	18	14	14	27	22	25	23	23	23	20	52	53	39	32	48	58	44		9	32	68
8:30			65	63	57	67	62	63	59	18	14	14	15	19	17	13	12	10	16	16	14	12	16	16	19	17	26	24	22	22	20	52	60	49	36	55	58	53		10	33	67
8:45			66	63	57	67	62	63	60	20	21	14	14	22	28	20	11	9	16	17	19	13	13	14	18	15	23	29	26	23	19	53	61	62	49	57	61	49		9	34	67
9:00			66	64	57	67	62	62	63	60	41	19	15	20	18	13	10	9	14	13	13	13	19	20	20	19	29	26	23	23	20	54	60	64	62	57	60	52		9	36	67
9:15			66	64	58	68	63	62	63	61	61	28	15	23	27	17	10	9	16	24	27	20	15	14	23	20	28	28	27	26	19	54	61	63	59	54	59	52		9	38	68
9:30			66	63	58	67	62	62	62	60	61	54	20	26	25	16	13	11	19	20	24	18	17	18	23	18	25	27	24	22	19	52	60	62	59	55	59	44		11	39	67
9:45			66	64	58	68	63	62	62	60	61	56	20	23	23	18	20	12	19	22	20	21	24	24	23	18	20	20	20	21	19	52	60	61	58	56	59	44		12	39	68
10:00			66	63	58	67	63	62	63	61	62	64	66	63	55	49	31	14	24	25	29	25	20	17	19	16	22	22	21	20	18	52	60	62	59	55	58	43		14	44	67
10:15			66	63	58	67	63	61	61	59	61	63	65	59	62	65	56	64	56	56	41	23	24	24	26	19	24	21	21	22	20	54	60	63	60	55	57	45		19	49	67
10:30			66	64	59	68	63	63	64	61	62	64	66	60	62	64	56	63	55	61	58	64	62	59	31	18	22	22	22	24	21	55	61	63	57	54	60	40		18	53	68
10:45			66	64	58	68	64	63	63	60	61	63	66	62	62	64	56	64	56	62	58	65	64	62	63	49	28	32	27	24	22	56	62	64	62	56	60	47		22	56	68
11:00			65	63	58	67	63	63	63	62	60	62	64	61	61	65	57	63	55	61	55	64	62	61	62	66	64	62	64	64	61	63	65	65	63	60	62	58		55	62	67
Column Summary																																							Overall Row Summary			
Min			65	62	56	65	57	60	27	14	12	10	13	16	17	13	10	8	12	13	12	10	13	14	18	15	20	20	20	20	18	52	53	32	31	46	46	40	Min	8	28	65
Avg			66	64	58	67	62	62	58	49	47	44	38	37	41	38	33	34	33	37	35	36	35	34	34	31	34	35	33	32	29	56	61	59	54	56	59	52	Avg	29	45	67
Max			68	66	61	69	66	64	65	62	62	65	66	63	63	65	57	64	56	62	58	65	64	62	63	66	64	64	66	65	63	64	65	65	65	62	63	65	Max	56	64	69

I-680 SB — **PARAMICS SPEED CONTOUR MAP - HOV 15% (03/2002 - Run 2a)** — **October 3 (Wednesday)**

Section number

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00			67	66	61	68	65	63	64	61	61	63	65	62	62	63	62	63	58	64	59	63	61	61	60	66	64	64	65	64	66	64	64	65	64	62	62	66		58	63	68
5:15			66	63	58	65	61	60	61	58	60	62	64	58	60	63	61	62	57	64	60	64	62	62	62	66	64	64	65	65	66	64	65	65	64	62	62	66		57	63	66
5:30			66	64	59	68	63	61	61	58	59	62	61	47	55	56	58	59	56	63	56	63	60	59	58	65	62	62	63	63	64	61	64	64	63	60	61	63		47	61	68
5:45			66	64	60	67	64	62	63	61	61	63	65	56	58	62	60	62	57	64	58	63	58	54	57	65	60	63	63	62	59	60	63	64	63	60	61	63		54	61	67
6:00			66	64	59	67	63	62	62	60	61	62	63	53	57	61	59	62	57	63	57	62	58	60	58	63	59	62	63	61	52	60	63	64	63	59	61	63		52	61	67
6:15			66	63	58	66	61	60	61	59	60	62	62	50	55	60	58	62	57	64	58	63	59	60	59	61	54	63	63	60	45	58	62	64	63	58	60	62		45	60	66
6:30			66	63	58	67	60	62	60	54	58	61	58	43	54	49	53	56	53	62	56	63	54	52	46	37	50	61	59	53	38	58	62	64	62	55	59	60		37	56	67
6:45			65	63	57	65	60	61	61	58	60	62	61	50	57	55	53	56	52	64	55	55	31	30	26	27	51	61	60	53	36	57	61	62	60	54	59	58		26	54	65
7:00			66	62	57	66	59	59	59	56	58	61	46	39	52	50	50	55	48	49	34	31	26	27	23	23	51	61	53	41	29	57	61	63	61	51	58	52		23	50	66
7:15			65	63	57	66	60	61	61	59	60	62	53	40	42	35	37	33	33	32	27	25	24	23	28	26	31	28	26	27	26	56	61	62	57	53	58	47		23	45	66
7:30			65	63	57	67	61	62	62	58	60	62	62	50	55	33	37	33	34	35	21	18	21	21	23	20	25	25	25	25	24	55	60	54	39	49	58	39		18	43	67
7:45			66	63	57	68	62	63	62	61	61	63	65	58	60	56	28	25	25	24	24	17	17	18	22	19	23	24	25	25	24	55	60	56	37	44	55	41		17	43	68
8:00			67	64	58	68	63	63	63	61	60	63	65	59	60	63	46	21	23	23	24	20	18	18	23	21	28	26	23	24	23	56	61	58	39	48	56	45		18	45	68
8:15			66	64	57	68	64	63	63	62	61	64	66	62	61	63	61	54	51	39	21	21	23	19	23	20	26	24	24	25	22	56	60	57	38	46	53	44		19	47	68
8:30			66	63	57	68	62	62	62	60	62	63	66	61	63	63	62	62	57	64	57	60	35	21	21	19	29	28	24	23	22	56	60	55	38	49	57	44		19	51	68
8:45			66	64	58	68	63	63	63	61	60	63	65	60	63	64	62	59	55	63	57	64	62	51	35	23	24	24	22	22	21	54	59	54	40	51	53	42		21	52	68
9:00			66	64	57	68	63	63	63	61	62	64	67	63	64	64	63	62	58	64	55	66	65	63	58	41	32	24	22	23	21	55	59	52	39	54	54	38		21	54	68
9:15			66	64	58	68	63	63	63	61	60	63	66	61	63	64	63	63	58	64	59	65	64	62	62	64	46	27	26	27	25	54	59	59	55	55	58	45		25	57	68
9:30			66	63	58	67	63	63	63	61	61	63	66	62	63	64	63	63	58	64	61	66	64	63	62	66	62	60	61	57	42	57	61	64	62	57	59	49		42	61	67
9:45			66	64	57	68	63	62	62	61	61	63	66	62	63	64	62	63	58	64	59	65	63	62	62	65	62	61	62	62	57	60	63	64	62	58	61	56		56	62	68
10:00			65	63	58	66	62	62	62	61	60	63	66	60	61	63	61	63	57	65	60	65	63	62	62	66	63	61	62	61	52	60	63	64	62	57	60	59		52	62	66
10:15			65	62	57	66	61	60	60	59	59	62	65	60	62	63	61	61	56	63	57	64	63	62	62	65	63	62	62	63	57	61	62	64	63	59	61	61		56	61	66
10:30			66	63	58	67	62	62	62	60	61	62	66	61	62	62	61	61	57	63	58	64	63	62	62	65	63	61	63	63	60	60	63	64	63	59	61	65		57	62	67
10:45			66	63	59	67	62	63	63	61	61	63	66	62	62	63	61	62	58	64	59	64	64	63	62	66	64	62	63	63	61	61	63	64	63	60	62	65		58	63	67
11:00			67	64	57	67	63	62	62	61	60	63	66	62	61	63	61	61	57	63	58	63	62	62	61	65	63	62	63	63	64	61	63	64	62	60	61	65		57	62	67
Column Summary																																							Overall Row Summary			
Min			65	62	57	65	59	59	59	54	58	61	46	39	42	33	28	21	23	23	21	17	17	18	21	19	23	24	22	22	21	54	59	52	37	44	53	38	Min	17	39	65
Avg			66	63	58	67	62	62	62	60	60	63	63	56	59	59	56	55	52	56	50	53	50	48	47	47	49	49	48	47	42	58	62	61	55	55	59	54	Avg	42	56	67
Max			67	66	61	68	65	63	64	62	62	64	67	63	64	64	63	63	58	65	61	66	65	63	62	66	64	64	65	65	66	64	65	65	64	62	62	66	Max	58	64	68

Figure 17a: Wednesday Speed Contour Maps, Base Case versus HOV Case

I-680 SB — **PARAMICS SPEED CONTOUR - Base Run** — **October 4 (Thursday)**

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00			66	63	58	66	64	60	60	57	60	63	61	51	59	64	56	61	53	61	58	63	62	61	60	67	63	65	67	66	63	65	66	66	65	64	64	66		51	62	67
5:15			65	63	58	65	61	59	59	54	59	54	32	36	52	49	50	63	49	59	58	63	60	60	58	65	59	65	65	65	63	64	65	65	64	62	63	65		32	59	65
5:30			66	63	58	65	62	58	58	52	59	52	22	29	45	35	43	46	34	52	53	62	57	56	56	64	54	65	66	65	62	64	65	65	64	62	63	65		22	56	66
5:45			66	63	58	65	61	60	60	57	59	57	30	30	40	32	46	39	33	51	51	62	47	43	53	63	57	64	65	63	59	61	64	64	63	60	61	63		30	55	66
6:00			65	63	58	65	62	60	59	57	59	55	23	29	40	38	44	42	33	54	53	51	37	35	46	41	48	63	64	61	48	60	63	64	63	61	62	63		23	53	65
6:15			65	63	58	66	59	60	59	56	51	43	23	32	43	33	37	43	33	41	31	25	29	33	28	25	47	62	64	60	42	58	63	64	63	59	60	62		23	48	66
6:30			66	63	56	67	62	61	60	58	56	34	18	24	34	30	26	21	23	26	27	24	22	24	24	26	46	62	60	50	31	57	62	64	61	58	60	62		18	45	67
6:45			65	62	58	66	60	61	61	57	42	29	20	22	31	24	20	12	14	15	16	19	27	31	30	28	40	43	33	30	24	54	60	63	56	54	57	54		12	40	66
7:00			65	62	57	65	60	60	52	31	22	14	16	25	36	32	24	19	24	26	20	20	23	23	24	21	30	23	21	22	21	55	61	59	42	53	61	52		14	37	65
7:15			65	63	57	65	60	57	40	25	23	15	15	21	27	24	19	10	13	16	19	19	19	20	25	20	29	24	21	22	20	53	60	59	40	55	57	44		10	34	65
7:30			66	63	57	67	60	59	31	16	16	13	15	23	30	20	13	9	18	21	21	18	17	16	21	18	31	33	25	23	21	54	60	51	36	54	57	44		9	33	67
7:45			65	63	56	68	63	41	21	20	18	15	14	19	18	15	12	11	19	23	19	15	22	22	25	21	34	28	22	22	21	54	61	59	42	55	54	43		11	33	68
8:00			66	63	57	67	62	58	27	15	18	15	15	19	24	19	15	9	14	16	18	19	22	20	22	22	38	36	26	24	20	53	60	57	40	53	56	49		9	34	67
8:15			66	64	58	68	63	63	35	18	16	13	17	28	29	19	12	11	22	25	23	21	21	22	21	20	34	25	22	23	21	54	61	58	39	57	60	44		11	35	68
8:30			65	63	57	67	62	62	40	24	26	18	19	25	27	18	13	10	18	21	20	16	19	15	24	21	31	23	21	22	20	54	59	59	42	55	59	52		10	35	67
8:45			66	64	59	68	64	63	63	35	23	20	17	21	21	14	11	10	17	18	17	14	17	21	21	19	28	22	20	22	20	54	60	62	51	56	59	46		10	35	68
9:00			66	64	58	68	64	62	63	61	56	16	14	18	20	16	12	8	14	16	16	15	18	16	21	18	25	23	21	23	20	53	61	63	60	57	59	49		8	36	68
9:15			65	62	57	66	61	60	60	59	58	32	16	23	23	16	15	11	18	18	13	13	17	16	20	19	28	24	22	22	20	53	60	63	61	57	60	50		11	37	66
9:30			66	63	57	66	61	60	61	60	60	44	15	19	21	14	10	9	18	21	31	21	16	15	19	17	26	24	21	22	21	54	60	62	59	56	60	50		9	38	66
9:45			66	63	58	68	63	62	62	61	61	47	22	25	24	18	13	10	19	21	23	22	22	26	26	21	28	23	22	24	21	54	61	63	61	57	60	45		10	39	68
10:00			66	64	58	67	63	62	62	60	60	62	43	31	36	33	27	13	24	27	27	22	24	25	25	21	28	25	22	22	20	54	61	63	61	57	59	50		13	42	67
10:15			66	64	58	67	62	62	63	61	61	63	66	60	62	65	56	26	23	27	33	54	31	25	26	23	36	36	25	24	22	55	61	63	61	56	59	53		22	49	67
10:30			66	63	58	66	62	61	62	60	60	63	65	59	62	65	56	64	55	62	58	65	52	54	47	33	41	63	59	46	31	57	62	64	62	58	60	42		31	57	66
10:45			66	64	58	67	62	61	61	59	59	62	65	60	61	64	55	63	52	60	57	65	63	61	61	66	62	63	64	64	59	61	63	64	63	60	61	59		52	61	67
11:00			67	63	57	68	62	61	61	60	61	62	65	60	61	64	56	63	55	62	58	63	62	61	61	66	62	62	64	62	59	63	64	65	64	62	63	60		55	62	68
Column Summary																																							Overall Row Summary			
Min			65	62	56	65	59	41	21	15	16	13	14	18	18	14	10	8	13	15	13	13	16	15	19	17	25	22	20	22	20	53	59	51	36	53	54	42	Min	8	30	65
Avg			66	63	58	66	62	60	54	47	46	39	29	31	37	33	30	27	28	33	33	34	32	32	34	33	40	42	39	38	33	57	62	62	55	57	60	53	Avg	27	44	66
Max			67	64	59	68	64	63	63	61	61	63	66	60	62	65	56	64	55	62	58	65	63	61	61	67	63	65	67	66	63	65	66	66	64	62	63	65	Max	55	63	68

