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CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
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Freeway Detector Data Analysis for Simulation of the Santa Monica Freeway — Summary Report

Loren D. Bloomberg
Adolf D. May

UCB-ITS-PWP-93-10

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

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

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The authors of this working paper would like to acknowledge the help of several individuals who provided valued help in this study. Officials at Caltrans District 07 in Los Angeles were asked for assistance in several instances, and responded with information, time, and resources on each occasion. Don Mattson was the primary contact for the data collection trip, and his assistance made the endeavor a success. Marty Stevens spent much time explaining the detector configuration and researching which detectors were functioning. Alex Kalbasi facilitated the initial tape download for the pilot study, and provided technical support throughout. Finally, Pat Perovich graciously facilitated the authors' efforts at Caltrans.

The help of several individuals from UC Berkeley should also be recognized. Mark Miller (from the PATH program) helped to initiate the study of the Smart Corridor freeway detectors, and provided key contacts throughout. Vinton Bacon was an integral part of the pilot study and assisted in the data collection effort. Justine Davis' tireless data entry made the study possible. Finally, Yonnel Gardes was a continued source of insight and advice on issues related to the simulation of the Santa Monica Freeway.

This report is part of an effort to simulate various IVHS strategies on the Santa Monica Freeway corridor (I-10) in Los Angeles. This corridor is also known as the "Smart Corridor" because of the project of the same name that is currently underway on the corridor. While much of the data used for this report were obtained from the agencies involved in the Smart Corridor project, it should be made clear that this research was conducted at the University of California at Berkeley and is not a part of the Smart Corridor project itself. The results arrived at in this report do not necessarily reflect the views of any of the agencies involved in the Smart Corridor project.

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Section 1: Executive Summary

A team at the University of California at Berkeley is investigating the benefits of Intelligent-Vehicle Highway Systems (IVHS) using a simulation model of the Santa Monica Freeway in Los Angeles. To accomplish this, detailed demand data (vehicle volumes and occupancies) are needed for mainline stations and ramps on the freeway. A pilot study was conducted in December, 1992 to assess the viability of collecting these data. It was decided that a manual data collection effort was needed; this effort and the analysis of the data are summarized in this report.

Data were collected for May 25-27, 1993 (from 6 A.M. to 8 P.M.) along a fourteen mile stretch of the Santa Monica Freeway. The MODCOMP computer system at Caltrans was queried and printouts listing five minute volume and occupancy counts for 243 detectors in 44 different zones were created. These data were entered as flat files and converted to a spreadsheet format. Using the graphs and charts from these spreadsheets, a number of analyses were performed.

It was found that many mainline detectors (across all lanes) appear to return accurate data (i.e., traffic volumes in the range of 1000 to 2500 vehicles/hour/lane), but most of these detectors are concentrated in the middle section between the 405 and the 110 freeways. The ramp data are somewhat less robust. Approximately 50% of the on-ramps and 15% of the off-ramps were found to have detectors that provide data that appears reasonable for ramps.

Many of the detectors that returned data appear to give reasonable results. Specific analyses of detectors using volume-occupancy scatter plots, flow versus time graphs, and occupancy contour maps suggested that many of the detectors are functioning properly.

However, the simulation effort will require more data; counts from the ramps are especially important so that the team can develop a synthetic origin-destination model for trips involving the freeway. The team is continuing to look for additional sources of data for the model. The collection of these data, combined with the data obtained in this study, will be essential to the development of the simulation of the Santa Monica Freeway.

Section 2: Rationale

Several ongoing projects are investigating the benefits of Intelligent Vehicle-Highway System (IVHS) technology for the Smart Corridor in Los Angeles. One of these projects is a simulation of the Santa Monica Freeway and five parallel arterials (the Smart Corridor) using the INTEGRATION model. A team at UC Berkeley (that includes the authors) is developing the simulation as part of a multi-year research project. The goal of this research is to assess and refine individual and combined Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) strategies.

In order to assess the benefits of IVHS, it is first necessary to develop a baseline model for comparison. Since demand data is critical for such a model, the simulation project team is currently working to collect and analyze data to develop the model of the freeway (arterial data is being gathered in a parallel study).

The key input to the model is demand data: the INTEGRATION model requires origin/destination (O/D) data for each node in the network. These data can either be input directly (i.e., data on trips between origin/destination pairs can be collected by means of surveys or other techniques), or synthesized (by using traffic flow data at specific points). To minimize time and resource requirements, the simulation project will **use** synthesized origin/destination data as the source of its demand data. However, in order to build a useful model, it is critical for the team to have access to timely and accurate demand data.

As a first step, it was decided to undertake a pilot study of the available sources of data. Since the California Department of Transportation (Caltrans) has developed a network of freeway detectors for the Santa Monica Freeway, determining the usefulness of the data from these detectors was considered to be an important first step.

The pilot study was initiated in late 1992. Data from December 7, 1992 for Santa Monica Freeway detectors were provided by Caltrans on magnetic tapes. Then, data from these tapes were extracted, organized, and analyzed to assess the viability for use in the simulation model. The overall goal was to make a general assessment of the validity and usefulness of the freeway data in order to help define future work. This pilot study is documented in a previous research report (PATH Working Paper UCB-ITS-PWP-93-1 "Freeway Detector Analysis for Simulation of the Santa Monica Freeway: Initial Investigations").

Unfortunately, the data available from the pilot study proved to be insufficient for the development of the simulation model, for several reasons. First, ramp traffic volumes (which are more important than mainline counts from the perspective of origin/destination synthesis) were not easily obtained from the Caltrans tapes. A program that was developed at UC Irvine was used to extract data from the tapes into a format suitable for analysis on a PC. However, this program was developed only for mainline data;

modification of the program to support extraction of other data (e.g., ramps, collector/distributor lanes) would have required a substantial investment in time and resources. Also, some detectors that are currently operational were not functioning at the time of the pilot study. Simulating the Santa Monica Freeway is a data intensive effort, so it is important to collect data during a time period when a maximum number of detectors are functioning.

Therefore, it was determined that another data collection effort would be needed; this project is summarized in this report. The objective of the study is to collect, organize, analyze, and summarize available detector data for the Santa Monica Freeway. The primary goal is to develop on/off ramp counts as input to a synthetic O/D model; mainline freeway counts will also be needed. Also, strategies for synthesizing data from stations where current detector data are unavailable are considered. Finally, plans for further investigations are examined.

Section 3 outlines the data collection process for the study, and Section 4 summarizes the results from the detector data analysis. Section 5 discusses plans for future study, including the simulation effort for the freeway corridor. The appendices contain technical details on the process, and a more complete presentation of the results.

Note that the freeway detector analysis was undertaken as a part of the research effort for the simulation of the Santa Monica Freeway corridor (often called the Smart Corridor). Separate efforts are underway to evaluate the effectiveness of IVHS strategies on the real-life Smart Corridor; the simulation project is a separate and independent research effort. Also, the data collection study is not intended as an evaluation of the effectiveness of the freeway detectors or an assessment of Caltrans policies.

Section 3: Process

This section outlines the data collection and extraction process. The steps that were undertaken to prepare the data for analysis are described.

A. Scope of Data Collection Effort

Flow and occupancy data are automatically collected by Caltrans for detectors throughout the Los Angeles area. For this study, detectors along the Santa Monica freeway (I-10) were targeted in an area from Centinela Avenue (west of the 1-405 interchange near Santa Monica) to Soto Street (east of the 1-5 interchange in southeast Los Angeles). Data were gathered for detectors on the eastbound and westbound lanes of the freeway, as well as for ramps, collector/distributor lanes, and interchanges with other freeways. Figure 1 places the study section within an overview map of the Los Angeles area.

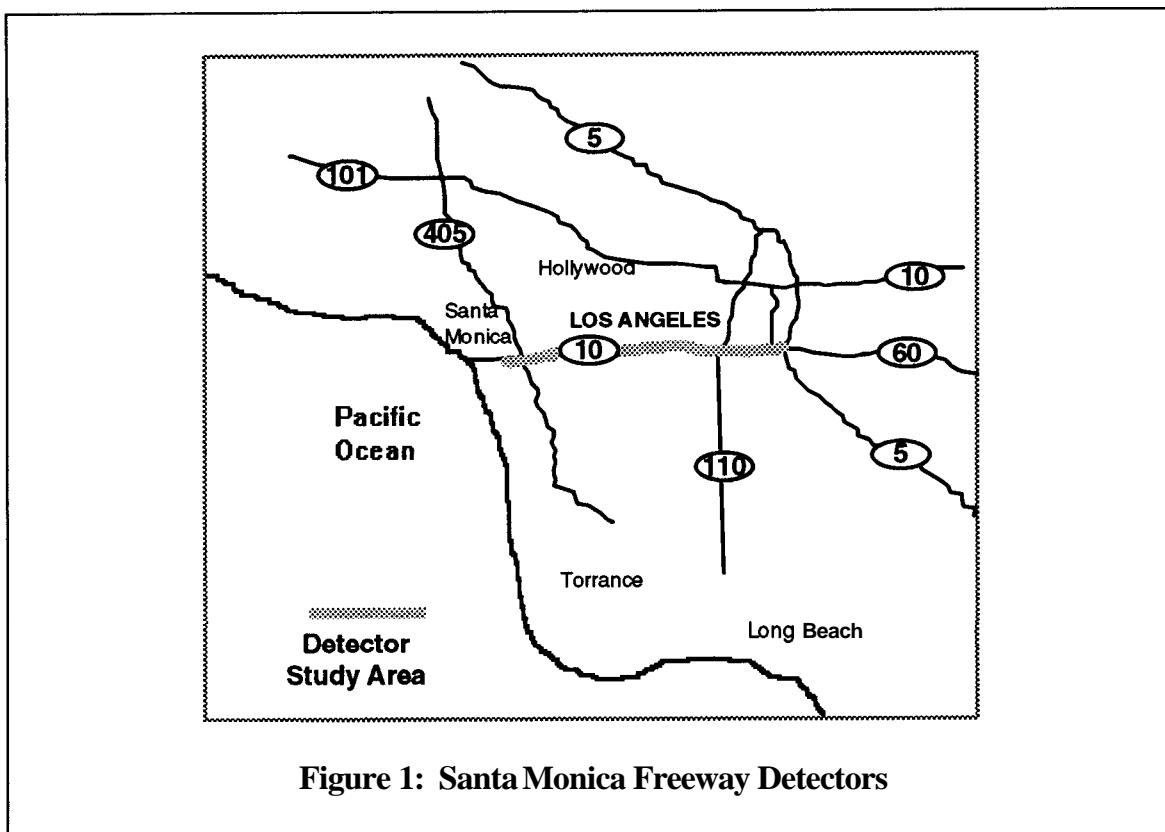


Figure 1: Santa Monica Freeway Detectors

For this project, detector data for three days (Tuesday May 25 through Thursday May 27, 1993) were targeted for collection. Data were needed during the 6:00 A.M. to 8:00 P.M. time period each day. During the study period the weather was clear and warm and no unusual events occurred.

B. Data Gathering at Caltrans

Data collection took place at Caltrans headquarters on May 26 and 27, 1993. The MODCOMP computer system at Caltrans was queried for reports on flow and occupancy for the freeway area of the study.

In the MODCOMP system, detectors are grouped by zones, with 5 to 10 detectors contained in most zones. These zones are generally located near odoff ramps on the freeway, and are often named for the odoff ramp nearby. Within each zone, there are usually 4 to 6 mainline freeway detectors, as well as a number of detectors for ramps (denoted as on, passage, demand, queue, HOV, and off), collector/distributor roads and ramps (CD1, CD2, CD on, and CD off), and opposite side detectors (alt1-alt6).

Users can query MODCOMP for information on detectors for a single zone, or for a range of zones along a single linear path (i.e., along a section of freeway). Also, it is possible to query the database for current flow and occupancy summaries, or for historical data up to 36 hours previous. These data can be summarized in groups of 30 seconds, 5 minutes (for historical or current data), or 15 minutes (for the current data only).

Using the system, the MODCOMP historical database was queried for 5 minute volume/occupancy counts by zone throughout the time range for each of the three days. The study section contained 41 detector zones on the eastbound section (from Centinela to Soto) and 30 detector zones on the westbound section (from St. Louis to Centinela). Because MODCOMP was limited to a maximum of 11 zones per page, it was necessary to print 4 pages for the eastbound section and 3 pages for the westbound section for each 5 minute time period. Figure 2 summarizes the output from the data collection effort in terms of the hardcopy produced. (A sample printout from MODCOMP is given in Appendix 1.)

Eastbound Detector Zones:	41
# of Pages/Time Period:	4
Westbound Detector Zones:	30
# of Pages/Time Period:	3
Total Pages/Time Period:	7
Time Periods/Hour:	12
Hours/Day:	14
# of Days:	3
Total Pages (7 x12 x14 x3):	3528

Figure 2: Output from MODCOMP

C. Data Entry at UC Berkeley

Managing the volume of data collected from the MODCOMP system was not a trivial task. Each of the 3528 pages of output averaged 35 non-zero entries for both volume and occupancy; approximately 250,000 numbers needed to be entered.

Several methodologies for data entry were considered. A first attempt involved entering the detector data directly into spreadsheets. However, the spreadsheets were organized by detector zone (as discussed in the next subsection) and the printouts were grouped by time. This was found to severely limit data entry speed because much page-turning was needed.

Therefore, it was decided to enter all of the data for a single page into a flat file and use a utility program to tabulate the data into a usable format (this process is described in detail in Appendix 1). A full-time data entry clerk was employed to create the flat files, and a short custom Pascal program was developed to convert the data to tabular form.

D. Data Organization

Once the data were available in an automated format, it was necessary to determine the most effective means of analysis. Since most of the data analysis performed for the study was done on a zone-by-zone basis, it decided to develop a spreadsheet for each detector zone that contained non-zero volume or occupancy data (44 of 71).

These spreadsheets contain detailed information on the detectors in each zone. All spreadsheets are formatted using a shell, so a large number of charts and graphs are generated simply by importing the tabular output from the conversion utility. For each detector, 5 minute volume and occupancy counts are stored by day and time. Then, these data are aggregated into 15 minute summaries (for volume) and 30 minute summaries (for volume and occupancy). Finally, two sets of graphs are provided: graphs of volume vs. occupancy for each detector (aggregated for all three days) and graphs of volume vs. time for each detector by day (i.e., separate graphs for Tuesday, Wednesday, and Thursday). Figure 3 (on the following page) shows excerpts from a sample spreadsheet; a complete detector zone spreadsheet is given in Appendix 1. Spreadsheets for each zone in the study can be found in Appendix 2 (unpublished, but available from the authors).

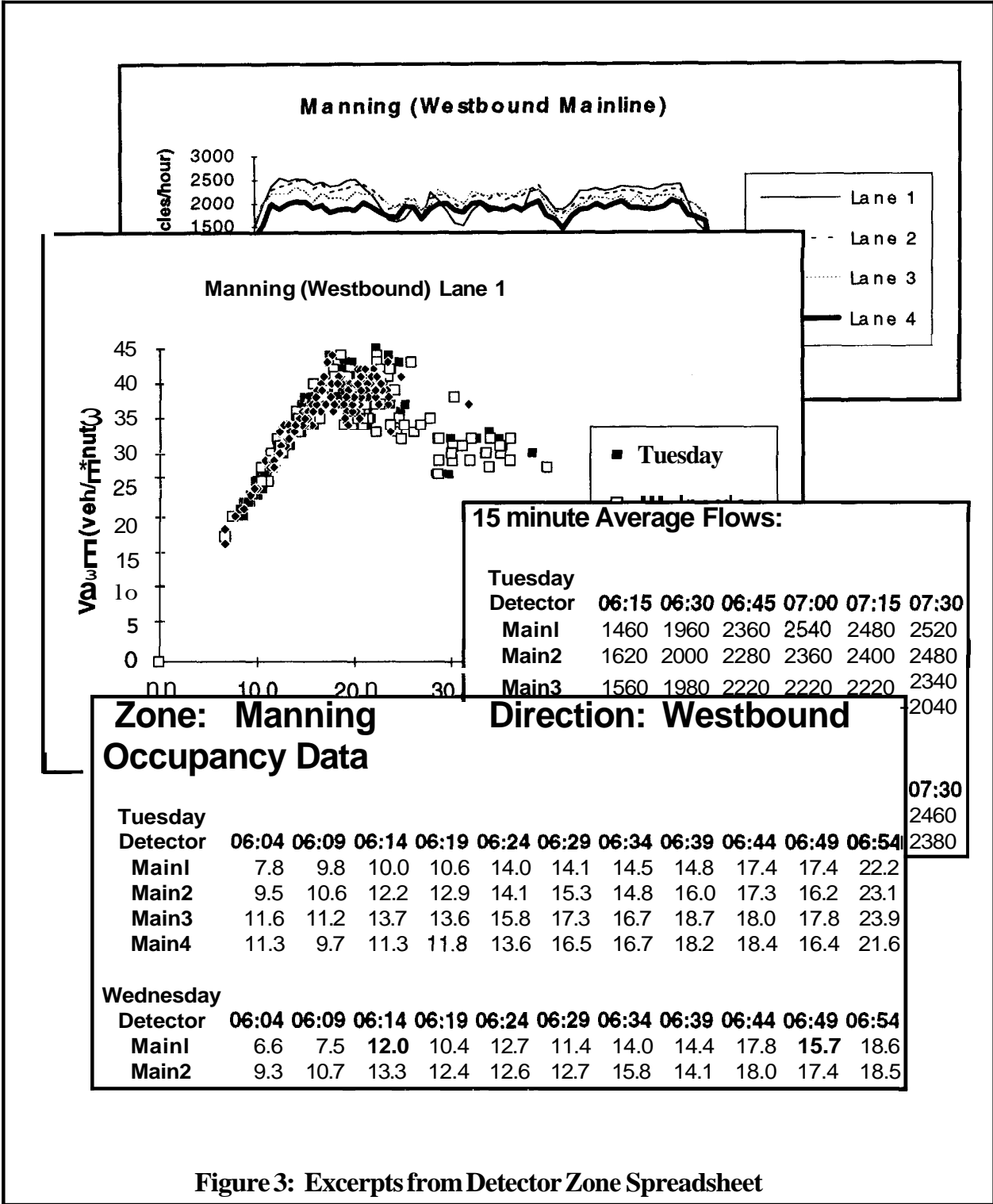


Figure 3: Excerpts from Detector Zone Spreadsheet

Section 4: Results

This section outlines the results of the analysis of the Santa Monica Freeway detector data. A general assessment of the data integrity is made, and then several studies of specific data (e.g., volumes and occupancies) are presented. Discussions of the data are given in terms of individual zones, and breakdowns are provided for mainline freeway, ramp, and other detector data types.

A. Overall Assessment of Detector Data

The spreadsheets and graphs described in the previous section were appraised to determine which zones (and which specific detectors within these zones) were returning data that were useful to the simulation development effort. Figures 4 and 5 present the results of this analysis. (Figure 4 is for the eastbound detectors and Figure 5 is for the westbound detectors).

The first two columns in each table list the name of the detector zone and its location along the Santa Monica Freeway. (Note that the milepost marking scheme becomes irregular at the interchange of the 1-5, but the detector zones are presented along a roughly linear path.) The other four columns specify detectors providing "reasonable" (defined below) data for each of four general categories: mainline freeway detectors, on-ramp detectors, off-ramp detectors, and connector/distributor lane detectors.

In general, an entry in a cell indicates that there is some detector information available for the location. The mainline freeway column lists the number of working detectors and the total possible number of working detectors; in some cases only some of the mainline detectors are providing data. The blank cells indicate detectors that are not functioning or do not exist; data are not available in either case. Shaded cells indicate where a ramp, C/D lane or mainline detector zone does not exist; a key is given on page 10.

The on-ramp and off-ramp columns show where at least one ramp detector is returning data. Some of the locations do not have either an on-ramp or an off-ramp; these are shaded on the figures. A "✓" in a cell indicates there is ramp data available; a blank cell indicates the ramp is present but no detector data is available. Several other points should be noted about the ramp data:

- In some cases, the number of ramps at a particular zone is somewhat arbitrary. Some ramps have no detectors and are located between two zone mileposts. These ramps were counted as part of the nearest zone. However, the critical issue is that all ramps with the study section were counted.
- Several locations have more than one ramp. This generally occurs where there are separate on- and off- ramps for northbound and southbound traffic. However, in no case is there ever more than one ramp in a zone with detector data.

EASTBOUND					
Location		Available Data			
Zone	Mile	Mainline Freeway	On Ramp	Off Ramp	C/D Lanes
Centinela	3.93				
Pico	4.37				
Bundy	4.77				
Westwood	6.15				
Overland	6.50	4/4	✓		
Motor	6.73	5/5			
Manning	7.22	5/5	✓		
Robertson	7.82				
National	7.99	5/5	✓		
Cattarauga	8.36				
La Cienega	8.73		✓		
Venice	9.01	4/4	✓	✓	1
Fairfax	9.21	5/5			
Washington	9.51	3/5	✓		
Hauser	9.80				
La Brea 1	10.23	4/4	✓		1
La Brea 2	10.53	4/4	✓	✓	
Harcourt	10.70	2/4			
West	11.06	4/4			
Crenshaw	11.53	5/5	✓		
Arlington 1	12.23	4/5			
Arlington 2	12.45				
Gramercy	12.58	4/4			1
Western 2	12.95	3/5	✓		1
Normandie 2	13.44				
Budlong	13.53	3/3			
Vermont 1	13.95	5/5	✓	✓*	2
Hoover	14.12				
East of 110	14.81				
Flower	15.33		✓		
Los Angeles	15.78		✓		
San Pedro	16.21		✓		
Central	16.84				
Alameda	17.09				
Olympic	17.40	2/4			
West of 5	17.78				
East of Macy	0.18				
Echandia	0.52				
State	18.53	3/3	✓		
St. Louis	18.75	4/4			1
Soto	19.03				

Figure 4: Availability of Detector Data (Eastbound Zones)

WESTBOUND					
Location		Available Data			
Zone	Mile	Mainline Freeway	On Ramp	Off Ramp	C/D Lanes
St. Louis	18.75	4/4			
State	18.53	3/3			
Bus Station	18.50			✓	1
Echandia	0.52				
East of Macy	0.18	3/3			
Oak	14.74				
Hoover	14.12				
Vermont 1	13.66		✓	✓*	2
Budlong	13.53	4/4			
Normandie 1	13.21	4/4	✓		2
Western 2	12.95	4/4			1*
Western 1	12.70		✓		
Gramercy	12.58	2/4			1*
Arlington	12.23	5/5	✓		
Crenshaw	11.53	5/5			
West	11.06	4/5	✓*		
Harcourt	10.70				
La Brea 2	10.53	4/4	✓	✓	1
La Brea 1	10.24				
Hauser	9.80				
Fairfax	9.21	4/4	✓	✓	
La Cienaga	8.75				
Cattarauga	8.36				
Robertson	7.81				
Manning	7.22	4/4			
Motor	6.73	3/4			
Westwood	6.15				
Bundy	4.77				
Pico	4.37				
Centinela	3.93				

key:	x/y	mainline detectors returning data/total
		no mainline detector data available
		no mainline detectors at this location
	✓	ramp data available
		no ramp data available
	*	no ramp or C/D at this location
		alternate side detector

Figure 5: Availability of Detector Data (Westbound Zones)

- The section of the freeway east of the 110 has not been precisely defined in this research. There were not any detailed maps available to reference for this section; commercial maps were used.
- For the purposes of synthetic origin/destination generation, data for the mainline flows in and out of the study section are critical. These are not explicitly listed as either ramps or mainline data, but there are not a great deal of data for the endpoints of the freeway section.