I-680 SB — **PARAMICS SPEED CONTOUR MAP - HOV 15% (03/2002 - Run 3a)** — **October 4 (Thursday)**

Interval Start	0	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	30	31	32	33	34	35	36	37		Row Summary Min	Avg	Max
5:00			66	64	59	67	63	61	60	56	59	61	64	53	58	63	60	62	57	64	58	63	61	61	61	66	62	64	65	65	66	64	64	65	64	63	63	67		53	62	67
5:15			66	64	59	66	62	60	60	56	59	61	51	39	54	55	58	61	57	64	56	62	58	59	57	65	58	65	65	66	66	64	64	65	64	61	62	65		39	60	66
5:30			66	63	58	66	62	61	61	57	59	61	51	40	51	46	47	53	49	63	52	63	57	58	56	65	61	64	65	65	66	63	64	65	64	61	61	63		40	59	66
5:45			65	63	58	65	61	59	60	58	60	62	63	53	57	52	51	53	49	63	51	62	50	58	55	50	48	64	65	65	65	63	64	64	63	60	61	64		48	59	65
6:00			65	62	58	65	61	59	58	55	58	62	61	50	55	57	57	61	57	63	58	63	59	55	50	34	49	63	64	63	59	60	63	64	63	59	61	63		34	59	65
6:15			65	63	59	66	61	61	60	58	58	61	50	39	53	48	48	58	55	63	53	62	52	57	38	30	49	62	63	59	45	58	62	64	62	57	60	62		30	56	66
6:30			65	63	56	65	59	57	58	57	60	62	51	37	44	41	45	53	48	62	54	52	33	31	28	29	47	62	62	56	39	58	62	63	62	55	59	63		28	53	65
6:45			65	63	58	66	60	60	59	57	60	61	36	32	42	40	39	38	37	45	36	31	25	27	25	28	50	62	60	49	32	58	61	59	44	54	57	52		25	48	66
7:00			65	63	58	67	61	62	61	58	60	58	32	30	35	31	32	29	33	36	26	24	27	29	29	29	38	35	30	29	26	57	61	62	53	51	52	47		24	44	67
7:15			66	63	57	66	61	61	61	59	59	50	23	28	39	33	32	27	29	33	34	37	26	20	24	23	37	31	25	25	23	56	59	60	42	52	56	51		20	42	66
7:30			65	63	57	67	61	61	61	59	61	57	30	33	37	29	33	28	30	30	25	24	26	28	28	23	33	32	24	24	22	56	59	56	39	47	55	45		22	42	67
7:45			66	63	56	68	62	62	61	57	60	62	62	49	58	49	42	25	23	24	24	26	25	21	24	24	34	29	24	25	24	56	61	58	41	40	44	38		21	43	68
8:00			66	63	56	67	61	62	61	58	59	62	63	56	61	62	55	50	53	55	35	21	19	17	23	20	31	31	25	25	24	55	60	55	36	44	54	41		17	47	67
8:15			66	63	58	67	62	61	61	59	59	62	64	57	61	63	61	59	55	63	49	29	24	24	23	24	37	37	27	24	22	53	59	51	37	47	52	43		22	49	67
8:30			66	63	58	67	62	62	62	60	60	63	65	59	62	63	62	61	57	64	58	62	37	30	22	21	34	32	24	24	22	54	59	56	44	46	51	48		21	51	67
8:45			67	64	58	68	63	62	62	60	60	63	66	61	62	63	62	61	57	64	58	65	62	51	37	22	30	27	25	25	23	55	59	54	38	44	50	50		22	53	68
9:00			66	63	58	67	63	62	62	60	61	63	65	61	63	64	62	62	57	64	59	66	64	63	59	29	28	25	24	25	24	54	59	62	55	52	57	42		24	55	67
9:15			66	63	58	67	63	62	62	61	61	63	66	60	63	64	62	62	57	64	58	65	63	62	62	65	56	40	37	32	29	57	61	64	62	56	55	37		29	58	67
9:30			66	63	58	66	63	61	62	61	61	63	65	62	62	63	62	62	57	64	59	65	63	61	61	64	60	62	62	59	47	58	61	63	62	55	59	53		47	61	66
9:45			65	63	58	67	62	61	62	60	60	63	66	61	62	63	62	62	58	64	58	65	63	62	63	65	63	62	63	62	59	60	63	64	62	59	60	59		58	62	67
10:00			66	64	58	67	63	62	62	61	61	63	66	62	63	64	63	64	59	64	61	65	63	62	62	65	62	64	65	65	63	61	63	64	63	59	61	58		58	63	67
10:15			66	63	58	66	61	63	62	61	61	63	66	61	61	63	62	62	58	64	59	65	63	62	61	65	63	64	64	64	62	61	63	64	63	58	61	64		58	62	66
10:30			66	64	58	67	62	61	62	60	59	62	66	60	61	63	61	63	58	64	58	64	63	62	62	66	64	64	65	66	65	63	64	64	64	61	62	66		58	63	67
10:45			66	63	58	67	63	62	62	60	61	62	66	61	61	63	61	62	57	64	59	65	63	62	63	66	63	64	65	65	65	62	63	64	63	60	61	64		57	63	67
11:00			65	64	59	67	64	62	62	60	60	62	65	61	60	62	61	61	57	64	57	64	61	61	61	65	64	63	64	64	65	62	64	64	63	61	61	66		57	62	67
Column Summary																																							Overall Row Summary			
Min			65	62	56	65	59	57	58	55	58	50	23	28	35	29	32	25	23	24	24	21	19	17	22	20	28	25	24	24	22	53	59	51	36	40	44	37	Min	17	38	65
Avg			66	63	58	67	62	61	61	59	60	61	57	51	56	55	54	53	51	57	50	53	48	47	45	44	49	51	49	48	44	59	62	61	54	54	57	54	Avg	44	55	67
Max			67	64	59	68	64	63	62	61	61	63	66	62	63	64	63	64	59	64	61	66	64	63	63	66	64	65	65	66	66	64	64	65	64	61	62	66	Max	59	64	68

Figure 17b: Thursday Speed Contour Maps, Base Case versus HOV Case

The comparison of the speed contour maps in the Base case (no HOV) and in the HOV case, both for the Wednesday and Thursday demands, indicates that the extent of congestion is significantly reduced with an HOV lane added. The bottleneck still occurs at the same location on the freeway with the HOV lane, but its effects are not seen as far upstream as in the base case, and the congestion appears on the freeway for a shorter time period within the peak period.

Average 15-minute interval travel times to cross the entire freeway sections are displayed graphically in Figure 18. The top graph shows the results of the Wednesday demand scenario, and the bottom graph shows the Thursday scenario. In both cases, it can be observed that the freeway travel times for the HOV vehicles have dramatically decreased after the HOV addition. The single occupancy vehicles also benefited. The maximum travel times in the HOV cases never exceed the base case travel times. Although bottleneck conditions start at about the same time, in the HOV scenarios the congestion conditions never reach the proportion of the base cases.

6.5 Conclusions

The purposes of these investigations were to determine how freeways with high occupancy vehicle (HOV) lanes could be simulated using the Paramics model, to evaluate the effectiveness of adding an HOV lane to the existing I-680 freeway, and to investigate the sensitivity of results to varying conditions. In order to represent driver behavior in the presence of contiguous HOV lanes, Paramics Modeller was used with an Application Programming Interface (API) that controls certain aspects of driver behavior in the presence of a contiguous HOV lane. After preliminary tests on a simple straight-pipe network developed especially for the purpose of this experiment, the investigations were focused on applying Modeller and the API on the southbound morning peak I-680 freeway network previously developed and calibrated.

The simple network was created in order to test the model in a situation where simulation results could be viewed and analyzed easily. It was concluded that Modeller and the API used together are successful in modeling vehicle behavior in the presence of contiguous HOV lanes, and that the investigations provided a satisfactory basis from which to move forward with investigations on the I-680 study corridor.

From the existing freeway model to the freeway with an HOV lane, it was found that the total vehicle hours traveled decreased 28 percent and the overall average speed increased 40 percent. The sensitivity analysis produced interesting findings regarding to what extend the model could be used to investigate various changes in the input scenarios.

An issue encountered in the analysis of the freeway HOV lanes in Paramics is the lack of lane-by-lane aggregated statistics. It would be useful to be able to gather aggregated lane-by-lane performance statistics, similar to the link statistics that can be obtained through the Paramics Analyzer. These would help in determining how an HOV lane performs in comparison to mixed-flow lanes. It should be noted however, that lane-specific traffic information at detector locations can be obtained for individual vehicle types, which allows evaluation of the traffic volume carried by the HOV lane at a particular point on the freeway. In addition, travel time information for specified origin-destination (O-D) pairs by vehicle type can also be obtained.

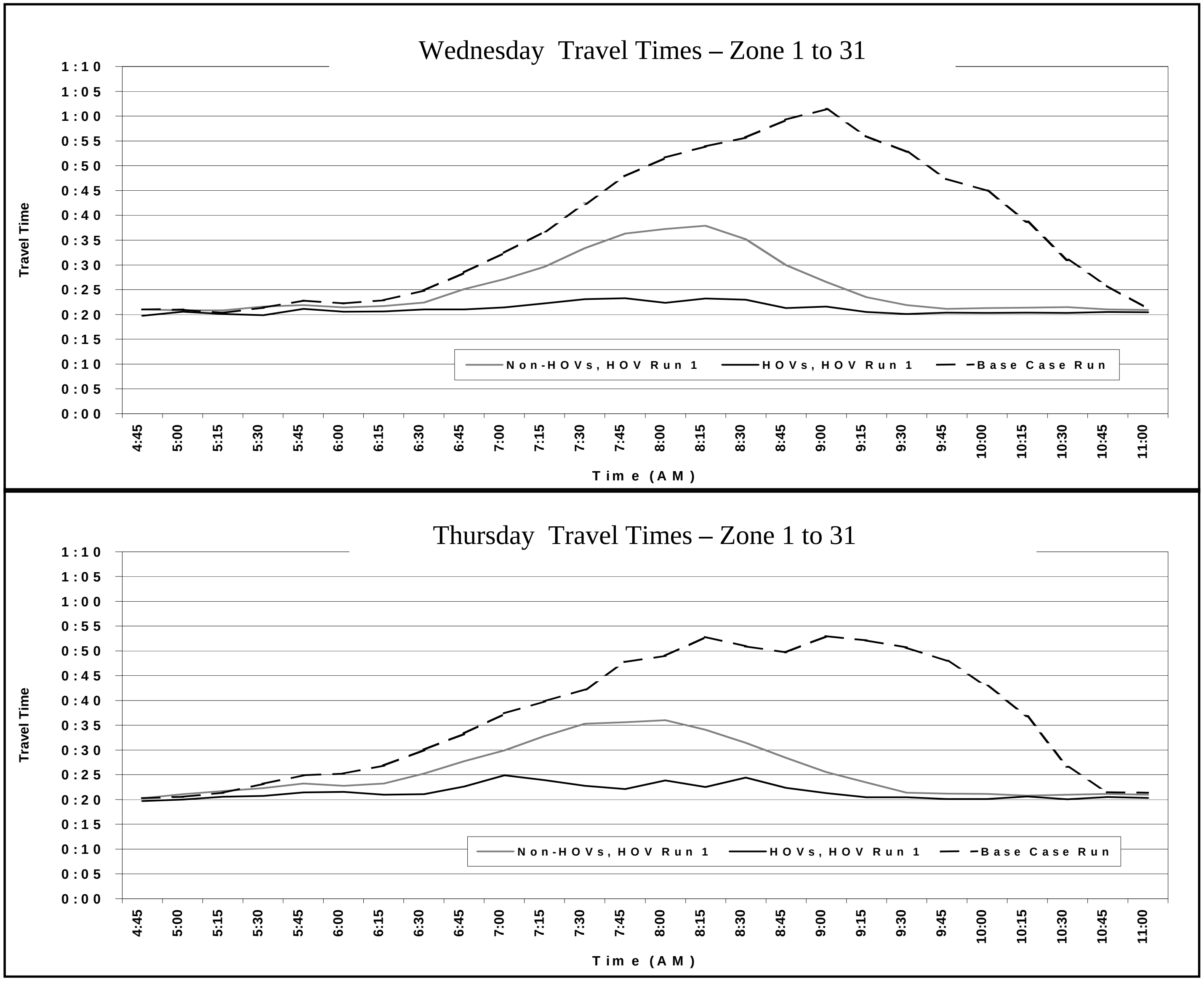

Figure 18: Wednesday and Thursday Freeway Travel Times - Base and HOV Cases

70

CHAPTER 7: MODELLING RAMP METERING ON I-680

7.1 Introduction

Once the I-680 network was calibrated and validated for the base conditions, various alternative scenarios including the addition of HOV lanes and ramp metering systems were studied. The scenarios that involve adding only an HOV lane was documented in Chapter 6.