The C/D lanes are described in a similar fashion. The number of detectors returning data are listed in the last column. The shaded cells indicate where no C/D lanes are present.

Occasionally, detectors for a particular zone are grouped within another zone (usually on the opposite side of the freeway). These are denoted as alternate lane detectors (i.e., alt1, alt2, etc.) For example, the on-ramp detector at the eastbound Vermont 1 zone is stored as the "alt1" detector for the *westbound* Vermont 1 zone. Caltrans uses this procedure to simplify the communications requirements for its detectors. On Figures 4 and 5, these detectors are denoted with an asterisk (*).

The definition of "reasonable" is somewhat arbitrary, but a fairly liberal working standard was used. Three different types of data were returned from each freeway detector. Many detectors returned nothing (denoted as "--" on the printouts). Most of these detectors have been nonfunctional for some time (mostly due to communications failures) or simply do not exist. Many detectors returned positive flow and occupancy values; these are the working detectors. A smaller percentage of the detectors returned zero values for flow and occupancy.

For mainline detectors, it was fairly straightforward to determine which were functional: all detectors either returned volumes within typical freeway ranges (i.e., 1000-2500 vehicles/hour) or returned nothing. A few mainline detectors would occasionally "go out" (i.e., start returning nothing) for short periods and then resume functioning. These detectors were also counted as working. In general the mainline detectors were consistent and straightforward to classify.

The ramp and other detectors were more difficult to assess. Since this group of detectors included many different types of roadways (i.e., ramps, C/D lanes, and freeway connectors) it was not possible to specify a range of volume values that would be acceptable. However, it was possible to subjectively assess which detectors were giving workable data: values in a discrete range with some randomness and variation by time of day. These detectors were considered to return good data.

Another issue was that many of the ramp detectors returned reasonable results for a few hours and then went out or returned bad data for a period of time. However, even partial

ramp data will be useful for the simulation development, so detectors that gave good results for part of the study period were classified as reasonable.

All of these data can be analyzed subjectively by scanning the columns for numbers and empty cells. For non-shaded cells, numbers indicate available data and blank cells indicate where detector data are needed. In terms of the simulation effort, this is especially critical for the ramps.

B. Availability of Data for Simulation

For the simulation project, it was important to consider that the key issue was not the number of detectors that were providing data, but rather whether or not required data are available. Three general categories of data are critical to the simulation effort: selected mainline volume/occupancy counts, on-ramp counts, and off-ramp counts. Each is discussed below in some detail.

- **Mainline data.** For the mainline Santa Monica Freeway, it may not be essential to obtain data from every detector station. It was thought sufficient to have detector data from one station west of the 405, three or four stations between the 405 and the 110, one or two stations between the 110 and the 5, and one station east of the 5. Data are needed for mainline stations in both directions; they need not necessarily be the same zone.

In terms of the data from the detectors in this study, the freeway section with the most working detectors is the area between the 405 and the 110. The section east of the 5 also has enough detector data for the simulation project. However, the available detector data is spotty in a few areas: The section west of the 405 is currently under construction, so detectors on that section of the freeway are not functioning. No detectors are installed on the westbound section between the 5 and the 110; detectors may be installed there in the near future. The detectors on the eastbound side of that sections are problematic; magnetic detectors are used which may be affected by the steel road structure.

Overall, there were somewhat more mainline detector datasets available in May, 1993 (compared to the preliminary study in December). There were 110 available mainline detectors in December 1992; by May 1993 there were 128 available.

Caltrans is aware that many of the detectors **do** not return data. Most of these detectors have not been functional for some time, so a discussion of the number of working vs. non-working detectors may not be appropriate. Therefore, this paper will focus on those detectors that are returning useful data. However, the simulation project still must consider sources of mainline data for those sections where detector data are unavailable.

- **On-ramp data.** For an accurate synthesis of origin/destination data, it will be critical to have data from each on-ramp along the freeway section. In general, Caltrans uses multiple detectors on a single ramp (this is discussed in some detail later in this section), but it may be sufficient to have data from one detector only. However, there are not detector data available for some on-ramps in the study area. Overall, 7 of 18 on-ramps have detectors that returned data on the westbound section. For the eastbound section, data were available for 14 of 23 on-ramps.

Another critical issue are the connectors to the major freeways (1405, I1 10, and 15). No detector data were found for the on-ramps from these freeways (although some of the alternate side detectors were not identified; these may be connector detectors).

- **Off-ramp data.** Again, counts for vehicles leaving the freeway **will be** essential to the simulation effort. Most of the ramp data in this study are from on-ramps; limited data are available for the off-ramps. Only **4** of 21 off-ramps (westbound) and 3 of 20 (eastbound) have detectors that returned data in this study. Also, detector data for the off-ramps connectors to other freeways were not available.

These results can be summarized in a number of ways. Figure 6 lists data that are needed for simulation, and describes what are available from the detector study. The first two columns describe the type of data that are required (these might come from detectors or other sources). *Also*, the number of stations desired and available are listed, and the last column is an indication if the detector data alone will be sufficient.

Description	Direction	Total Needed	Total Available	OK?
Mainline Counts West of I-405	eastbound	1-2	0	
	westbound	1-2	0	
Mainline Counts Between I-405 and I-1 10	eastbound	4-5	16	✓
	westbound	4-5	11	J
Mainline Counts Between I-1 10 and I-5	eastbound	2-3	1	
	westbound	2-3	0	
Mainline Counts East of I-5	eastbound	1-2	2	✓
	westbound	1-2	2	✓
Freeway Connectors to/from I-405	both	6	0	
Freeway Connectors to/from I-1 10	both	8	0	
Freeway Connectors to/from I-5	both	6	0	
On-Ramp Counts	eastbound	23	14	
	westbound	18	7	
Off-Ramp Counts	eastbound	20	3	
	westbound	21	4	

Figure 6: Data Availability Summary

The map presented in Figure 7 (on the next page) also summarizes the results of Figures 4 and 5. Mainline locations where detector data are available are indicated with a dark circle. All ramps are shown as slanted lines; those with available detector data are in black. The major connecting freeways (1-405, I-110, and 1-5) are shown in their approximate locations; no known data are available for connectors to these freeways. The names of the zones (e.g., Centinela, Pico, Bundy) are also shown by their approximate location. (Note there are some intentional errors in scale to improve the clarity of the map).

Note that other sources of data are available, but none have been available that are as detailed as the detector data. For example, Caltrans has provided hourly volume counts for most of the ramps on the Santa Monica Freeway. For most of these ramps, three days of hourly volume counts are listed by locations. These data are mostly from 1989 (a few are from 1990-1992). They also sent mainline volume data (again aggregated by hour) for Centinela, Overland, La Brea, and the 1-405 interchange. The simulation team will continue to investigate these and other potential sources of data.

Santa Monica Freeway Detectors

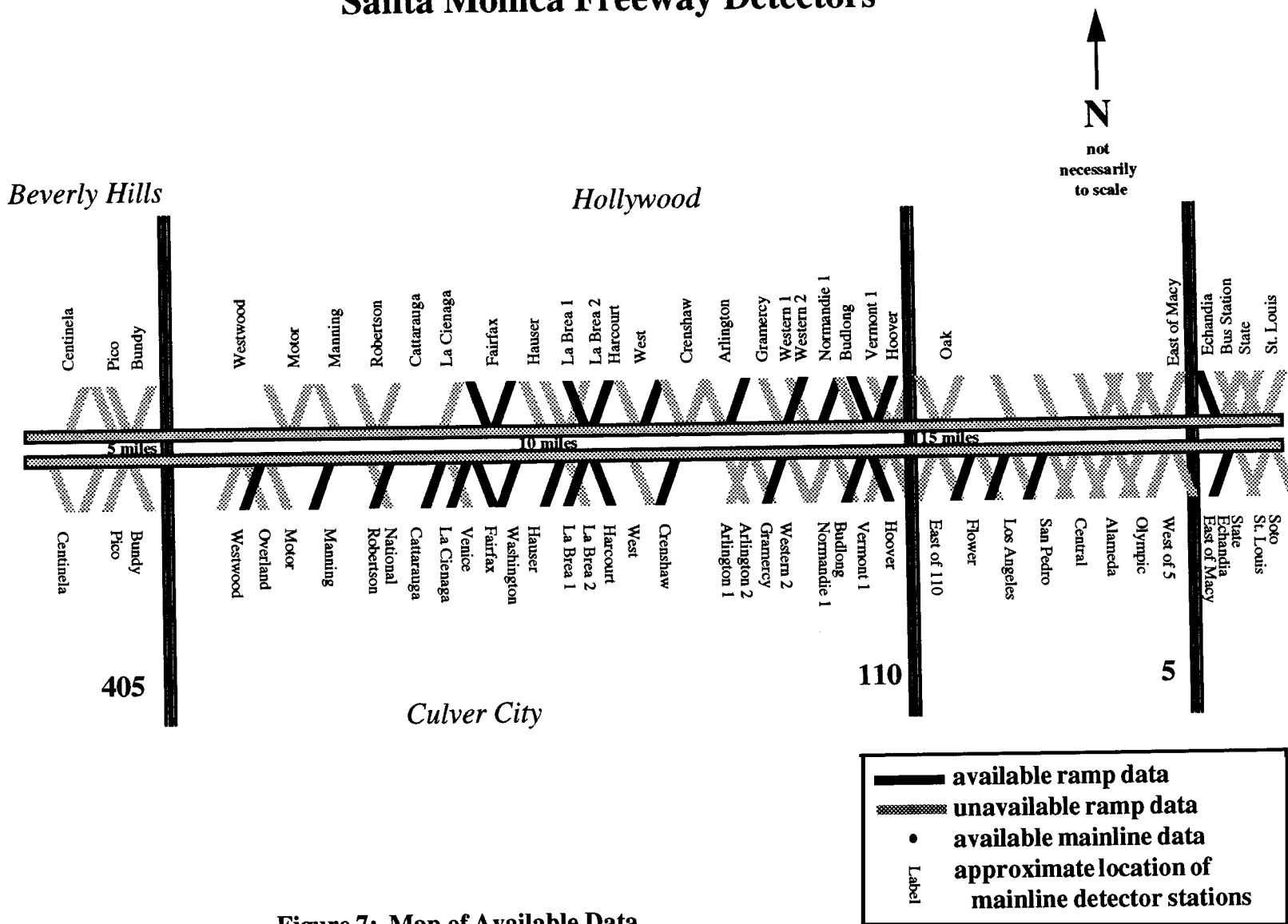


Figure 7: Map of Available Data

C. Mainline Flow and Occupancy Data

The next step in the study was a more detailed analysis of specific detectors. **As** discussed earlier, the overall assessment of the detector quality was based on an appraisal using the graphs from the spreadsheets. While this methodology is useful for general studies of large datasets, it was thought appropriate to consider individual detectors in more detail. This section describes analysis of mainline data for individual detectors. Also, it was interesting to consider congestion patterns on the freeway throughout the study period; this is also presented here.