The present chapter focuses on the preparation of ramp metering investigations, which were carried out on the I-680 network with the added mainline HOV lane. The objective was to test and calibrate generic ramp control strategies that are not commonly used in California presently, in order to assess their potential for future implementation.

A local actuated strategy, Alinea, was thus tested. The logic behind this strategy is first described in this chapter. Then the process of applying Alinea to the I-680 network is presented, including the development and calibration of the input files. The results will be presented in the next chapter.

7.2 Caltrans design plan for ramp metering

Information from the local Caltrans office provided insights on the ramp metering strategies that could be implemented on the I-680. This information was useful in designing the simulation experiment plan. However, it was not the intention of the researchers to replicate typical strategies currently used in the field by Caltrans.

Caltrans had first proposed a tentative design plan for ramp metering on I-680 SB. Based on these recommendations and the updated count data from the October 2001 data collection effort, a revised ramp metering design plan was developed for the simulation project.

Table 13 shows the main characteristics of the ramp metering design plan, with the names of the ramps controlled, the number of mixed-flow and HOV bypass lanes. HOV bypass lanes allow for priority entry control to be implemented, by allowing HOV vehicles to bypass the ramp metering system.

As shown on Table 13, in the simulation, most of the on-ramps are controlled (12 out of 16) and most of the metered ramps have HOV bypass lanes (11 out of 12). All these specifications will be followed for all ramp metering investigations reported here.

Ramp Name	Ramp #	Ramp control ?	# mixed-flow lanes	# HOV bypass lanes
Stoneridge WB Loop	1	YES	1	1
Stoneridge EB Diagonal	2	YES	1	1
Bernal	3	YES	1	1
Sunol	4	YES	2	1
Route 84 WB	5	YES	2	1
Calaveras / Route 84	6	YES	2	1
Andrade	7	NO	1	0
Sheridan	8	YES	1	1
Vargas	9	NO	1	0
Mission (238)	10	YES	1	1
Washington	11	YES	1	1
AutoMall	12	YES	2	1
Mission 262 SB Loop	13	YES	2	0
Mission 262 NB Diagonal	14	YES	1	1
Scott Creek	15	NO	1	0
Jacklin	16	NO	1	0

Table 13: Ramp Metering Design Plan for Simulation

7.3 The Alinea strategy

The ramp metering strategy to be tested on the I-680 network is a local traffic responsive strategy called Alinea.

The Alinea algorithm was first proposed by Papageorgiou et al. (Reference 9). It is a local feedback ramp metering strategy, derived from a classical automatic control method. The algorithm uses real-time mainline occupancy as an input, typically measured about 50 meters downstream of the ramp gore. It adjusts the metering rate to maintain a desired (near critical) occupancy on the mainline freeway.

The metering rate in time step *k* is given by:

$$r(k) = r(k-1) + K \cdot (O^* - O(k))$$

In this equation:

$r(k-1)$ is the measured metering rate in the previous time step;

K is a regulator parameter to be adjusted;

*O** is the desired occupancy (typically, it is set equal to or slightly less than the critical occupancy) of the downstream detector station;

O(k) is the measured occupancy of time in time step *k*.

When Alinea is applied, the metering rate is updated at each time interval, based on the above equation and the following two constraints:

- Minimum and maximum values of metering rates have to be specified for each controlled ramp;

- Queue control: if the queue detector installed at the beginning of the on-ramp detects congestion on the ramp, queue control is activated. In this case, the Paramics Alinea API described in the next section forces the metering rate to switch to the maximum metering rate.

The limitation with Alinea, or any local traffic responsive strategy, is that the situation at one on-ramp é unknown to other on-ramps. The idea behind the Alinea algorithm is to attempt to maintain free-flow conditions as long as possible. However, when the queue detector alerts to a queue problem, it overrides the Alinea control strategy, and the rate needs to be increased. This does not necessarily have to be the maximum metering rate, but it is so when using the current Paramics API.

7.4 Implementing the Alinea strategy in Paramics

A set of plug-ins (also called APIs) developed for Paramics by a PATH research team at the University of California at Irvine was used in this study (Reference 10). In order to simulate any adaptive ramp metering strategy, Paramics Modeller must interact as the simulation is running, with different modules that first compute and then update the metering rates.

Figure 19 below illustrates the framework of the ramp metering APIs as implemented by PATH researchers from UC Irvine. The ramp controller API, through which metering rates in the simulation can be obtained and set, controls the ramp signals. The loop data aggregator emulates the data collection process of a real-world loop detector. At each time increment, the Alinea API obtains up-to-date traffic information from the loop data API and historical metering rates from the ramp control API; then the Alinea API computes the updated metering rate and sends it to the ramp controller for implementation.

This hierarchical framework is highly flexible. The ramp controller and loop data aggregator APIs are the basic modules. Different advanced ramp metering algorithms can be tested by replacing the Alinea API by another algorithm-specific plug-in.

The three APIs used in the I-680 project (loop data aggregator, ramp controller and Alinea APIs) will be successively presented in this section.

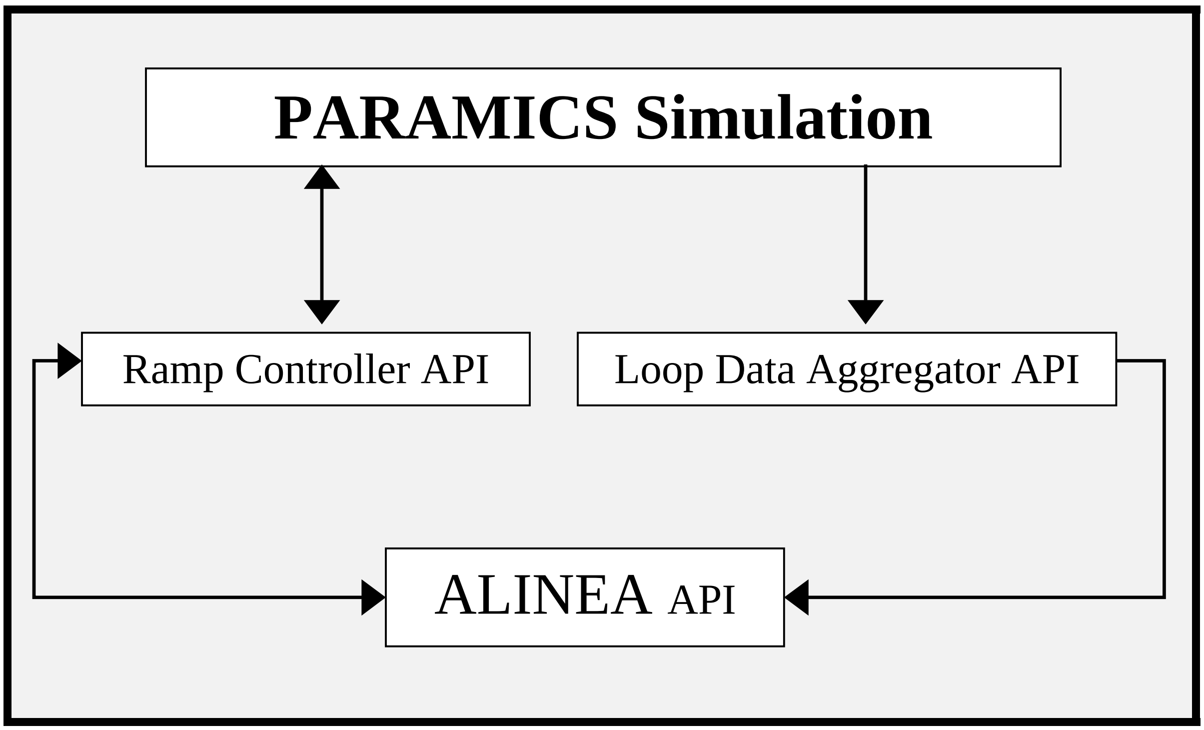

Figure 19: Ramp Metering APIs Framework (source:UCI)

7.4.1 Loop data aggregator API

The loop data aggregator API is one of the supporting modules. It emulates the data collection process of real-life loop detectors. Aggregated occupancy data, typically over 30 seconds, are used in the Alinea control algorithm.

The structure of the loop data aggregator input file is shown in Figure 20. The first part contains general information about loop data aggregation, including: the number of detectors, the report cycle for the output text file (in seconds, used for analysis only), the activation and deactivation time. The second part indicates for each loop, the data aggregation time interval (30 seconds in this case).

```
detector count           36
report cycle             300
activation time          04:40:00
deactivation time        11:15:00
gather smoothed data: no
output to files:         yes

name                     QSTONL
gather interval           00:00:30
…
```

Figure 20: Structure of the Loop Data Aggregator API Input File

7.4.2 Ramp controller API

The ramp controller API identifies the ramps to be controlled with their respective loops, and specifies the type of control (no metering, fixed rates, actuated rates, etc.) to be implemented during the simulation period. The structure of this file is shown on Figure 21.

```
total number of controlled entrance ramps is          12
control cycle of ramp metering                        30

on-ramp signal                212
name                          I-680 @ BER
demand detector               PBER
number of control plans       2
from 4:30 to 5:00             METER_OFF
from 5:00 to 11:15            METER_ON with 1 veh per 6 sec
…
```

Figure 21: Structure of the Ramp Controller API Input File

Again, the first part of the input file contains general information, and it is followed by information specific to each ramp. In this example taken from the I-680 ramp metering application, the simulation started at 4:30 AM, but the Alinea ramp metering control was turned on only at 5 AM. The metering rate specified from 5 AM to 11:15 AM (1 vehicle per 6 seconds) is only used to initiate the ramp metering algorithm at 5 AM; for the subsequent time steps, the Alinea control API takes over to compute the metering rate and feeds it back to the ramp controller API.

7.4.3 Alinea API

The Alinea API calculates the optimum metering rate by implementing the algorithm described in Section 7.3. The structure of the input file for this API is shown on Figure 22. The data to be specified includes the "metering rate update interval", which should be the same as the loop data aggregation interval, and the "time period to accumulate detector data", which is used for computing the metering rates based on a number of previous observations.

```
total number of alinea controlled ramps is    12
checking control file                         yes
metering rate update interval                 30
time period to accumulate detector data       60
algorithm activation time                     05:00:00
algorithm deactivation time                   11:15:00
report metering rate                          yes

ramp                      212
mainline detector         MEBER
on-ramp detector          PBER
queue detector            QBER
HOV                       0
control type              1
desired occupancy         0.15
regulator                 70.0
rate restriction          180 900
…
```

Figure 22: Structure of the Alinea API Input File

For instance, in the case shown in Figure 22, the metering rate at time t will be calculated using the loop data aggregated over the last two 30-second time intervals. The "report metering rate" instruction produces a text file with the metering rate computed by the Alinea algorithm for each controlled ramp and at every update cycle.

The rest of the Alinea API input file contains information related to each controlled ramp. The various detectors associated with each ramp signal are declared, including the mainline detector (collecting freeway occupancy data), the on-ramp detector (located just before the signal and detecting the presence of a vehicle) and the queue detector (at the beginning of the on-ramp, used to implement queue control). It is possible to run Alinea without queue control; in this case, the queue detector information should be "N/A" instead of the name of an actual queue detector. The "control type" instruction refers to the number of vehicles allowed to proceed per green time (the options are 1, 2 or 3 vehicles per green). In this case, one vehicle per green was used.

The last three lines for each ramp refer to he desired mainline occupancy, the regulator value, and the minimum and maximum metering rates. These parameters have to be calibrated carefully on a ramp-by-ramp basis. A discussion of the impact of these parameters, and the process followed in the I-680 application to calibrate these parameters will be presented in Section 7.6.

7.5 Preparing the input data files for I-680

7.5.1 Network adjustments

In order to be able to simulate the ramp metering strategy in Paramics, a number of adjustments were required on the network previously developed. As the ramp metering strategies were to be implemented in addition to the HOV lane, the adjustments were made on the network that included the added HOV lane. As described in Section 6.2.1, the HOV network already included a number of modifications from the base network.

Modeling a ramp metering scheme in Paramics first requires the meters to be coded as traffic signals. This is done by specifying the priority rules and signal settings in the "priorities" file. Meters are coded simply as two-phase signals.

The HOV bypass lanes are not as straightforward to model as the regular on-ramp lanes. Because Paramics did not allow for different control strategies to be applied on different lanes of the same link, it was necessary to code the HOV bypass lane as a separate link parallel to the SOV lane(s). By doing so, the HOV bypass lane can be controlled independently. In our case, the idea was to always allow HOV vehicles from the bypass lane to go through without stopping at the meter. Therefore, the signal controlling the HOV bypass lanes was coded as staying on green all the time. It should be noticed, however, that between the origin zone and the beginning of the HOV bypass lane, as well as in the ramp section past the meter, the HOV vehicles must travel in mixed-flow lanes.

The coding of the ramp configuration, signal settings and HOV bypass lanes reflects the design plan presented in Table 13.

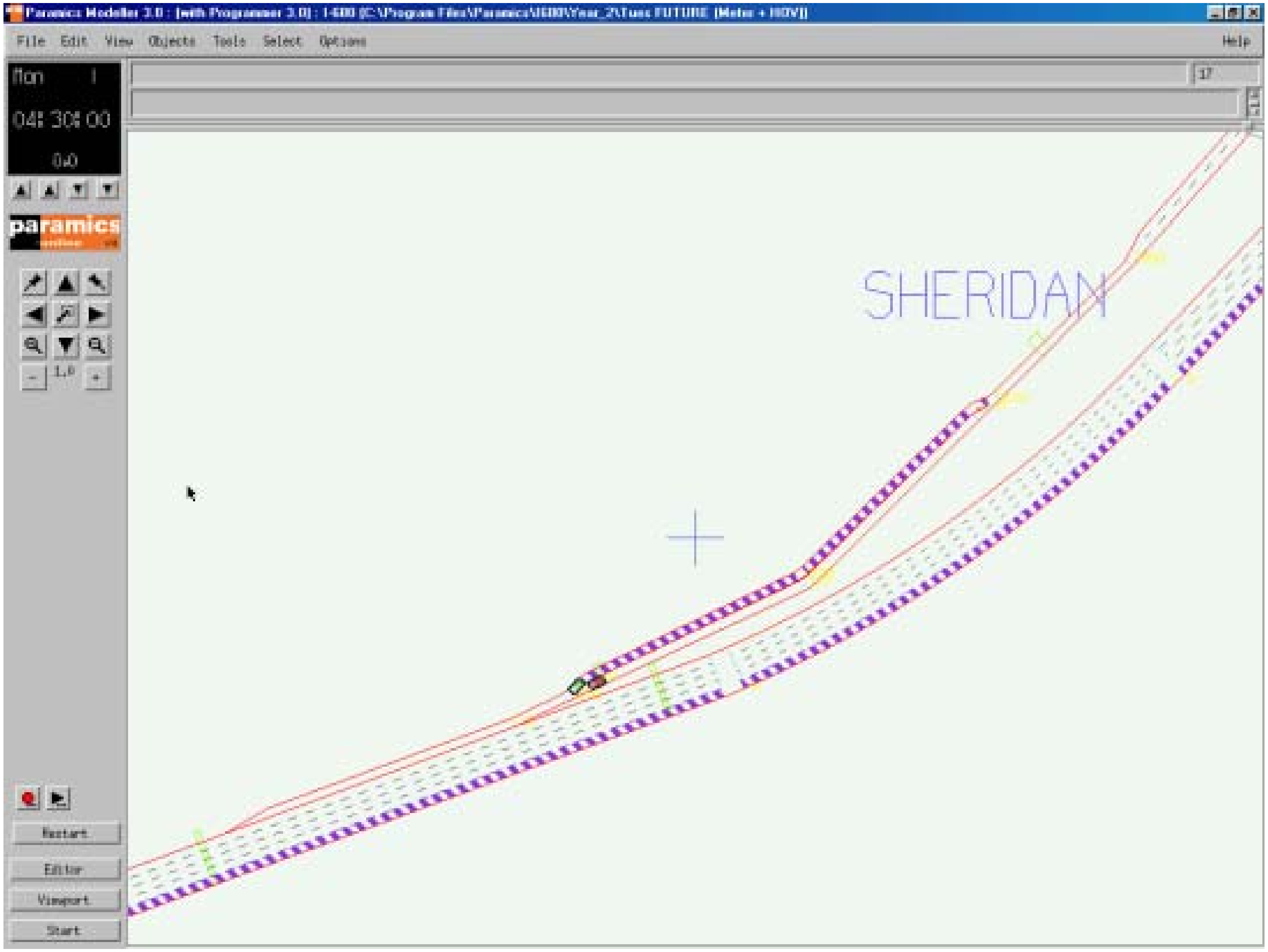

Figure 23: Example of On-Ramp Layout (Sheridan)

Finally, the detectors required for the traffic-actuated Alinea strategy were added. These included the mainline detector immediately upstream of the merge area, a demand detector (on the ramp just before the meter) and a queue detector (at the beginning of the ramp).

As an illustration of the network adjustments, an example of on-ramp setup is presented on Figure 23. This is a screen capture from the Paramics I-680 network, representing the Sheridan on-ramp. As indicated in Table 13, it was recommended that this particular ramp be controlled, with one SOV lane and one HOV bypass lane. All controlled entrance ramps of the I-680 network were coded in a similar way.

7.5.2 Preparing the signal and API inputs data

Once the ramp geometry had been modified to include the ramp meters, it was necessary to specify the priority rules, phase structure and maximum cycle length for each signal. This is done with the Junction menu of the Network editor. The text file that is created is called the “priorities” file, and its structure is shown in Figure 24.

```
actions 233
phase offset 0.00 sec
phase 1
        0.00
        max 30.00
red phase 0.00
fill
all barred except
from 293 to 213 major   ## HOV lane
phase 2
        0.00
        max 30.00
red phase 0.00
fill
all barred except
from 230 to 213 major   ## SOV lane
from 293 to 213 major   ## HOV lane
```

Figure 24: Structure of the Priorities File

This example shows the signal settings for one particular meter (at node 233). The setup is similar to the one illustrated in Figure 23, with a mixed-flow lane and a bypass lane controlled by the same signal. The mixed-flow lane approach (from 230 to 213) has the green in phase 2 only; the bypass lane (from 293 to 213) has the green both in phases 1 and 2.

As indicated in Section 7.4, the use of the ramp metering APIs required three specific API input files to be developed for the I-680 network:

- Loop data aggregator API input file;
- Ramp controller API input file;
- Alinea API input file.

The structure of these three files was presented respectively in Figures 20, 21 and 22. Since there are 12 controlled ramps and 3 loops required by Alinea for each ramp, the loop data aggregator uses 36 declared loops.

Finally, a "plugins" file must be created to list the APIs to be used for each run. Figure 25 shows an example of such a file.

```
C:\uci\dll\loop_agg.dll

C:\uci\dll\ramp_controller.dll

C:\uci\dll\alinea.dll

C:\Program Files\Paramics\programmer\plugins\HOV\hov-rm.dll
```

Figure 25: Plugins File

In this case, four APIs were activated: three for replicating the Alinea control strategy and one for modeling HOV behavior. The Alinea API must always be specified after the loop data and ramp controller APIs.

7.6 Optimization of Alinea parameters on I-680

Different research teams at PATH have recently attempted to optimize the Alinea strategy by applying Paramics on a stretch of freeway I-405 with six interchanges in Orange County, California (References 11,12). The I-680 project provided an opportunity to analyze the sensitivity of the various parameters in another environment, using a large-scale calibrated freeway network.

The earlier work was helpful in identifying what the key parameters were likely to be. Those parameters were successfully analyzed to study their sensitivity to the overall performance of the Alinea control strategy.

7.6.1 Location of mainline freeway detectors

The mainline freeway detector plays a crucial role in the Alinea algorithm, by computing the average freeway occupancy, which is the main control parameter in the ramp metering rate optimization. It was found that placing the detector at approximately 50 meters downstream of the ramp gore, was appropriate to capture the impact of the merging traffic on the mainline freeway.

7.6.2 Update metering rate cycle

The frequency of updating metering rates is another important parameter likely to affect the results. It was found that an update cycle of 30 seconds was suitable to ensure that the system was able to react to dynamic changes in the traffic conditions without too much instability. The loop data aggregation period was also set to 30 seconds accordingly.

7.6.3 Regulator parameter

The regulator parameter can be used for adjusting the disturbances of the feedback control. The simulation was found to perform well with a value of 70, which is a typical value based on previously reported applications of Alinea.

7.6.4 Desired occupancy rate

The desired occupancy rate is a key parameter to calibrate, as the performance of the system is highly sensitive to the values specified. Typically, it is set equal to or slightly less than the critical occupancy of the freeway section downstream of the ramp merge. The desired occupancy rate is ramp specific, and must be calibrated for each controlled ramp based on the local traffic conditions before the implementation of the ramp metering system.

In order to identify the critical occupancy values, plots of flows versus occupancy rates were produced for each of the 12 mainline detectors immediately downstream of the ramps to be controlled. The flow and occupancy data used for this analysis were produced by the loop data aggregator API, which created a report every 300 seconds (5 minutes) as indicated in Figure 20. These data were obtained for the scenario with no metering system.

An example of such a flow-occupancy plot is presented on Figure 26. This particular plot was obtained with 5-min data collected in the base run at the freeway detector downstream of the Mission Route 238 on-ramp. Based on this graph, it was determined that the desired occupancy rate was around 15 percent.

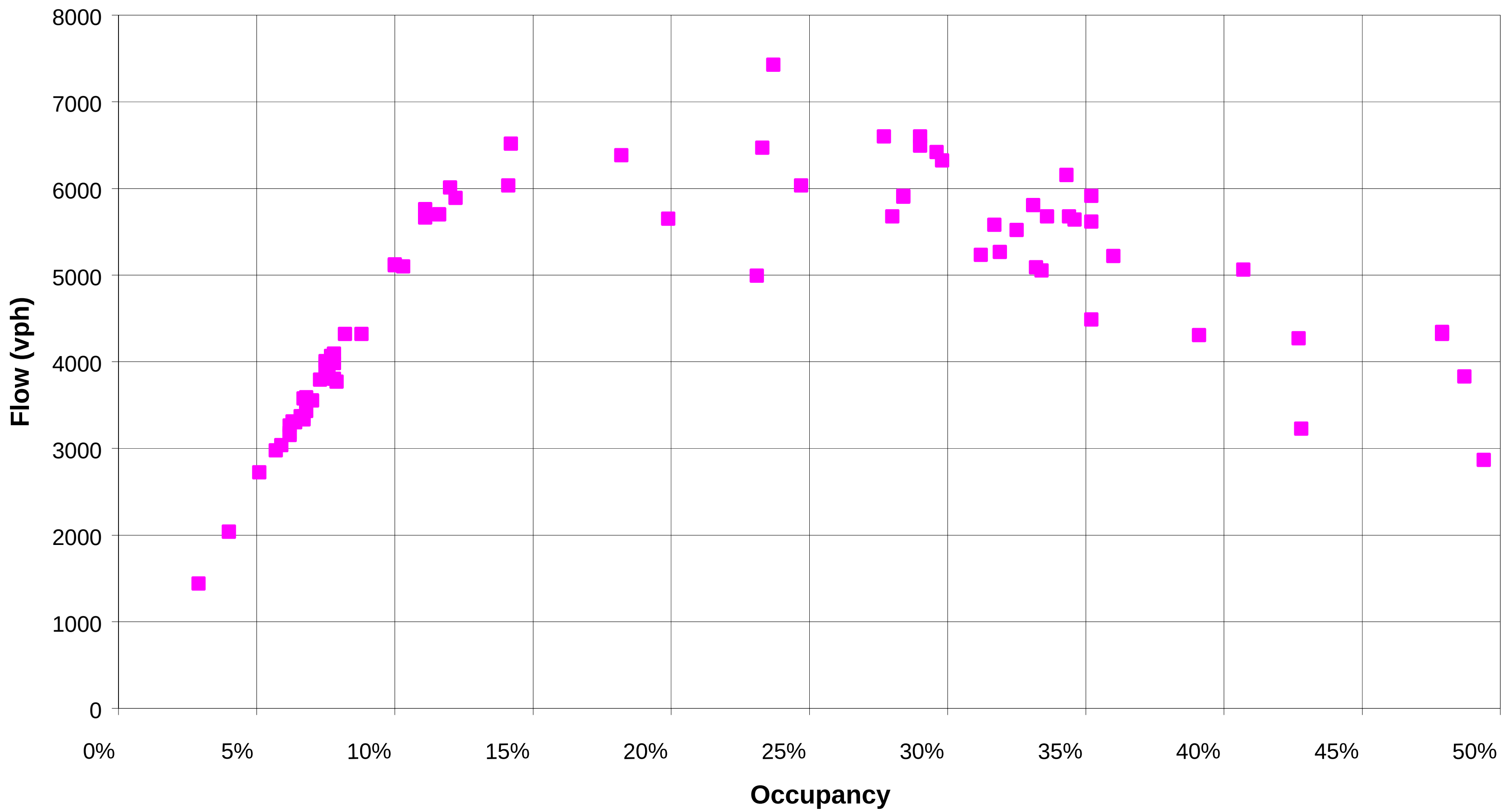

Figure 26: Mainline Detector at Mission/238 on-ramp

A first run with metering control was made with all desired occupancy rates set to 15 percent. The overall performance of the system was assessed. Then, a series of runs was carried out, with everything being fixed except the desired occupancy rates, which was varied on a ramp- by- ramp basis from the base value of 15 percent.