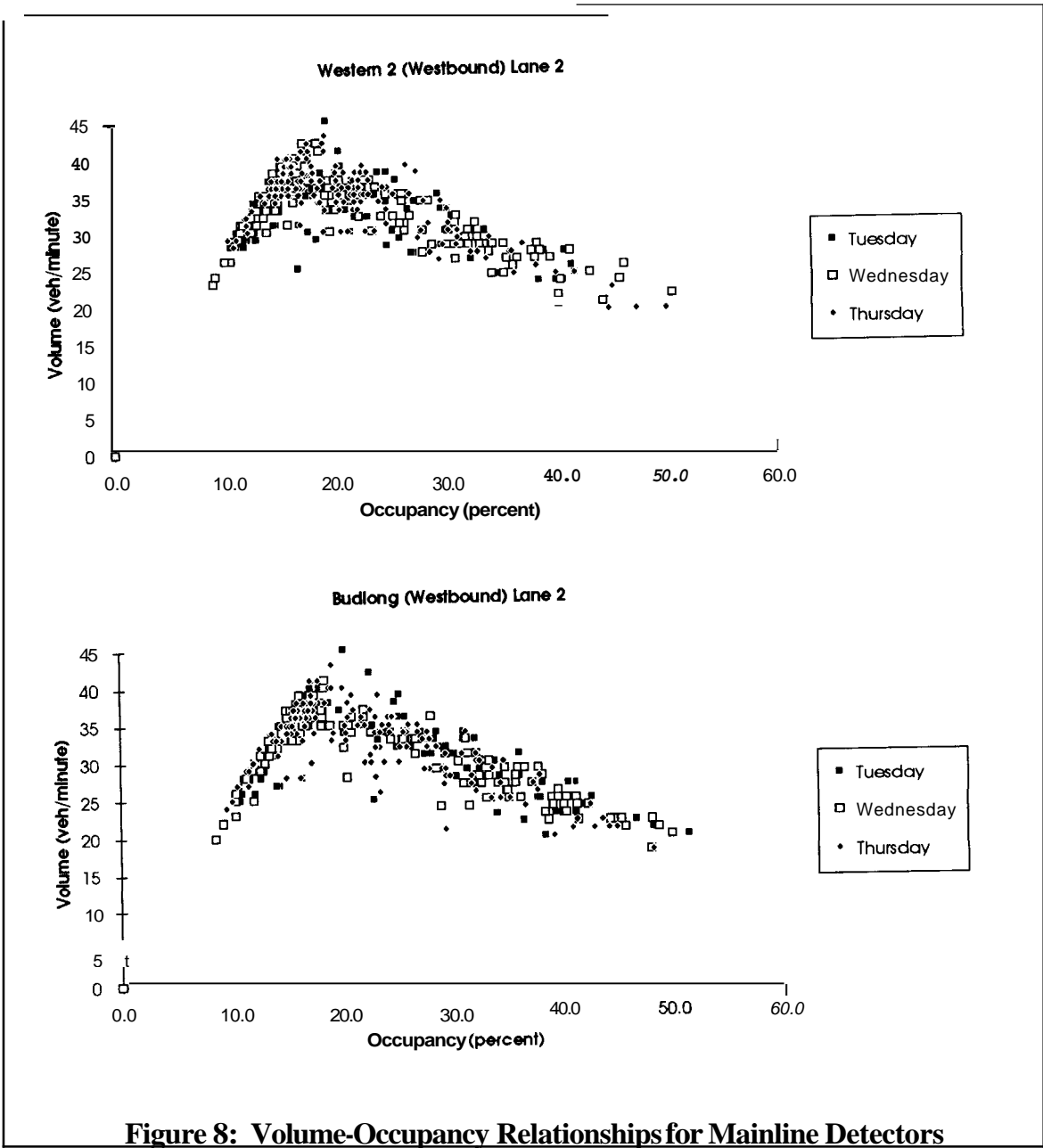
Figure 8 shows graphs of volume and occupancy for two selected mainline detectors (Western 2 and Budlong). Data are given for five minute observation periods throughout the three day study period. The parabolic shape of the scatter plot was common to many of the detectors in the study. The highest volumes (2400-2500 vehicles per hour) were found at occupancies of 18-20%. At lower occupancies, there is a roughly linear (increasing) relationship between density and volume. Above this occupancy, volume drops off as congestion begins.

These empirical relationships follow what is predicted by theory. The point at which the volume (i.e., flow) begins to decrease is the capacity of the roadway. Once the demand exceeds this capacity, occupancies increase but the road cannot handle the additional traffic. Therefore, the volumes must decrease. For densities below capacity, the (nearly) linear relationship between volume and occupancy suggests that up to a given flow (the capacity of the roadway), additional vehicles can join the traffic flow and maintain (nearly) the same speed. This speed is (nearly) the free flow speed of the roadway; it is derived in the discussion below.

The data presented in Figure 8 shows the linearity of the relationship when occupancies are less than 20%. However, the two detectors in the example measured above-capacity traffic for much of the study period. **An** example of an relatively uncongested detector is the westbound St. Louis detector shown in Figure 9.

The best fit line was derived using the least squares method of linear regression. The line has a slope of 2.01/minute and an intercept of 2.08 vehicles/minute. To convert the slope to units with speed it is necessary to convert occupancy into a density equivalent. Dividing occupancy by the average length of a vehicle (assuming there is independence between vehicle length and speed) gives density. For example, a 10% occupancy corresponds to density of 21.1 vehicles/mile, assuming a 25 foot vehicle length:

$$10\% \text{ vehicles} \cdot \frac{1}{100\%} \cdot \frac{1}{25 \text{ feet}} \cdot \frac{5280 \text{ feet}}{\text{mile}} = 21.1 \frac{\text{vehicles}}{\text{mile}}$$



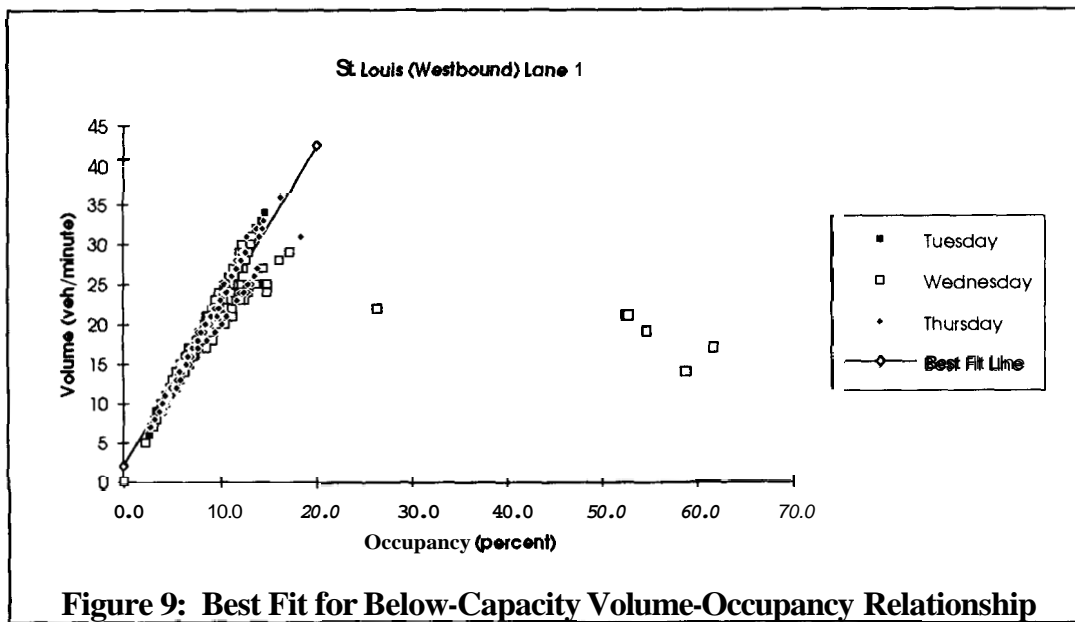


Figure 9: Best Fit for Below-Capacity Volume-Occupancy Relationship

The slope of the best fit line (2.01/minute) can be converted to a speed value by multiplying by vehicle length (since slope is calculated by dividing by occupancy). Therefore, the slope of the linear regression line is 2.011 feet-%/minute (where 1 is vehicle length), or 2.281 mph. If a vehicle length of 25 feet is assumed, then the speed of the best fit line is about 58 mph. This appears to be a reasonable estimate for free flow speed on the freeway.

Graphs of traffic volume over time were also studied. Figure 10 is an example of such a graph for the Fairfax (westbound) mainline lanes on Wednesday. Volume data were aggregated in fifteen minute time slices and graphed versus time. From the graph, there appears to be good correlation between the volume data for the four detectors; the lane 4 detector has lower volumes since it is the right-hand lane. Volume drops off during the morning rush hour (when the freeway was congested) and then rises to a fairly steady volume of 1500-2000 vehicles per hour during the day. The sharp drop in volume at the end occurs because no detector data were returned for the last ten minutes of the day. The graph in Figure 10 is typical of many of the mainline detectors; similar analysis can be performed for other zones.

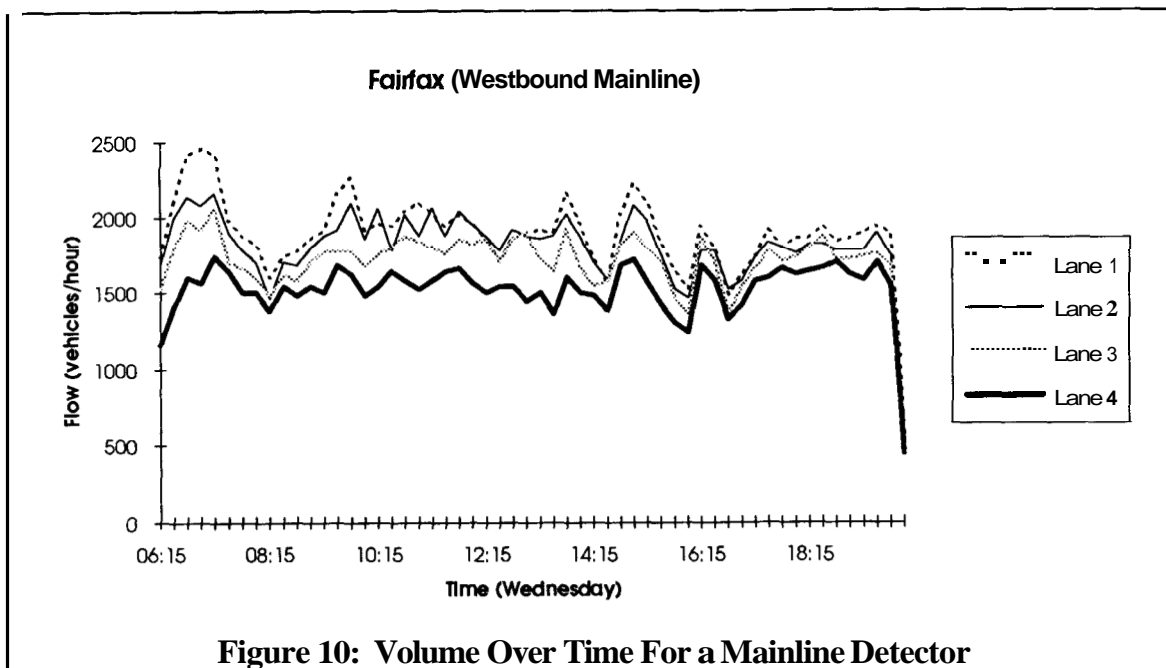


Figure 10: Volume Over Time For a Mainline Detector

Another analysis that was made from the data was a study of the congestion patterns for the freeway section. Figures 11 and 12 (on the following pages) present occupancy contour maps for the study section (eastbound and westbound) on the three days of the study (Tuesday-Thursday). The locations at the top are the zones, scaled to their relative locations on the freeway. The numbers on the graph represent percent occupancy. Values between 20 and 30% are lightly shaded; occupancies above 30% are darkly shaded. These shaded areas show areas of congestion.