It was confirmed that optimum results were obtained with desired rates adjusted ramp-by-ramp, as opposed to using a uniform desired rate for all ramps The desired occupancy rate was left at 15 percent for most of the ramps. However, several on-ramps with particularly heavy demands and large queues were found to perform better with higher desired rates. Finally, the optimum set of parameters was found to be:

- 17 percent at the Westbound Route 84 and Auto Mall on-ramps;
- 16 percent at the Sheridan and Mission Route 238 on-ramps;
- 15 percent at all other ramps.

7.6.5 Minimum and maximum metering rates

The optimized metering rate is computed and updated by the Alinea algorithm as described in Section 7.3. However, optimized metering rates are subject to operational constraints and must be set between a lower and upper limit.

The <u>minimum metering rate</u> was set to 180 vehicles per hour per lane, or one vehicle every twenty seconds. Typically, the green time per vehicle is two seconds. If the maximum cycle is 20 seconds, the ramp meter cannot be set to red for more than 18 seconds when a vehicle ia detected on the presence detector.

The <u>maximum metering rate</u> is another highly sensitive parameter. Not only does it set the upper limit of the metering rate computed by Alinea, but also it specifies the metering rate to be used when the queue detector is activated. The queue control strategy embedded in the Paramics API for Alinea calls for the maximum metering rate to be used when the queue detector occupancy exceeds 50 percent.

As a number of the on-ramps in the I-680 network experienced heavy queue conditions, this parameter was of critical importance. It was typically set to 900 vehicles per hour per lane, but was increased to 1200 veh/h/l at two on-ramps (Westbound Route 84 and Auto Mall), and to 1000 veh/h/l at two other ramps (Sheridan and Mission Route 238).

7.6.6 Summary

The process of calibrating the parameters particular to the Alinea control and to the algorithm showed that instead of using global control parameter values for all ramps, each ramp should be evaluated individually and parameters should be specified independently for each particular ramp.

Ramps were “classified” based on the vehicle demand at that particular ramp. The two parameters that were altered on a ramp-by-ramp basis were the desired threshold detector occupancy and the maximum metering rate restriction. The initial values were 15 percent for the desired occupancy rate and 900 vehicles per hour per lane for the maximum metering rate.

Basically the ramps with the greatest demands were re-evaluated and new values were specified for these two parameters. The most optimal performance of the algorithm, in terms of total (mainline and ramp) travel times and average vehicle speed, was seen with the specifications below:

- 17 percent threshold occupancy and maximum metering rate of 1200 veh/h/l at ramps Route 84 and Auto Mall Parkway;
- 16 percent threshold occupancy and maximum metering rate of 1000 veh/h/l at ramps Sheridan and Mission 238;
- 15 percent threshold occupancy and maximum metering rate of 900 veh/h/l at other eight remaining on-ramps;

Table 14 summarizes the main parameters that were calibrated and the optimum values after fine-tuning. These values were coded in the various network and API input files previously described.

It should be pointed out that this set of optimized parameters was only valid for the particular conditions experienced on the I-680 network in the base case scenario. In particular, the occupancy rates and maximum metering rates values suggested here reflect specific network and traffic patterns. Ideally, these parameters should be re-evaluated and re-calibrated every time changes are made in the supply or demand characteristics.

Location of mainline detectors	About 50 meters downstream of ramp gore
Update cycle of metering rates	30 seconds
Alinea regulator parameter	70
Desired mainline occupancy rates	Ramp specific, between 15 and 17 percent
Minimum metering rates	180 vehicles per hour per lane
Maximum metering rates	Ramp specific, between 900 and 1200 veh/h/l

Table 14: Optimized Alinea Parameters for I-680

CHAPTER 8: RESULTS OF RAMP METERING INVESTIGATIONS ON I-680

8.1 Introduction

This chapter presents the results of the ramp metering investigations carried out on the I-680 network. Ramp metering investigations were performed with the network including the HOV lane on the mainline freeway, in an effort to represent a "Future" scenario that could be implemented in 2005 or 2006.

The Paramics I-680 network used in the ramp metering investigations reported here incorporates all the background development performed earlier: the general simulation configuration, network and demand characteristics were based on the calibrated base scenario as described in Chapters 3 and 4; the mainline HOV lane was modeled as reported in Chapter 6; and finally, the ramp metering features were derived from the work presented in Chapter 7.

In order to model the "Future" scenarios the vehicle demand was increased by 5 percent of the demand previously used for the base conditions. The "Future base case" scenario for the I-680 freeway study corridor was therefore established as one where the HOV lane is operational, vehicle demand is 105 percent of the present demand, and there is no metering plan in place. The vehicle occupancy breakdown is identical to the one used in the initial HOV run and in the reference scenario (see Section 3.3.2). Ramp metering scenarios will be compared against this "Future base case" scenario to evaluate the impact of ramp metering on that particular network.

Analyzing ramp metering scenarios requires specific model outputs to be collected. The first section of this chapter will discuss different ways of gathering and analyzing simulation results. Then, the results of the base Alinea run will be presented in details and discussed. Finally, a sensitivity analysis of various key control parameters will be described.

8.2 Collecting relevant statistics

8.2.1 Overall statistics from Modeller "general" file

The results of the different metering scenarios were first analyzed and compared using overall performance statistics computed by Paramics Modeller in the "general" file, for the entire network and simulation period. The figures available from the general file included the total vehicle count, the total travel time of all vehicles (in veh-hours), the total distance traveled (in veh-miles) and the average speed of all vehicles over the simulation period (mph). These statistics were taken at the end of the simulation period. They refer to all vehicles, whether they have reached their destination or are still traveling.

8.2.2 Overall statistics from Analyzer “O/D travel times”

Another way to compute overall network statistics is to use the counts and travel time information provided by Paramics Analyzer. This is done by requesting a report of average travel times for each time interval and for all possible origin-destination pairs. Since the number of vehicles that have completed each O/D journey within each time interval is also available, it is possible to compute the overall network travel time. In this case, only the vehicles that have completed their trip at the end of the simulation period are taken into account, which can explain some discrepancies with the method described in Section 8.2.1.

8.2.3 Report Analyzer

Ramp metering scenarios are usually compared not only in terms of overall network performance, but also in terms the relative performances of the mainline freeway and the on-ramps. Because statistics for the mainline freeway or the on-ramps alone are not directly available in Paramics Modeller or Paramics Analyzer, a utility tool developed by Garret Smith for Caltrans (Reference 13) was used. The “Report Analyzer” is a Microsoft Access database that reads the link speed and link flow results of Paramics Analyzer to generate additional reports. As in Paramics Analyzer, the data is organized by time slice.

Among the interesting features of the Report Analyzer tool is the capability to generate reports by section type. For instance, once the mainline and on-ramp links of the network have been identified, the results can be organized by section type. Overall network statistics are also available by combining all section types (mainline, on-ramp, off-ramp and urban links).

Output reports that can be generated with the Report Analyzer include VHT (vehicle-hours traveled), VMT (vehicle-miles traveled), speed and delay. Delay is defined as the difference between the actual travel time and the travel time at 35 mph.

8.3 Results of the base Alinea scenario

The Alinea ramp metering strategy was tested on the I-680 network with the HOV lane in operation, the demand increased by 5%, the optimal set of parameters presented in the previous chapters. The results are presented in this section for one particular run, with a specific seed number (set to 8610) and ramp queue engaged. As part of the sensitivity analysis presented in Section 8.4, the metering period, queue control process and sees number will be changed to study their impact on the results. Results are successively presented in terms of overall performance, speed output, delays and trip times.

8.3.1 Overall statistics

Table 15 displays the results obtained through the Report Analyzer tool described in Section 8.2.3. The Alinea control run is compared to the scenario with metering turned off, and everything else remaining the same.

The Report Analyzer provided statistics by section type for the entire simulation period. The mainline freeway statistics include all freeway subsections. The on-ramp statistics include on-ramp mixed-flow and HOV bypass links. The overall network statistics include all links: mainline, on-ramps and off-ramps.

	METER OFF (w/ HOV lane)	**ALINEA Base Run**	**Difference**	
MAINLINE FREEWAY				
Total travel time (veh-hrs)	13,188	12,323	-865	-6.6 %
Total travel distance (veh-miles)	597,253	597,243	-10	0 %
Average speed (mph)	45.3	48.5	+3.2	+7 %
ON-RAMPS ONLY				
Total travel time (veh-hrs)	1961	2823	+862	+44 %
Total travel distance (veh-miles)	35,363	35,306	-57	-0.2 %
Average speed (mph)	18	12.5	-5.5	-30.6 %
OVERALL NETWORK				
Total travel time (veh-hrs)	15,550	15,544	-6	0 %
Total travel distance (veh-miles)	646,420	646,170	-250	0 %
Average speed (mph)	41.6	41.6	0	0 %

Table 15: Overall Results of Base Alinea Control

When looking at the mainline freeway performance only, the benefit of ramp metering, measured in terms of total vehicle travel time reduction, is found to be 6.6 percent. The average freeway speed, measured for the entire simulation period, has increased by 7 percent, from 45.3 mph in the no metering case to 48.5 mph in the metering scenario.

As expected, the benefits on the mainline freeway are counterbalanced by a decrease of traffic performance on the ramps. The total travel time on the on-ramps increased by 44 percent, from 1961 veh-hrs to 2823 veh-hrs. This represents a drop of average speed on the on-ramps from 18 mph in the base case to 12.5 mph in the metering case.

Overall, the system performance appears to be similar between the two scenarios: the benefits achieved on the freeway by metering the ramps do not exceed the decrease of performance on the ramps. The overall network-wide performance remained stable, whether it is measured in terms of total travel time, travel distance, or average speed.

8.3.2 Speed analysis

The difference in freeway subsection speeds between the Base Alinea and the No Metering scenarios are presented in Figure 27. Three levels of speed differences are graphically depicted: unshaded regions represent differences of less than 2 mph; speed increases over 5 mph are shown in gray while speed decreases over 5 mph are shown in black.

As suggested by the overall mainline statistics in Table 15, the freeway conditions have slightly improved in the metering scenario. The congestion pattern, however, remains very similar to the one before ramp metering. The main bottleneck at the Mission 262 interchange (subsection 30) remains. The improvements are more significant in the first part of the study section, upstream of the Route 84 on-ramp (subsection 12) and downstream of the main bottleneck (subsection 30).

8.3.3 Delay analysis

With the Report Analyzer tool, it is possible to compute delay on a link-by-link basis, and then aggregate by section type. Delay is defined in Report Analyzer as the difference between the actual travel time and the travel time at 35 mph. It is measured in vehicle-hours.

Table 16 presents the overall delay results by section type. It can be seen that the reduction of delay experienced on the freeway (449 veh-hrs) does not compensate for the additional delay on the on-ramps. The overall system delay has increased in this case by 315 veh-hrs, or 13 percent.