Unfortunately, it is not possible to see all of the details (since some detector data is not available), but the figures do give a general sense of the congestion patterns for the freeway during the study period.

For the eastbound section periods of heavy congestion were found during the rush hours (from about 7:30 to 9:00 A.M. and 3:30 to 6:00 P.M.). There was also heavy traffic near the 110 interchange in the afternoon. These are not surprising results. For the westbound section, the heaviest congestion occurs between 7 A.M. and 9 P.M. and 4 P.M. and 7 P.M. Expectedly, the congestion is centered further west in the morning (closer to the civic center), while the afternoon congestion is somewhat heaviest in the eastern section of the freeway. From the occupancy contour map, there are not any obvious major incidents (these might be indicated with a definite line of heavy density). During the study period, the data collection team monitored incidents on the Los Angeles freeway system using Caltrans' FreewayVision system. No major incidents were observed; this agrees with the data in Figures 11 and 12.

D Data July, 1993

Direction of Traffic: ↕ (Numbers indicate % occupancy)

Time	Centinelia	Pico	Bundy	Westwood	Overland	Mohor	Manning	Robertson	National	Catharaugus	La Cienega	Venice	Fairfax	Washington	Hauser	La Brea 1	La Brea 2	Harcourt	West	Crenshaw	Arlington 1	Arlington 2	Gramercy	Western 2	Normandie 2	Budlong	Vernon 1	Hoover	East of 110	Flower	Los Angeles	San Pedro	Central	Alameda	Olympic	West of 5	St. Louis State	Solo									
Tuesday																																															
6:30					12	4	6	5			6	4	6	1	9	9	8	8	8	8	8	8	9	8	9	1	0		10	6									2	2							
7:00					18	10	10	11			13	10	13	16	14	16	16	16	16	16	15	14	14	15	20		14	11											2	3							
7:30					23	14	13	16			23	16	24	35	23	26	27	24	21	23	28	23	28	29	45		13	11											3	3							
8:00					21	12	13	35			38	22	34	38	32	30	33	29	26	32	39	30	45	30	45		15	12												4	5						
8:30					24	18	30	37			38	22	35	47	27	25	28	24	22	26	31	29	40	29	40		13	11													4	5					
9:00					28	18	27	34			33	21	30	39	26	26	26	24	21	28	32	32	47	32	47		12	10													3	4					
9:30					21	11	13	21			33	21	32	28	25	26	24	20	19	26	23	27	40	27	40		12	10													4	4					
10:00					21	12	13	12			14	11	16	18	16	17	17	17	15	17	16	26	31	26	31		12	9													4	5					
10:30					20	10	13	11			12	9	12	18	15	14	14	14	13	15	14	0	14	0	14		13	9													4	4					
11:00					20	10	12	10			12	9	12	18	14	14	14	14	13	15	13	0	13	0	13		15	9													5	5					
11:30					22	10	12	11			12	9	12	17	14	15	15	15	14	16	13	0	13	0	13		17	10														5	6				
12:00					21	10	13	10			12	8	12	12	15	15	15	15	14	16	14	14	14	14	14		16	11														6	6				
12:30					21	10	13	10			11	8	11	14	14	14	14	14	14	13	17	19	17	13	17	13		16	10														6	7			
13:00					20	10	12	11			12	9	12	17	14	14	14	14	14	14	16	13	14	13	14	13		18	11														6	7			
13:30					21	10	13	11			12	9	12	20	15	14	14	15	13	15	13	14	13	14	13		18	11															7	7			
14:00					22	12	13	12			13	10	13	15	15	15	18	16	16	15	16	14	15	13	15	13		19	12															7	8		
14:30					23	12	14	14			15	11	15	35	16	17	18	17	16	17	15	16	16	16	16		19	13																8	9		
15:00					23	13	14	14			21	14	21	24	22	18	18	17	15	17	14	17	18	17	18		25	19																10	11		
15:30					24	13	14	18			31	22	28	32	22	19	20	20	22	17	14	14	19	14	19		26	20																	10	11	
16:00					25	15	15	27			31	21	30	42	20	17	22	20	14	17	21	15	27	15	27		27	19																	11	12	
16:30					22	12	13	19			32	21	29	31	23	21	17	16	14	16	13	16	33	16	33		30	20																	10	12	
17:00					22	12	13	23			30	22	28	20	19	19	17	16	15	17	13	0	15	0	15		31	20																	10	11	
17:30					24	14	14	20			30	21	26	14	19	19	17	16	15	16	12	4	16	4	16		32	20																	11	12	
18:00					22	13	13	22			28	20	27	32	21	19	17	16	14	17	13	0	32	0	32		31	20																	12	13	
18:30					22	12	13	14			26	19	27	37	20	19	16	16	14	16	13	0	34	0	34		32	21																	10	11	
19:00					21	11	12	12			16	13	16	13	17	18	17	17	16	20	21	0	49	0	49		21	18																	10	10	
19:30					19	9	10	8			11	8	11	14	13	13	13	13	12	13	12	0	46	0	46		14	10																	8	9	
20:00					1	1	5	6			6	4	6	7	7	7	7	7	7	7	6	7	6	0	9		9	6																	5	6	

Figure 11: Congestion Patterns (Eastbound)

Direction of Traffic: ↕ (Numbers indicate % occupancy)

Time	Centinela	Pico	Bundy	Westwood	Overland	Mokor	Manning	Robertson	National	Catarraug	La Cienaga	Venice	Fairfax	Washington	Hansen	La Brea 1	La Brea 2	Harcourt	West	Crenshaw	Arlington 1	Arlington 2	Gramercy	Western 2	Normandie 2	Budlong	Vermont 1	Hoover	East of 110	Flower	Los Angeles	San Pedro	Central	Alameda	Olympic	West of 5	St. Louis State	Soto									
Wednesday																																															
6:30				12	4	6	4					6	4	6			8	8	7	8	8	8	10	9		9		9	6										2	2							
7:00				18	17	9	8					13	9	12			16	14	15	15	16	15	15	14		18		13	11											2	3						
7:30				20	56	11	47					23	17	23			32	23	24	22	20	21	18	18		38		12	10											3	4						
8:00				19	13	11	12					41	25	39			38	31	30	31	20	26	29	36		47		14	11												4	4					
8:30				21	14	15	29					41	22	37			43	30	31	31	25	23	28	33		46		13	10													4	5				
9:00				1	9	2	3	28	35			38	23	35			32	26	27	27	19	21	22	23		45		12	9													3	4				
9:30				22	16	13	18					30	20	29			17	24	21	21	20	21	23	23		44		12	9													3	3				
10:00				21	14	11	12					19	16	22			26	23	22	21	23	22	22	20		37		13	9														4	4			
10:30				17	12	10	11					11	9	12			39	19	22	26	24	25	16	13		13		14	8														4	4			
11:00				13	13	11	11					11	8	12			15	15	16	15	15	15	16	14		14		15	9														5	5			
11:30				11	9	13	7					12	9	12			25	11	14	15	12	14	15	13		14		16	9														6	7			
12:00				38	11	6	13					12	9	12			27	15	16	15	15	14	15	13		14		17	10															6	6		
12:30				9	10	13	12					12	8	12			18	15	15	15	15	14	15	13		14		18	11															6	7		
13:00				7	11	19	10					12	9	12			19	15	15	15	16	14	16	13		14		18	10															6	7		
13:30				9	11	22	11					12	9	12			18	15	15	15	15	14	15	14		14		19	11															6	7		
14:00				10	26	18	12					13	10	13			52	16	17	16	16	15	16	14		14		22	12														7	8			
14:30				13	7	28	10					14	11	15			36	16	17	17	17	16	16	14		15		24	16															9	10		
15:00				14	8	33	11					21	14	21			39	22	4	19	17	7	18	14		27		30	20															11	12		
15:30				22	21	22	16					31	22	28			33	23	19	20	20	21	24	23		38		30	15															10	11		
16:00				32	37	22	23					83	21	30			43	20	17	23	20	14	20	17		37		34	21															10	11		
16:30				32	35	18	22					30	21	30			20	19	19	17	16	17	18	13		28		34	20															9	10		
17:00				29	21	25	12					32	20	28			34	21	21	18	16	14	17	13		15		32	20															11	12		
17:30				28	29	36	20					32	23	29			20	19	18	18	16	14	17	12		29		34	22																12	13	
18:00				16	16	26	14					30	20	25			20	18	18	17	16	15	18	13		43		34	21																12	13	
18:30				29	44	14	32					27	20	28			23	18	18	17	17	15	16	15		42		36	26															11	12		
19:00				21	13	9	11					25	17	23			20	22	19	17	19	7	27	25		48		25	18															10	11		
19:30				11	12	10	18					12	9	12			34	14	15	16	19	27	28	26		48		14	11																7	8	
20:00				4	5	5	5					6	4	6			15	8	7	7	7	7	8	9		22		10	7																4	5	

Figure 11: Congestion Patterns (Eastbound)

Direction of Traffic: ↕ (Numbers indicate % occupancy)

Time	Centinela	Pico	Bundy	Westwood	Overland	Motor	Manning	Robertson	National	Catarraugus	La Cienega	Venice	Fairfax	Washington	Hausert	La Brea 1	La Brea 2	Harcourt	West	Orenshaw	Arlington 1	Arlington 2	Gramercy	Western 2	Normandie 2	Budlong	Vermont 1	Hoover	East of 110	Flower	Los Angeles	San Pedro	Central	Alameda	Olympic	West of 5	St. Louis State	Soto				
Thursday																																										
6:30					1	2	4	6	5			6	4	6			8	8	8	8	8	8	9	8		9		10		7									2	2		
7:00					19	10	10		12			13	10	13			17	14	15	16	16	15	15	14		17		14		11									2	3		
7:30					23	13	13		15			24	16	24			25	20	20	21	20	18	19	17		40		13		11									3	4		
8:00					20	11	12		22			36	22	34			40	30	29	32	27	26	32	36		43		15		12									4	5		
8:30					20	11	14		39			41	24	37			53	28	29	27	22	21	25	30		37		14		11									4	4		
9:00					21	11	17		30			32	21	31			41	25	23	22	21	22	27	28		46		13		10									4	4		
9:30					21	12	12		12			24	15	25			33	20	20	18	17	18	23	20		43		13		9									3	4		
10:00					21	11	12		12			13	10	13			22	15	16	16	16	16	20	16		29		14		10									4	4		
10:30					20	10	12		11			12	9	12			13	14	14	14	15	13	15	13		13		14		9									5	5		
11:00					22	11	12		11			12	9	12			17	15	16	16	15	14	14	13		14		15		9									4	5		
11:30					21	11	12		16			12	9	12			27	15	15	15	15	14	15	13		13		16		10									5	6		
12:00					22	11	12		19			12	9	13			16	15	15	17	16	15	16	14		15		16		10									6	7		
12:30					22	11	13		11			12	9	12			28	15	15	15	15	14	16	14		14		18		11									6	7		
13:00					21	10	12		11			12	11	12			20	15	15	15	16	15	17	13		14		20		11									7	7		
13:30					21	10	13		20			12	9	13			22	16	5	16	16	5	16	14		14		20		12									7	8		
14:00					20	11	11		2			12	9	12			16	15	15	16	16	15	16	14		13		20		12									7	8		
14:30					22	12	13		13			15	11	15			21	17	18	15	18	15	16	19		14		23		13									9	10		
15:00					22	12	13		13			20	14	22			56	23	21	18	18	18	20	16		21		31		19									10	11		
15:30					24	14	17		23			33	22	30			70	23	21	17	17	15	17	14		30		35		19									9	11		
16:00					22	14	23		30			32	22	28			36	22	22	18	17	16	17	14		35		36		19									10	11		
16:30					22	12	14		33			31	21	29			33	21	21	20	18	15	17	13		22		36		20									10	12		
17:00					23	14	26		29			34	21	32			39	21	19	17	16	13	17	12		14		40		18									11	13		
17:30					23	17	28		29			31	21	28			33	19	20	17	16	14	16	12		21		40		20									12	14		
18:00					27	23	28		30			31	21	30			33	22	19	17	16	15	17	13		42		40		19									11	13		
18:30					21	12	13		18			24	18	24			22	19	19	17	16	16	18	13		36		37		19									11	11		
19:00					19	11	11		11			12	10	13			23	16	15	15	14	13	14	12		23		34		21									10	11		
19:30					19	10	11		10			11	8	11			11	13	13	13	13	13	13	12		12		20		12									9	9		
20:00					17	8	10		9			9	7	9			35	11	11	11	11	11	10	11		11		15		9									7	7		

Figure 11: Congestion Patterns (Eastbound)

Direction of Traffic: ↵ (Numbers indicate % occupancy)

Time	St. Louis	State	Bus Station	Oak	Hoover	Vermont 1	Budlong	Normandie	Western 2	Western 1	Gramercy	Arlington	Orenshaw	West	Harcourt	La Brea 2	La Brea 1	Hauser	La Cienega	Fairfax	Cattaraugus	Robertson	Manning	Motom	Westwood	Bundy	Pico	Centinela
Tuesday																												
6:30	11	10					14	25	14	15	14	14	14	14	15				14				11	10				
7:00	13	12					17	30	17	19	17	16	19	20					19				18	17				
7:30	12	11					24	34	25	26	24	23	28	25					21				19	19				
8:00	11	10					31	42	30	31	29	39	35	30					30				22	20				
8:30	11	10					11	25	20	26	31	39	39	31					29				22	20				
9:00	11	10					12	22	15	24	26	30	33	32					28				22	20				
9:30	9	9					12	23	14	20	19	23	27	25					21				20	19				
10:00	8	8					13	24	13	17	14	14	15	18					14				14	14				
10:30	7	7					17	23	13	15	14	12	11	15					11				11	11				
11:00	8	7					15	26	15	19	17	14	14	17					13				12	12				
11:30	7	7					13	24	14	18	13	13	13	17					12				19	18				
12:00	6	6					13	24	13	17	13	13	13	17					13				14	13				
12:30	5	5					37	21	11	13	10	11	10	14					10				10	10				
13:00	6	5					20	30	18	19	16	14	14	18					14				13	13				
13:30	6	6					11	21	12	17	13	13	13	17					12				12	13				
14:00	6	5					14	25	13	16	14	13	13	16					13				13	13				
14:30	5	5					16	27	15	17	13	14	15	17					14				14	14				
15:00	6	6					16	27	15	17	14	15	15	17					16				19	16				
15:30	5	5					15	28	16	17	5	14	17	19					28				31	14				
16:00	5	5					28	38	25	24	27	30	31	28					31				26	17				
16:30	5	5					31	39	23	20	20	22	29	22					25				22	18				
17:00	5	5					30	39	23	19	22	22	28	25					22				19	17				
17:30	10	8					31	39	26	24	23	27	26	23					19				20	18				
18:00	8	7					33	41	26	24	28	30	30	26					27				22	18				
18:30	5	4					38	46	34	29	31	20	29	24					18				19	18				
19:00	4	4					22	30	22	20	25	19	24	21					20				21	19				
19:30	4	4					9	16	10	13	16	12	11	13					11				12	12				
20:00	2	2					5	1	0	6	8	7	7	7	8				7				6	6				

Figure 12: Congestion Patterns (Westbound)

Direction of Traffic: ↕ (Numbers indicate % occupancy)

D	Data	ly	ag	July, 1993	Time	St. Louis	State	Bus Station	Oak	Hoover	Vermont 1	Budlong	Normandie	Western 2	Western 1	Graneray	Arlington	Censhaw	West	Harcourt	La Brea 2	La Brea 1	Hausert	Fairfax	La Cienega	Cattarauga	Robertson	Manning	Motort	Westwood	Bundy	Pico	Centinela			
					Wednesday																															
					6:30	11	10					13	29	14		16	15	14	14		15			13				10	10							
					7:00	13	11					23	34	22		22	20	17	21		21			18				16	16							
					7:30	12	11					30	43	27		28	23	24	28		25			24				17	17							
					8:00	11	10					38	44	38		34	35	38	41		31			32				21	20							
					8:30	11	16					8	20	14		22	25	37	42		37			35				2	4	2	0					
					9:00	44	52					12	22	14		19	22	33	35		29			32				2	2	2	0					
					9:30	18	21					13	23	14		16	14	18	27		27			17				23	19							
					10:00	10	9					18	29	16		17	16	14	15		17			18				19	17							
					10:30	7	7					15	28	17		17	15	13	14		17			14				13	14							
					11:00	7	7					16	30	17		18	16	14	15		18			14				14	14							
					11:30	6	6					14	27	15		18	15	14	14		18			14				13	13							
					12:00	6	5					13	25	14		17	15	14	14		17			14				13	13							
					12:30	6	5					12	23	13		16	14	13	13		16			12				12	12							
					13:00	6	5					12	23	13		16	13	13	13		16			12				13	12							
					13:30	6	6					13	25	15		19	15	14	14		18			13				12	12							
					14:00	6	5					14	27	16		17	15	14	14		18			17				26	14							
					14:30	6	6					14	26	16		18	16	19	26		27			26				19	15							
					15:00	6	6					30	39	27		26	9	27	28		22			16				17	16							
					15:30	5	5					26	37	21		19	20	22	23		22			21				30	15							
					16:00	5	5					30	37	28		27	23	34	35		33			36				28	15							
					16:30	8	7					33	42	28		29	29	34	30		25			28				25	17							
					17:00	14	10					38	42	32		30	31	34	37		34			37				29	15							
					17:30	12	8					41	49	37		32	30	35	34		27			29				21	18							
					18:00	13	9					39	44	33		28	31	30	34		29			27				21	17							
					18:30	8	8					36	42	29		26	29	32	31		26			23				21	18							
					19:00	5	5					31	40	30		27	29	30	30		32			22				21	19							
					19:30	4	4					24	31	22		20	21	28	32		26			19				24	21							
					20:00	2	2					6	1	1	7		9	7	8	7		9			11			15	15							

Figure 12: Congestion Patterns (Westbound)

Fr Date Data by July

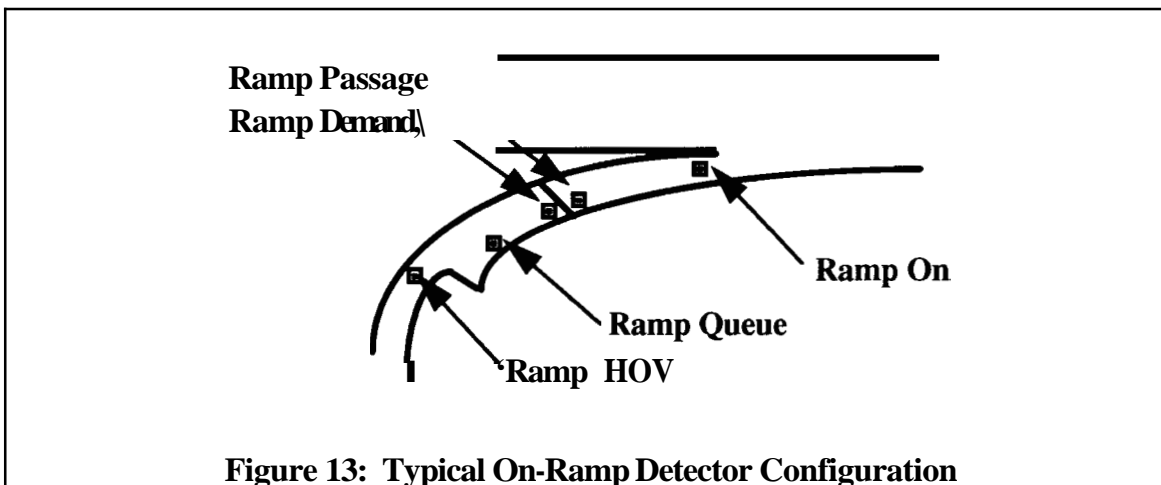
Direction of Traffic: ↕ (Numbers indicate % occupancy)

Time	St. Louis	State	Bus Station	Oak	Hoover	Vermont 1	Budlong	Normandie	Western 2	Western 1	Graneray	Arlington	Crenshaw	West	Harcourt	La Brea 2	La Brea 1	Hausert	Fairfax	La Cienega	Cattarauga	Robertson	Manning	Mokor	Westwood	Bundy	Pico	Centinela
Thursday																												
6:30	11	10				14	26	14		16	15	12	12		16					11	10							
7:00	13	11				15	28	17		23	22	16	17		19				18	15								
7:30	14	12				28	39	24		26	22	24	23		26				26	18								
8:00	12	10				32	47	38		41	34	42	44		35				35	21								
8:30	10	9				39	46	36		38	33	41	43		38				36	24								
9:00	10	9				32	44	35		35	34	40	36		34				31	22								
9:30	9	9				21	36	22		22	21	30	32		27				28	22								
10:00	10	9				15	29	16		17	15	17	19		22				22	20								
10:30	9	8				19	28	16		17	18	14	12		17				12	13								
11:00	9	8				23	31	18		18	16	18	15		18				14	14								
11:30	7	7				17	29	16		18	16	18	15		18				12	12								
12:00	7	6				14	26	15		18	15	12	15		18				15	16								
12:30	6	6				13	24	14		16	18	12	12		17				13	12								
13:00	5	5				12	24	14		16	12	14	13		17				13	12								
13:30	5	5				13	24	12		17	5	12	14		17				13	13								
14:00	6	6				13	25	18		18	18	14	12		18				14	16								
14:30	6	6				16	27	15		18	16	17	15		18				16	18								
15:00	6	5				16	30	17		18	18	13	20		20				16	18								
15:30	5	5				19	31	22		22	38	22	29		26				14	18								
16:00	6	5				24	35	22		22	21	21	25		21				20	16								
16:30	5	5				25	36	23		21	22	17	22		21				15	18								
17:00	9	7				26	37	21		18	17	16	23		20				17	21								
17:30	14	9				25	36	21		18	17	16	20		19				22	21								
18:00	10	8				30	42	28		22	24	26	28		26				22	21								
18:30	6	6				29	40	28		25	25	26	30		26				24	20								
19:00	4	4				26	41	26		22	24	65	27		23				20	21								
19:30	4	4				11	25	12		15	12	18	16		17				12	18								
20:00	3	3				7	15	8		12	10	11	10		13				10	10								

Figure 12: Congestion Patterns (Westbound)

D. On-Ramp Data

Analysis of on-ramp data from MODCOMP is somewhat more complicated, because multiple detectors are used for a single on-ramp. A discussion of the data from these detectors first requires an explanation of the nomenclature for the on-ramp detectors. A map of a typical configuration is presented in Figure 13.