I-680 SB — **SPEED DIFFERENCE CONTOUR (Alinea vs. Meter Off)**

Interval Start	Section number 0	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	30	31	32	33	34	35	36	37
5:00		0	0	0	0	0	0	0	1	0	0	-1	-1	0	1	1	2	1	0	0	-1	0	0	0	1	0	2	-1	0	-1	0	0	0	0	0	0	0	0
5:15		-1	-1	1	2	-1	-1	2	3	5	2	2	-22	-5	3	9	7	1	1	1	2	0	0	4	1	0	1	0	0	0	-1	0	0	0	-1	-1	0	1
5:30		1	0	0	1	2	0	1	0	-1	6	7	6	4	2	0	2	9	6	1	7	0	-2	1	-2	0	3	1	1	0	1	1	1	0	1	1	0	-1
5:45		0	0	-1	-1	-1	-2	1	5	7	1	1	5	-2	-8	-4	2	10	17	13	3	1	1	0	2	1	-1	1	1	2	0	1	1	0	0	0	-1	-1
6:00		0	1	0	1	0	1	1	0	1	2	-4	6	4	4	3	2	8	5	10	18	32	4	-3	1	-1	0	0	0	1	4	0	0	0	-1	0	-1	-2
6:15		0	0	0	1	-1	-2	0	-2	0	1	17	20	5	9	5	-1	1	4	11	8	17	5	4	3	4	1	0	0	1	9	1	0	-1	0	0	1	1
6:30		1	1	2	3	2	2	1	1	-3	8	19	11	-3	-1	-3	8	5	5	6	6	6	5	1	4	11	2	-1	-4	-6	-5	0	0	0	1	2	2	2
6:45		1	0	-1	-1	-1	-2	1	2	19	29	18	9	4	4	5	11	13	5	17	12	11	5	-4	-5	-5	4	-6	-4	-4	-1	-1	1	0	0	-1	-1	-5
7:00		0	0	1	1	1	-1	-1	10	34	35	39	13	8	-1	-3	-10	-12	-16	-21	-19	-19	-2	0	4	1	4	3	2	2	2	1	4	1	0	-1	-3	-6
7:15		0	0	0	-1	0	-2	1	22	30	26	-1	-4	-7	-3	-1	-2	4	1	5	8	9	4	-1	-2	2	15	21	7	3	2	1	0	-1	-5	1	-4	-2
7:30		0	1	0	0	0	-1	1	3	35	28	13	3	1	1	-1	1	8	4	4	3	3	0	-1	2	3	5	-1	3	3	4	2	7	0	1	1	5	12
7:45		0	1	1	1	1	2	1	2	21	23	36	14	10	9	4	5	7	3	-2	-2	1	1	-2	1	1	-3	-6	3	5	5	2	4	3	6	0	-2	5
8:00		0	0	0	-1	-1	-4	-1	-1	-1	12	34	26	8	2	-2	0	3	-4	-1	3	5	4	-1	0	0	9	5	0	-1	-1	-1	-2	11	5	0	1	-2
8:15		0	0	-1	0	-1	-3	-1	-1	-2	-1	8	37	15	11	9	12	12	10	9	-6	-9	0	2	3	2	-5	-24	-5	1	2	1	5	-1	1	4	-3	8
8:30		1	0	0	0	0	-1	-1	-1	-1	0	0	11	5	16	38	28	8	-1	-6	3	-4	1	4	-1	0	-4	-24	-4	4	4	1	3	9	5	-4	-4	1
8:45		0	0	1	0	0	1	0	0	0	0	-1	0	1	0	0	1	8	13	21	30	42	-3	-10	-10	-5	-3	-17	-4	2	4	1	17	26	4	1	2	5
9:00		0	-1	-1	-1	-1	-2	-1	-1	-1	0	-1	-2	-2	0	0	0	-1	0	-1	0	-1	0	12	-4	5	3	1	1	1	2	1	12	21	28	21	16	2
9:15		0	0	0	0	0	0	0	1	0	0	0	-1	-1	-1	-1	-1	-2	-1	0	1	0	0	-1	-6	-18	0	3	4	3	3	1	4	3	12	14	18	23
9:30		0	0	-1	-1	-1	-1	0	0	0	-1	0	0	-1	-1	0	-1	-1	0	0	-2	-1	0	-2	-1	-4	-6	-12	-6	-2	0	-1	5	0	8	11	18	30
9:45		-1	-1	-1	0	-1	-2	-1	0	0	-1	-1	-1	-3	-1	0	0	0	0	0	0	0	1	0	1	1	2	0	-6	-14	-17	-1	-1	1	7	0	2	22
10:00		-1	0	-1	0	0	-1	0	0	0	1	-1	0	1	-1	-1	0	-1	-1	0	-1	-1	-2	-2	-1	0	-1	-1	-1	-1	-1	-1	0	0	0	1	0	0
10:15		1	1	1	1	1	0	0	0	-1	-1	-1	-1	-2	0	-1	0	-2	-2	-1	-1	-1	-1	-1	0	-1	-1	1	1	0	0	-1	-1	0	0	0	-1	-1
10:30		0	0	1	0	0	0	1	0	1	1	1	1	2	1	1	2	1	1	1	1	2	1	1	1	1	1	0	0	-1	-4	-2	-1	0	-1	-3	-1	0
10:45		0	0	0	0	-1	-1	1	0	0	0	0	-1	-2	-1	-1	1	0	0	0	-1	1	0	0	0	0	-1	0	0	0	-2	0	0	1	1	0	-1	1
11:00		-7	-1	-2	-2	-2	0	-1	0	0	0	-1	0	1	0	0	0	1	1	0	0	1	1	1	1	0	1	1	0	0	-1	0	0	0	-1	0	1	1

Figure 27: Ramp Metering Scenario - Speed Difference Contour Map

DELAY (veh-hrs)	METER OFF	ALINEA Base Run	Difference	
MAINLINE FREEWAY	1253	804	-449	-35.8%
ON-RAMPS ONLY	1137	1898	+761	+66.9%
OVERALL NETWORK	2411	2726	315	+13.1%

Table 16: Results of Base Alinea Control – Delay Statistics

Figures 28 and 29 allows for a more detailed analysis of where and when the delays occurred on the freeway and the on-ramps. In the mainline delay contour on Figure 28, each cell represents the amount of delay experienced over a 15-minute time period on a given subsection of the freeway. The unshaded regions represent no delay conditions; delays lower than 10 veh-hrs are shaded in light gray, and delays higher than 10 veh-hrs are shaded in dark. All freeway subsections except subsections 23, 24 and 27 have experienced a decrease of the total delay at the end of the simulation period.

Figure 29 displays a ramp-by-ramp analysis of the total on-ramp delay experienced. Eight ramps had increased delay after the introduction of ramp control: Sunol, Route 84 Calaveras, Sheridan, Mission 238, Washington, AutoMall, Mission 262 SB and NB; two ramps had slightly reduced delay (WB Route 84 and Jacklin); six ramps had no delay in either case. The Jacklin on-ramp was not metered in the Alinea scenario, and the delay was reduced at this particular ramp when the other ramps were controlled.

8.3.4 Trip time analysis

Another interesting way to analyze the impact of the ramp metering is to compare the travel time required to reach the mainline freeway destination (southern boundary) from the different origins. Travel time includes both ramp and freeway travel time. Figure 30 illustrates the results. On average, the time required to traverse the entire freeway section (from mainline origin to mainline destination) decreased by 7.8 percent, from 29.8 minutes in the no metering case to 27.4 minutes in the metering scenario.

Except for the Route 84 Calaveras origin, all traffic entering the freeway before the Vargas junction (longer trips) benefited from implementation of the Alinea strategy, due to the freeway performance improvements that occurred in the first half of the network. Most vehicles entering the freeway further downstream (shorter trips) experienced an increased travel time, due to increased delay on the ramps and no significant improvements on the freeway. As expected, traffic on the four ramps that were not controlled (Andrade, Vargas, Scott Creek and Jacklin) does not experience higher travel times. This type of analysis highlights the equity issues involved in ramp metering.

I-680 SB	PARAMICS MAINLINE DELAY CONTOUR - NO METERING																																					
	Section number																																					
Interval Start	0	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	30	31	32	33	34	35	36	37	Total
5:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
5:45		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6:00		0	0	0	0	0	0	0	0	0	0	0	4	2	0	2	0	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
6:15		0	0	0	0	0	0	0	0	0	0	0	7	2	0	0	0	0	0	0	4	8	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	26
6:30		0	0	0	0	0	0	0	0	0	0	0	6	1	0	1	4	3	4	8	10	15	10	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	69
6:45		0	0	0	0	0	0	0	0	0	6	17	10	7	1	10	7	2	1	2	6	12	8	1	0	1	0	0	0	1	2	0	0	0	0	0	0	0	91
7:00		0	0	0	0	0	0	0	0	17	8	20	10	7	0	3	0	1	0	0	0	0	6	3	11	5	3	3	4	2	2	0	0	0	0	0	0	0	106
7:15		0	0	0	0	0	0	0	0	9	9	10	7	0	0	3	7	8	5	11	11	19	13	4	5	8	3	2	4	2	2	0	0	0	0	0	0	0	141
7:30		0	0	0	0	0	0	0	0	15	12	20	11	7	3	7	9	13	4	6	6	16	12	8	15	9	0	0	4	2	3	0	0	0	0	0	0	0	184
7:45		0	0	0	0	0	0	0	0	0	0	8	9	13	6	14	15	13	5	7	8	14	16	8	13	7	0	0	4	3	3	0	0	0	0	0	0	0	168
8:00		0	0	0	0	0	0	0	0	0	0	5	9	6	3	15	17	13	2	2	4	9	11	5	11	5	3	1	4	3	3	0	0	0	4	0	0	0	135
8:15		0	0	0	0	0	0	0	0	0	0	0	6	4	1	11	12	12	5	8	1	4	17	11	18	8	0	0	1	2	3	0	0	0	5	3	0	1	131
8:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	15	12	2	0	1	0	6	7	20	8	0	0	1	2	3	0	0	0	5	0	0	2	92
8:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	14	7	4	2	3	0	0	1	2	3	0	0	3	2	0	0	1	45
9:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	2	4	2	3	0	0	0	5	0	0	1	27
9:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	3	2	2	0	0	0	0	0	0	0	12
9:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	3
9:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																															Total Mainline Delay in Veh-hrs =								1253

I-680 SB	PARAMICS MAINLINE DELAY CONTOUR - ALINEA CONTROL																																					
	Section number																																					
Interval Start	0	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	30	31	32	33	34	35	36	37	Total
5:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:30		0	0	0	0	0	0	0	0	0	0	0	0	3	0	4	0	1	2	4	5	7	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
6:45		0	0	0	0	0	0	0	0	0	0	0	4	3	0	4	0	0	0	0	0	1	3	3	3	4	0	0	0	1	2	0	0	0	0	0	0	0	29
7:00		0	0	0	0	0	0	0	0	0	0	0	2	1	0	6	10	6	4	7	10	15	7	3	4	5	0	2	3	2	2	0	0	0	0	0	0	0	89
7:15		0	0	0	0	0	0	0	0	0	0	10	9	6	0	3	9	5	4	6	5	7	9	6	7	6	0	0	1	1	2	0	0	0	0	0	0	0	97
7:30		0	0	0	0	0	0	0	0	0	0	4	9	6	2	8	8	5	2	4	5	11	12	8	12	7	0	0	3	1	2	0	0	0	0	0	0	0	108
7:45		0	0	0	0	0	0	0	0	0	0	0	1	2	0	9	8	6	4	10	10	13	13	10	11	7	0	2	2	1	2	0	0	0	0	0	0	0	112
8:00		0	0	0	0	0	0	0	0	0	0	0	0	0	2	19	15	8	3	3	3	4	6	6	10	6	0	0	4	3	3	0	0	0	0	0	0	0	96
8:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	1	1	5	14	16	9	13	7	2	3	3	2	2	0	0	0	3	0	1	0	86
8:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	3	0	2	6	4	22	8	1	2	3	1	2	0	0	0	1	3	1	2	67
8:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	12	18	6	0	1	3	1	2	0	0	0	0	0	0	0	52
9:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	0	1	3	2	2	0	0	0	0	0	0	0	17
9:15		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	1	2	1	2	0	0	0	0	0	0	0	11
9:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	0	0	0	0	0	0	0	6
9:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:30		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																															Total Mainline Delay in Veh-hrs =								804

Figure 28: Ramp Metering Scenario - Mainline Delay Contour Maps

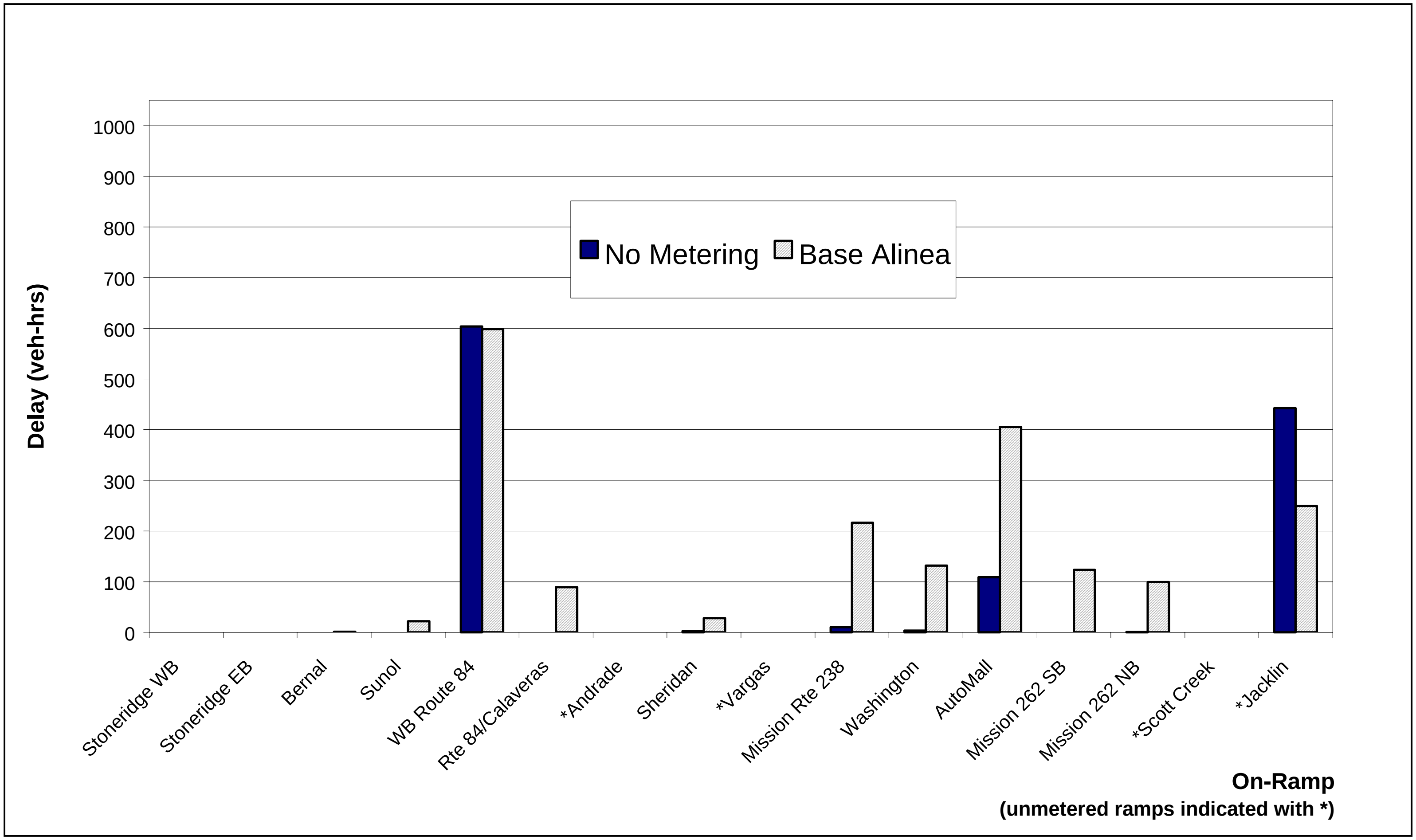

Figure 29: Ramp Metering Scenario - On-Ramp Delay

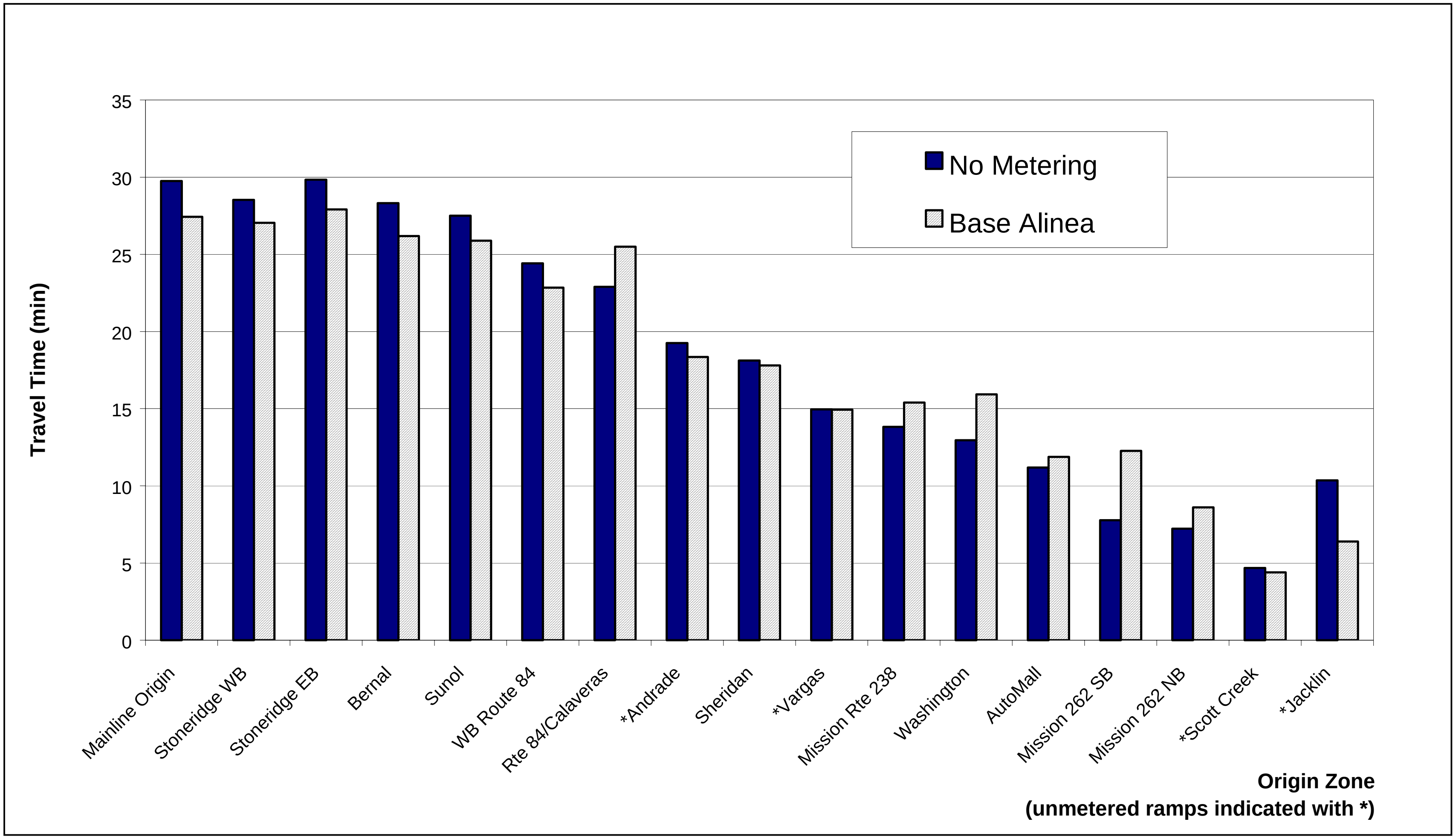

Figure 30: Ramp Metering Scenario - Travel Times to Mainline Destination

8.4 Sensitivity analysis

The results presented in Section 8.3 were related to one particular ramp metering run, representing the base ramp metering scenario. In the base Alinea scenario, the ramp metering strategy was tested with a specific random number on the I-680 network with the HOV lane in operation. The settings used for the Alinea control parameters were derived from the calibration effort described in Chapter 7.

It was found that the benefits experienced on the mainline freeway did not compensate for the additional delay on the on-ramps. The overall network-wide system performance (travel time, travel distance and average speed) remained similar after the implementation of ramp metering.

In an effort to improve the system performance in the metering case, a number of changes have been attempted. Different parameters were altered to study their effect on the network performance. The most significant investigations dealt with the duration of the ramp metering period, the effect of the queue detector and the random seed number.

8.4.1 Effect of metering period

The base Alinea run represented a scenario with ramp metering turned on at 5 AM and operating until the end of the simulation period at 11:15 AM. A new run was made with everything else being the same, except that the metering control was turned on at 5:30 AM and turned off at 9 AM. At 9 AM, all ramps rest on green and queued vehicles can discharge. The results are displayed on Table 17.

OVERALL NETWORK	**Metering Off**	**Base Alinea Metering from 5:00 to 11:15**	**Metering from 5:30 to 9:00**
Total travel time (veh-hrs)	15,550	15,544	15,417
Total travel distance (veh-miles)	646,420	646,170	644,010
Average speed (mph)	41.6	41.6	41.8
Total delay (Veh-hrrs)	2411	2726	2710

Table 17: Effect of Metering Period

By metering only from 5:30 AM to 9 AM, which is the heaviest period within the morning peak, the overall system performance has slightly improved over the base metering case. The total travel time is down by 127 veh-hrs, and is now one percent lower than in the no metering scenario.

Just like in the base metering run, there is a strong contrast between the improvement on the mainline (travel time reduced by 9% over the no metering case) and the deterioration on the ramps (travel time increased by 52%).

8.4.2 Effect of queue detector

The queue detectors are used in the Alinea control strategy to try to protect the ramps from being overloaded. When queue detectors are activated, the metering rate switches to the maximum metering rate so that more vehicles can enter the freeway. Queue control is critical to ensure that the ramp delays do not reach unacceptable levels. However, it reduces the potential of the Alinea control strategy to adjust the metering rates so as to obtain optimized traffic conditions on the freeway.

In order to illustrate how often the queue control process was activated during the base Alinea run, Figure 31 shows when queue spillback occurred, for each controlled on-ramps at 15-minute time intervals. It can clearly be seen that four on-ramps (Route 84 WB, Washington, AutoMall, and Mission 262 SB) experienced heavy congestion and spillback conditions during a high proportion of the simulation period. While ramp queue spillback occurs, the Alinea control strategy is not engaged and the ramp control strategy becomes ineffective in relieving freeway traffic congestion.

In order to further analyze the effects of the queue control, one run was made to replicate the base metering scenario in the absence of queue detectors. In this case, the Alinea algorithm was free to adjust the metering rates based on the mainline freeway conditions, with no other constraints than the specified minimum and maximum metering rates.

As expected, this scenario without queue control resulted in a significant improvement of the freeway traffic conditions: the average speed on the mainline freeway was up to 56 mph. However, the congestion of the ramps was so severe that the overall system travel time increased by 50 percent, from around 15,500 to 23,000 veh-hrs. Most of the ramps experienced delays that reached unreasonable levels.

8.4.3 Changing seed numbers

An analysis was carried out in order to assess the effect of the random seed number on the results. The two scenarios (with and without ramp metering) were run ten times each with different random numbers. The results in vehicle units are presented on Table 18.

	Stoneridge WB	Stoneridge EB	Bernal	Sunol	Route 84 WB	Route 84 Calaveras	Sheridan	Mission Rte 238	Washing-ton	AutoMall	Mission 262 SB	Mission 262 NB
5:00:00	0	0	0	0	0	0	0	0	0	0	0	0
5:15:00	0	0	0	0	0	0	0	0	0	0	0	0
5:30:00	0	0	0	0	0	0	0	0	0	0	0	0
5:45:00	0	0	0	0	1	0	0	0	0	0	0	0
6:00:00	0	0	0	0	0	0	0	0	1	0	0	0
6:15:00	0	0	0	0	1	0	0	0	0	0	0	0
6:30:00	0	0	0	0	0	1	0	0	0	0	0	0
6:45:00	0	0	0	0	0	0	0	1	0	0	0	0
7:00:00	0	0	0	0	1	0	0	1	0	1	0	1
7:15:00	0	0	0	0	1	0	0	0	0	1	0	0
7:30:00	0	0	0	0	1	0	0	0	0	1	0	0
7:45:00	0	0	0	0	1	1	0	0	1	1	1	0
8:00:00	0	0	0	0	1	0	0	0	1	1	1	1
8:15:00	0	0	0	0	0	0	0	0	1	1	1	0
8:30:00	0	0	0	0	0	0	1	0	0	0	1	0
8:45:00	1	0	0	0	0	0	0	1	1	1	1	0
9:00:00	0	0	0	0	0	0	0	0	0	1	1	0
9:15:00	0	0	0	0	0	1	0	0	1	1	1	0
9:30:00	0	0	0	0	0	0	0	0	1	1	1	1
9:45:00	0	0	0	0	0	0	0	0	0	1	1	0
10:00:00	0	0	0	0	0	0	0	0	0	1	1	0
10:15:00	0	0	0	0	0	0	0	0	0	0	1	0
10:30:00	0	0	0	0	0	0	0	0	0	0	0	0
10:45:00	0	0	0	0	0	0	0	0	0	0	0	0
11:00:00	0	0	0	0	0	0	0	0	0	0	0	0
11:15:00	0	0	0	0	0	0	0	0	0	0	0	0
	No Spillback		0	1	Spillback							

Figure 31: Ramp Metering Scenario - Ramp Queue Spillback

AVERAGE OF 10 RUNS WITH DIFFERENT SEED NUMBERS	METER OFF	ALINEA	Difference	
MAINLINE FREEWAY				
Total travel time (veh-hrs)	13,420	12,623	-796	-5.9 %
Total travel distance (veh-miles)	598,298	597,581	-716	-0.1 %
Average speed (mph)	44.6	47.4	+2.7	+6.2 %
ON-RAMPS ONLY				
Total travel time (veh-hrs)	1953	3562	+1609	+82.4 %
Total travel distance (veh-miles)	35,556	35,456	-99	-0.3 %
Average speed (mph)	18.2	10.0	-8.2	-45.1 %
OVERALL NETWORK				
Total travel time (veh-hrs)	15,775	16,587	+812	+5.1 %
Total travel distance (veh-miles)	647,676	646,744	-932	-0.1 %
Average speed (mph)	41.1	39.0	-2.1	-5.0 %

Table 18: Different Seed Numbers – Vehicle Units

The random number seed in Paramics sets the random number generator starting point, and varying this value will guarantee a different outcome from the simulation each time due to random release of traffic by the program and the effect of the seed number on diver behavior models such as car following, lane changing and gap acceptance. Users are advised to run the model with different seed values to test its sensitivity and stability.