The ramp shown above has two lanes up to the stop bar (where the ramp is metered by a signal). After the ramp meter, the ramp narrows to a single lane before the merge to the freeway. High occupancy vehicles can bypass the queue for the meter by using the left lane of the ramp (although they still must wait for the ramp signal),

Up to five detectors can be used for these ramps. The *Ramp On* detector measures the total flow of vehicles from the ramp to the freeway. The *Ramp Demand* and *Ramp Passage* detectors measure non-HOV vehicles immediately before and after the ramp meter. The *Ramp Queue* detector measures vehicles that are queued for the ramp meter, and the *Ramp HOV* detector counts high occupancy vehicles before the meter.

For any given on-ramp, some or all of these detectors may be in place. Also, note that Figure 13 applies to a typical on-ramp, but variations of this ramp alignment are common on the study section. Another common geometry is found near collector/distributor lanes, where a single lane (non-metered) ramp is used.

Detailed analyses were also performed for these ramp detectors. The first step (as in the mainline studies) was to consider volume/occupancy scatter plots for selected detectors. Figure 14 depicts this graph for the eastbound La Cienaga ramp passage detector. For Tuesday and Thursday, all of the data points fall in the roughly linear group of points up to 12 vehicles/minute (600 vehicles/hour). During a period of apparently heavier congestion on Wednesday, data were recorded when capacity was exceeded. This general pattern of volume/occupancy is found for many of the detectors; there is a linear

relationship between volume and occupancy (up to about 20% occupancy), and then volumes decrease.

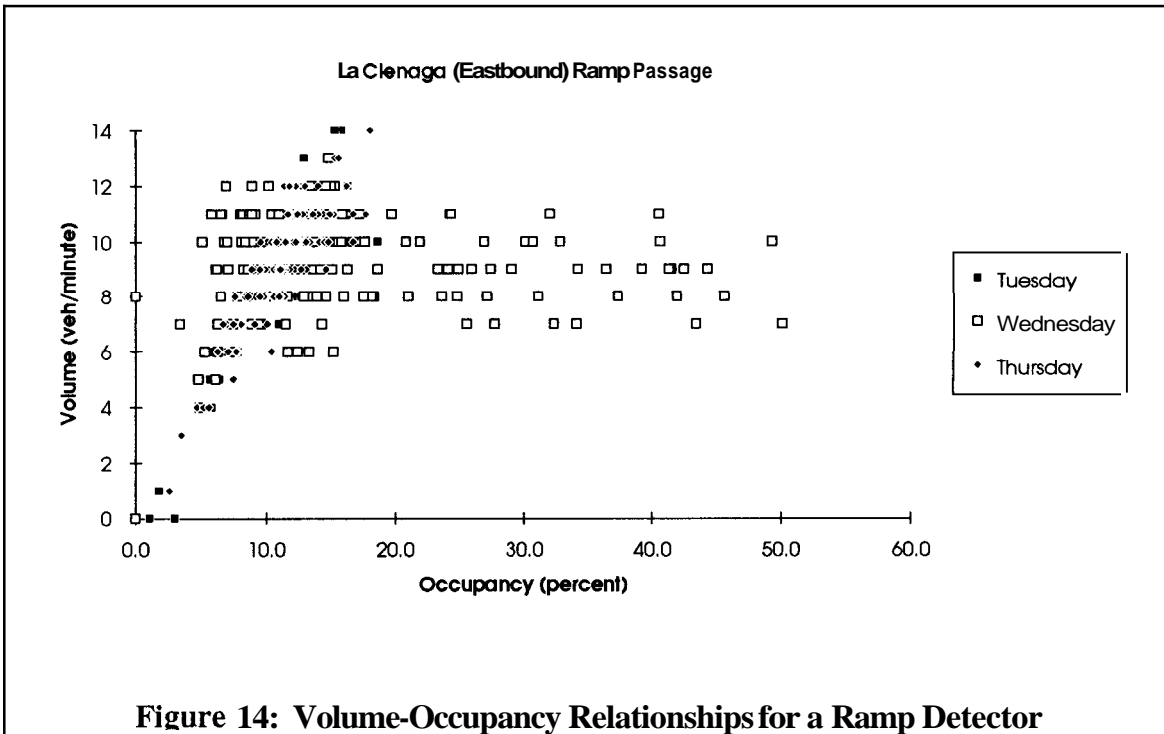


Figure 14: Volume-Occupancy Relationships for a Ramp Detector

For many of the ramp detectors, there is a high correlation between the ramp on, ramp passage, and ramp demand detectors. Figure 15 shows these detectors at the Vermont 1 (westbound) zone for Tuesday and Wednesday (the detectors were malfunctioning on Thursday). The similarity of the graphs suggests that all three detectors are recording data in a similar fashion.

Figure 16 shows the evolution of the volumes for these detectors throughout a single day (Tuesday). There is close correlation for the data for each of the three detectors. Interestingly, the ramp queue and ramp demand detectors have nearly the same values, while the ramp passage detector varies somewhat. This might be explained if HOV vehicles were counted by the ramp passage detector, but not the other detectors. However, the volume is often lower for the ramp passage detector, so this theory does not hold. The discrepancies in these detectors could be the subject of future study.

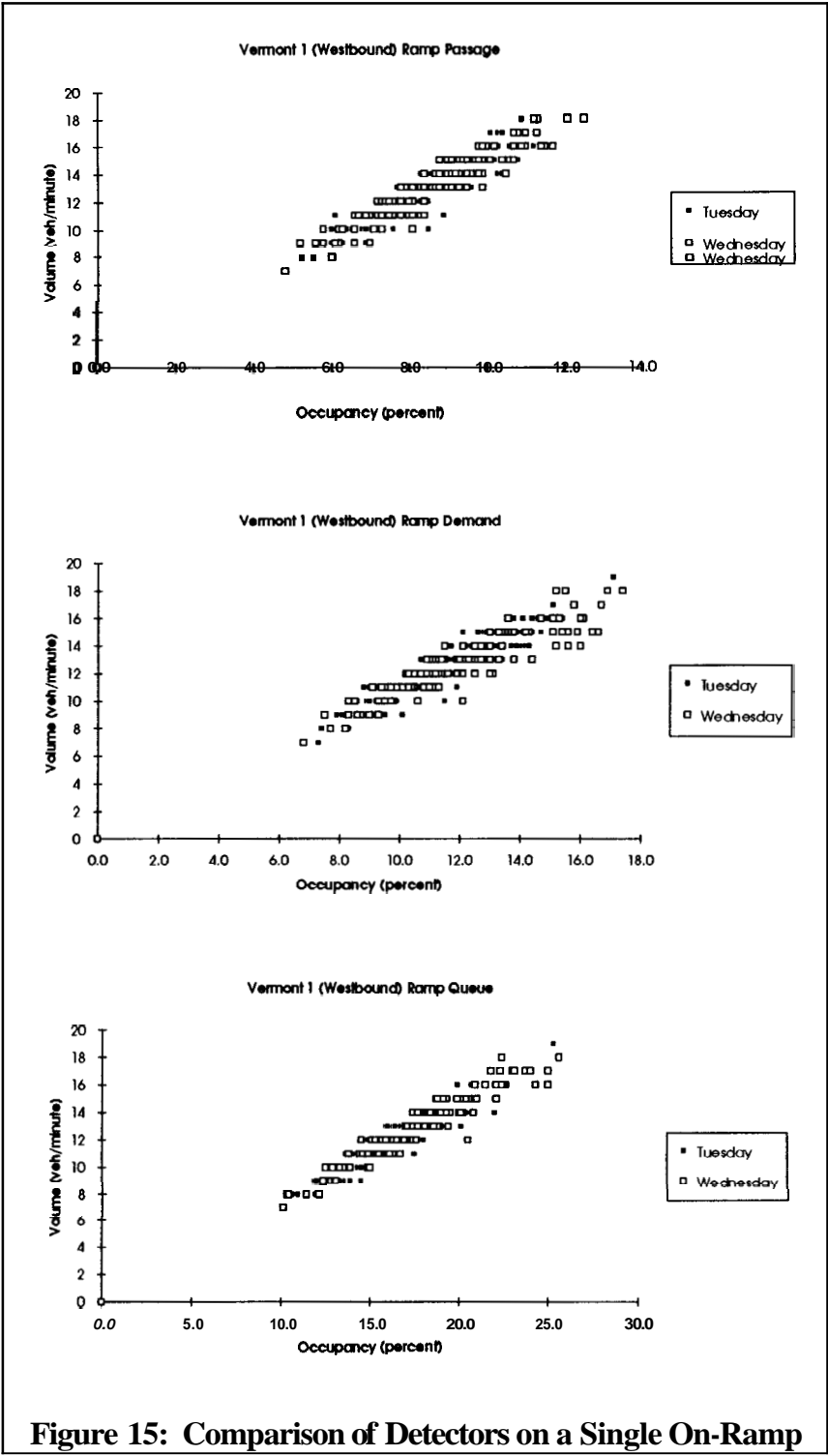
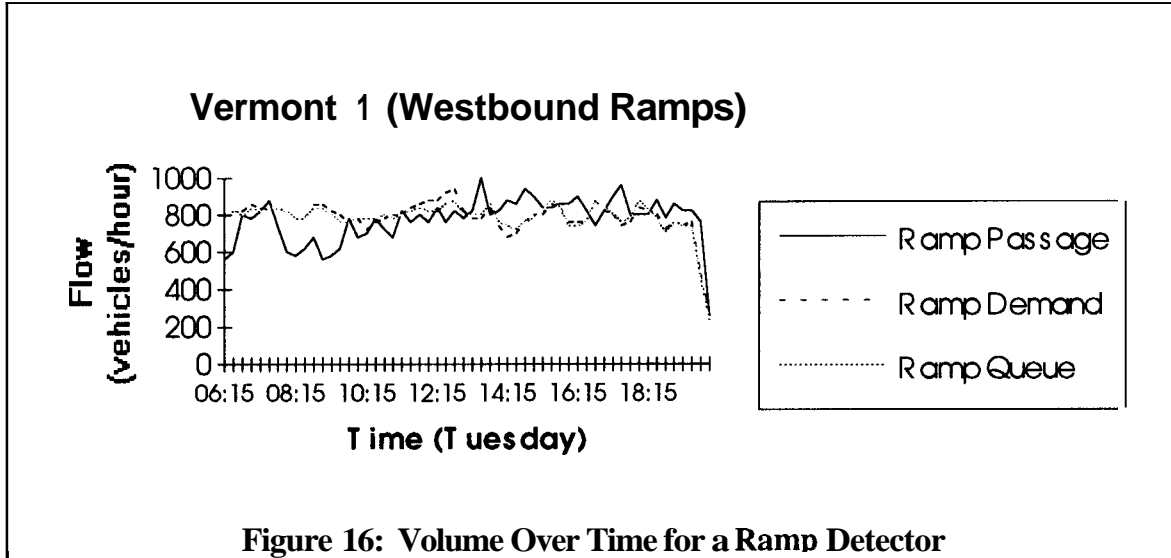


Figure 15: Comparison of Detectors on a Single On-Ramp



E. Other Results

With the volume of data collected from the detectors on the Santa Monica Freeway, much further analysis could be conducted. This section has presented specific examples for mainline freeway and on-ramp detectors. However, the spreadsheets developed for this study facilitate analysis of any of the detectors. Informal studies of other mainline and ramp detectors were made in the preparation of this report, and future analysis of these or other detectors would be relatively straightforward. In addition, discussions of off-ramp and C/D lane detectors have not been presented here, but will be important for subsequent research efforts.