These results show a similar pattern to the one presented before. However, when averaging over ten different seed numbers, the effect of ramp metering appears to be deterioration in the order of five percent, both for the total travel time and the network average speed.

These series of runs were also analyzed in terms of passenger units, in order to account for the different occupancy levels and the impact of the HOV mainline and bypass lanes. The vehicle breakdown used in the ramp metering investigations was the same than the one used in the initial HOV run (see Table 7). It was assumed that vehicle types 2 have an average occupancy of 2.4 passengers per vehicle, while vehicle types 15 have an average occupancy of 10 passengers per vehicle. All other vehicle types are single-occupancy vehicles. These average occupancy levels were used in Analyzer to compute statistics per vehicle type in passenger units. Table 19 presents the results of this analysis.

AVERAGE OF 10 RUNS WITH DIFFERENT SEED NUMBERS	**METER OFF**	**ALINEA**	**Difference**	
SINGLE-OCCUPANCY VEHICLES				
Total travel time (passenger-hours)	13,656	14,411	+755	+5.5 %
Total travel distance (passenger-miles)	545,474	543,365	-2110	-0.4 %
Average speed (mph)	40.0	37.7	-2.2	-5.6 %
HIGH-OCCUPANCY VEHICLES				
Total travel time (passenger-hours)	6,142	6,395	+253	+4.1%
Total travel distance (passenger-miles)	296,221	299,627	+3406	+1.1 %
Average speed (mph)	48.2	46.9	-1.4	-2.8 %
ALL VEHICLES				
Total travel time (passenger-hours)	19,799	20,807	+1008	+5.1 %
Total travel distance (passenger-miles)	841,696	842,992	+1296	+0.1 %
Average speed (mph)	42.5	40.5	-2.0	-4.7 %

Table 19: Different Seed Numbers – Passenger Units

It can be observed that when the results are aggregated over a series of ten runs with different seed numbers, similar conclusions are reached: both in terms of vehicle statistics and passenger statistics, the implementation of the Alinea control strategy results in a deterioration of the overall system performance, in the order of five percent. With the particular configuration used in this study, the benefits experienced on the mainline freeway due to ramp control are not sufficient to counterbalance the negative impact on the ramps.

8.5 Conclusions of ramp metering investigations

The ramp metering strategy was applied to the I-680 network, with an added HOV lane and a demand increased by 5 percent over the 2001 demand level. The Alinea local traffic actuated ramp control strategy was implemented in Paramics using different APIs and evaluated. The results were presented first for a specific metering scenario (base Alinea), and later a number of changes were made as part of a sensitivity analysis.

Looking at the system-wide statistics, both in terms of vehicle units and passenger units, it was found that the system did not perform better after the implementation of ramp control for the particular conditions that were simulated. As expected, the mainline freeway did experience better traffic conditions when the metering system was implemented; however, the level of benefits obtained on the freeway did not exceed the additional delay experienced on the ramps.

A number of reasons may have contributed to underestimate the likely benefits of ramp metering in this particular application:

The Alinea control strategy implemented in the ramp-metering scenario includes a **queue control** process that attempts to limit the number of vehicles stored on the on-ramps. When the queue detector placed at the beginning of the on-ramp is activated, the Alinea algorithm does not control the metering rate anymore, but instead, it is set to the maximum metering rate. This is a constraint embedded in the Paramics Alinea API in its current stage of development. However, this may not be the optimum strategy. Another less radical and potentially less harmful approach would be to increase the metering rate by a small increment rather than going to the maximum. The best way to ramp meter may even be not to use the queue detectors at all, providing that the metering operations are well tuned.

The traffic conditions on the I-680 network were so heavy that even before implementing ramp control, the ramps experienced some delays. With the metering on, the on-ramp demands and congestion increased, and therefore the queue detectors were activated very frequently; in this case, the ramp meters operate at their maximum metering rates, letting as much vehicles as possible onto the freeway. Under these conditions, the freeway cannot benefit much from the implementation of the ramp metering system.

The modeled I-680 network was limited to the freeway only, with no parallel surface streets modeled. **No diversion** was considered, as there was no opportunity for vehicles to use an alternative route after the implementation of the ramp metering. In general, the effects of diversion from the freeway to parallel routes generate most of the benefits reported in ramp metering evaluation studies. In the absence of diversion the benefits of ramp control are likely to be underestimated.

The benefits of ramp metering, as evaluated in this study, were likely to be further underestimated because **no modal response** was considered. The implementation of ramp control with HOV bypass lanes, in addition to the creation of the mainline HOV lane, should provide an incentive for travelers to carpool. The future demand scenario should be adjusted accordingly, so that these effects are accounted for in the evaluation.

CHAPTER 9: CONCLUSIONS

9.1 Summary of experiments

This research project focused on the investigation of the southbound morning peak period on a section of the I-680 freeway facility between I-580 in Pleasanton and SR 237 in San Jose. The objectives were to evaluate the capability of the Paramics microsimulation tool in evaluating a range of alternative traffic management strategies, and evaluate the impact of these strategies on the traffic conditions in the study area.

Prior to any alternative scenario investigations, the model had to be calibrated against real life traffic conditions. An extensive and reliable dataset including traffic counts, speed performance and occupancy distribution was collected by Caltrans District 4 over three days in October 2001. This dataset was used in the simulation project first to develop the input data files required by the model, and then to check the validity of the simulation results against field measurements. It was found that the model, once properly calibrated, was capable of accurately representing traffic conditions as observed in the field.

Alternative scenario investigations started with the addition of an HOV lane. In order to realistically represent driver behavior in the presence of a contiguous HOV lane, it was found necessary to modify various driver behavior specifications, which was done through the use of an Application Programming Interface (API) developed by Quadstone.

From the existing freeway model to the freeway with an HOV lane, in all three days of data (Tuesday, Wednesday, Thursday October 2-3-4, 2001), it was found that the total vehicle hours traveled decreased 28 percent and the overall average speed increased 40 percent. It was also found that about 66 percent of the eligible HOVs use the HOV lane. From these results, it was concluded that HOV lane implementation should improve operations on this freeway.

Several scenarios were also developed within the I-680 Paramics model as part of a sensitivity analysis, to assess the effects on the network of altering certain input parameters. The scenarios that were investigated included varying the HOV lane passenger occupancy cutoff level; testing different vehicle occupancy distributions; applying growth factors to the overall demand; investigating different typical weekday demand patterns.

The model was subsequently used to investigate a scenario combining the added HOV lane with a local traffic actuated ramp control strategy known as Alinea. Replicating the Alinea control strategy within Paramics required the use of a three APIs (loop data aggregator, ramp controller and Alinea) that had been developed by PATH researchers at UC Irvine. A number of highly sensitive parameters, such as the maximum metering rate and the desired mainline occupancy rate had to be fine-tuned on a ramp-by-ramp basis.

Results were analyzed in terms of freeway versus on-ramp performances with the support of the Report Analyzer tool. It was found that the improvements of traffic conditions on the mainline freeway due to ramp control did not outweigh the deterioration of the traffic performances on the on-ramps. Whether the analysis is performed in terms of vehicle or passenger units, the overall system performance was shown to deteriorate after the implementation of ramp control.

It was recognized, however, that a number of factors might have contributed to underestimate the likely benefits of ramp metering in this study. The most important factor is the absence of route diversion. Because no parallel surface street was modeled, the model did not capture the spatial diversion that is likely to occur when ramp metering is implemented. Another key issue is the ramp queue control process embedded in the Alinea control strategy: because of high demand levels on many on-ramps, the storage capacity is often reached during the simulation period, resulting in an override of the Alinea-optimized metering rate. This phenomenon prevents ramp control to reach the full potential of mainline freeway improvements. Finally, no modal response was considered in the scenario comparisons, which may have contributed to improving the overall system performance with a higher usage of HOV bypass and mainline lanes.

9.2 Future work

Following up on the initial I-680 freeway study, future research should be carried out in order to further improve the reliability and effectiveness of the modeling tools for freeway corridor applications.

A key aspect is to better replicate driver responses to the implementation of the different traffic management strategies. Two types of driver responses to corridor control should be addressed: spatial response (i.e. route diversion) and modal response (i.e. modal shift).

In general, the effects of diversion from the freeway to parallel routes generate most of the benefits reported in ramp metering evaluation studies. In the absence of diversion opportunities in the I-680 application, the benefits of ramp control were likely to be underestimated. In future studies, it will be critical to consider the interactions between the freeway and parallel routes, and implement routing assignment techniques that consider traffic conditions on all facilities.

Another element to investigate includes whether the HOV lane provides an incentive to drivers to carpool, and how modal shifts can be modeled in Paramics. A possible modal response is the shift by lower occupancy vehicle persons to join higher occupancy vehicles in order to use an HOV bypass lane at a ramp metering location, or to use some portion of an added HOV lane. The demand in the HOV scenarios should be adjusted accordingly, so that these effects are accounted for in the evaluation.

With regard to modeling ramp metering strategies, the Alinea API for Paramics could be further enhanced by allowing the user to specify the queue control process to be implemented. Queue control should be independent of the optimization algorithm, and parameters such as the threshold value of the queue detector should be user-specified.

Ramp metering should be further investigated by considering other strategies than the Alinea local traffic responsive control. Other strategies include coordinated control, where the interactions between ramp metering rates along a freeway section are taken into account. Some additional APIs have been developed to replicate some of these strategies, such as the Bottleneck, Zone, and Swarm ramp control algorithms. Testing, calibrating and comparing the performances of the different ramp control strategies would be of great value.

An issue encountered in the analysis of the freeway HOV lanes in Paramics is the lack of lane-by-lane aggregated statistics. It would be useful to be able to gather aggregated lane-by-lane performance statistics, similar to the link statistics that can be obtained through the Paramics Analyzer. These would help in determining how an HOV lane performs in comparison to mixed-flow lanes.

A benefits/costs analysis of different alternatives including HOV lanes and ramp metering could also be performed on the basis of the traffic performances predicted by the model.

The research team expects to participate in further applications of Paramics to I-680 or 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.

CHAPTER 10: REFERENCES

1. Y. Gardes, A. May, J. Dahlgren and A. Skabardonis. *Bay Area Simulation and Ramp Metering Study*. University of California at Berkeley. California PATH Report UCB-ITS-PWP-2002-6, February 2002

2. Caltrans Draft Project Report, *On Route 680 in Santa Clara and Alameda Counties from the Route 237 Interchange to Stoneridge Dr. Interchange*, November 1999

3. Caltrans Highway Congestion Monitoring Program 1998 report http://svhqsgi4.dot.ca.gov/hq/esc/D4HWOPS/98HICOMP

4. R. Dowling, Dowling Associates, *PARAMICS Training Course – Application of the Paramics Traffic Microsimulation Tool to Traffic Operations Analysis*, Oakland, California, June 2000

5. Y. Gardes, A. May, J. Dahlgren and A. Skabardonis. *Freeway Calibration and Application of the Paramics Model* 81st Transportation Research Board Annual Meeting. Washington D.C., January 2002

6. Transportation Research Board, *Highway Capacity Manual 2000*, Washington D.C., 1100 pp., 2000

7. Quadstone Limited, "*HOV Behavior – Lane changing API*, Quadstone Limited, Edinburgh, Scotland, unpublished document, June 2001

8. California Department of Transportation *2000 District 4 HOV Report*, California Department of Transportation, District 4 Oakland, Office of Highway Operations, California, December 2000

9. Papageorgiou, M., H. Hadj-Salem and F. Middelham. *ALINEA Local Ramp Metering: Summary of Field Results.* Transportation Research Record 1603, Transportation Research Board, National Research Council, Washington, D.C. January 1997

10. Chu, L., H. Liu and W. Recker. *PARAMICS API Development Document for Advanced Ramp Metering Algorithms.* University of California at Irvine. California PATH ATMS Center. Internal unpublished document. May 2002

11. Zhang, M., T. Kim, X. Nie, W. Jin, L. Chu and W. Recker. *Evaluation of On-ramp Control Algorithms.* University of California at Davis and Irvine. California PATH Research Report UCB-ITS-PRR-2001-36, December 2001

12. Yang, X., L. Chu and W. Recker. *GA-based Parameter Optimization for the ALINEA Ramp Metering Control*. University of California at Irvine. IEEE 5th International Conference on ITS, Singapore, September 2002

13. Smith, G. *Paramics Report Analyzer v1.0b6 – Tutorial and Instructions.* Developed for Caltrans Division of Traffic Operations, October 2002