The examples in this section should serve as representative for future work. Some of these efforts are discussed in Section 5; it is hoped that the reader will consider other applications and studies from the detector data.

Section 5: Further Investigations and Conclusions

This conclusions in this report are based on observations and analysis of a relatively limited dataset. For the purposes of the simulation effort, the collection of three days of detector data was thought to be sufficient. However, a more involved study of the freeway detectors could be undertaken; this section discusses possible next steps for such a study.

Also, the application of the detector data for the simulation effort is briefly discussed here. Other research efforts involving the Santa Monica Freeway are already underway; these will be described in future reports.

Finally, much was learned about the freeway detector data in this study and the pilot study. This section concludes with a short discussion of how data collection and analysis might be improved in subsequent efforts.

A. Additional Detector Data

For the studies of the Santa Monica Freeway detectors, seven days of data were collected: December 6-9, 1992 and May 25-27, 1993. Detailed analyses were performed for only half of these data (the morning of December 7 and May 25-27); this was sufficient for the simulation research project. However, further conclusions would probably be more appropriate after collection and analysis of additional detector data. In particular, studies involving recurring congestion and incidents could be made with these types of data, but only if a larger sample size was available. For future efforts involving the Santa Monica Freeway, it would be helpful to study data from multiple weeks (perhaps four weeks across the year) and to consider Monday and Friday detector data and off-peak (8 P.M. to 6 A.M., weekends, and holidays).

Also, it would be helpful to have data from detectors that are not currently functioning. Further studies would benefit from having volume and occupancy data from other stations along the mainline freeway. Perhaps more importantly, counts from all of the ramps on the freeway study section are needed. The authors are continuing to investigate other sources for these data (other than MODCOMP); feedback from the reader is appreciated.

B. Development of the Simulation Model

For the project team developing the simulation of the Santa Monica Freeway, the next step will be to create the INTEGRATION model. The critical element in this effort remains the availability of data, both in terms of supply and demand.

The demand data have been discussed to great length in this report. Wherever possible, the detailed information collected from the detectors will be used for the simulation model. However, while the available data are robust, the issue of missing detector data (specifically the ramp data) must **still** be addressed. **As** discussed above, other sources of these data are being sought; the hourly mainline and ramp counts provided by Caltrans

(discussed in Section 4A) may be helpful. Another option may be to use historical data for the missing detectors (from several years ago) and extrapolate by comparing the available new data and the historical data. Unfortunately, limited data are available for the freeway section east of the 110.

At the same time, detailed information about the supply side of the freeway (i.e., lane configurations, on/off ramps, and collector/distributor roads) is being collected and coded. A supply model of the mainline section of the freeway (using FREQ, an established freeway simulation model) is under development. Most of the supply information for the freeway section is available at the time of this report.

Once all of these data are available, the simulation effort can begin. Freeway simulations will be developed using both FREQ and INTEGRATION; the results from these simulations can be compared to assess the reliability of the models. Also, the development of the arterial network around the Santa Monica Freeway is underway; eventually the two efforts will merge and a complete simulation of the freeway corridor **will** be available for study.

C. Study Recommendations

From the results of this study, several recommendations are presented for the reader's consideration. These conclusions represent the authors' views only and do not necessarily imply agreement by others. However, it is hoped that some of these recommendations will prove to be beneficial; again, comments are welcomed.

- Volume and/or occupancy data from all ramps along the Santa Monica Freeway study section are critical to the synthesis of origin/destination data. Efforts are needed to gather these data.
- Mainline freeway data are very good in some sections and limited in others. Data should be gathered for missing sections (especially the eastern and western ends) to complete the mainline dataset.
- Time and resources were not available to perform detailed validity checks on all detectors in the study. Future research efforts might focus on analyzing the results from this report in some more detail.
- Other studies of the detectors could benefit by collecting data from additional days and/or times; the scope of this study was limited.

Appendix 1: Process

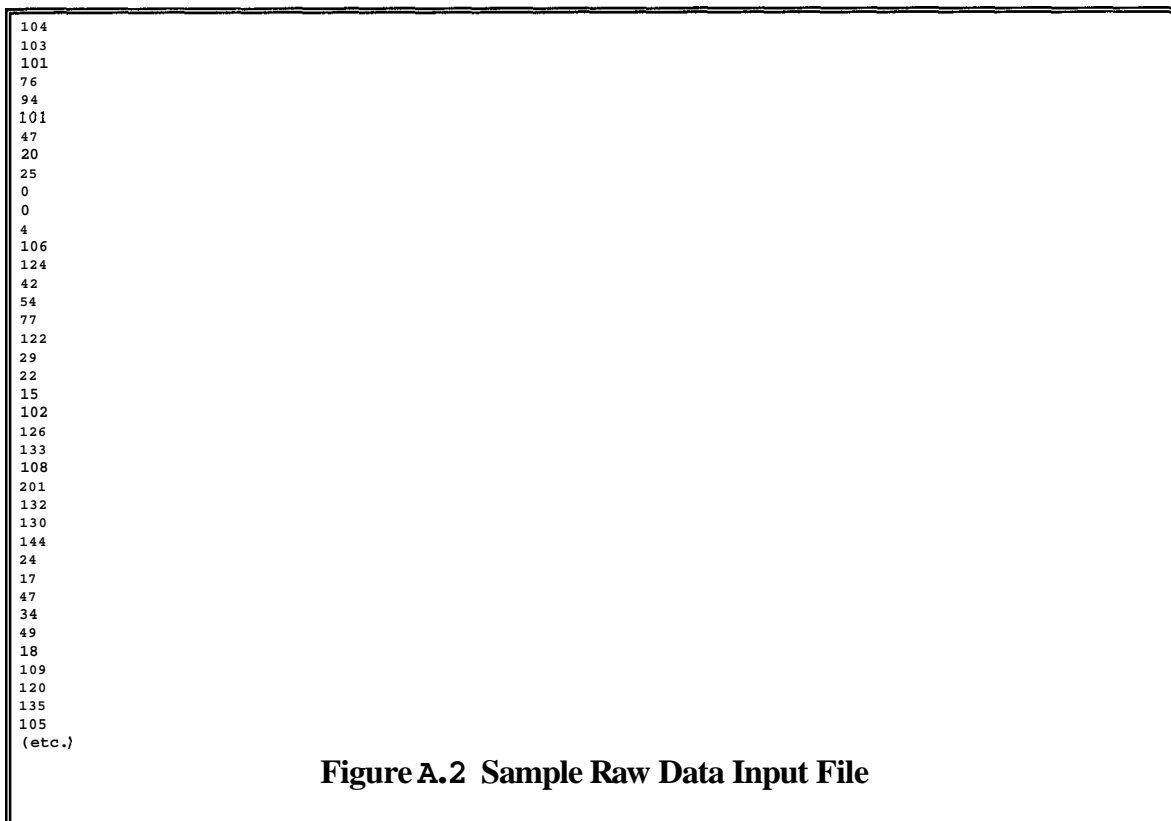
This appendix provides a detailed technical description of the steps employed to create the detector data spreadsheets described in the main body of the report. Figure A.1 to A.5 below are samples of the data files that are created in each step of the process. The text above each figure describes each particular step.

Figure A.1 is a sample printout from the MODCOMP system (it is one of 3528 pages). The zone group from St. Louis to Western 2 is one of seven groups; this section includes westbound lanes on the eastern part of the freeway study section. The page shown below contains data for Thursday, May 27, 1993 for a five minute period ending at 6:05 A.M. Occupancy and volume data are present for detectors in eight zones (St. Louis, State, Bus Station, East of Macy, Vermont 1, Budlong, Normandie 1, and Western 2).

TIME-11:38		5-MINUTE VOLUMES AND OCCUPANCIES										DATE-05/27/93	
FREEWAY LIMITS:		L- 10-W 18.75 (S LOUIS)		TO L- 10-W 3.93 (CENTINELA)									
TIME RANGE:		THURSDAY AT 0600:00 TO THURSDAY AT 1000:00											
THESE DATA FOR		THURSDAY ENDING AT 0604:30											
CROSS ST	S LOUIS	STATE	BUS STATE	ECHANDIA	E OP MAC\	OAK	HOOVER	VERMONT 1	BUDLONG	NORMANDI	WESTERN 2		
POST MILE	18.75	18.53	18.50	S 0.52	S 0.18	14.74	14.12	13.66	13.53	13.21	12.95		
DET_ID	occ VOL	occ VOL	OCC VOL	OCC VOL	OCC VOL	occ VOL	occ VOL	occ VOL	occ VOL	occ VOL	occ VOL		
MAIN 1	10.4 25	9.4 25	---	---	10.6 26	.0 0	---	---	10.2 27	20.1 29	10.9 31		
MAIN 2	10.3 24	10.1 24	---	---	12.4 27	.0 0	---	---	12.6 32	13.2 32	12.0 32		
MAIN 3	10.1 22	4.7 12	---	---	4.2 9	.0 0	---	---	13.3 28	13.0 29	13.5 31		
MAIN 4	7.6 15	---	---	---	---	---	---	---	10.8 21	14.4 18	10.5 21		
MAIN 5	---	---	---	---	---	---	---	---	---	---	---		
MAIN 6	---	---	---	---	---	---	---	---	---	---	---		
RMP ON	---	---	---	---	---	---	---	---	---	2.4 4	---		
R HOV	---	---	---	---	---	---	---	---	---	---	---		
R PASA	---	---	---	---	---	---	---	5.4 9	---	2.4 4	---		
R DHD	---	---	---	---	---	---	---	7.7 9	---	4.7 4	---		
R QUE	---	---	.0 0	---	---	---	---	12.2 9	---	.0 0	---		
R OPP	---	---	---	---	---	---	---	---	---	.0 0	---		
CD ON	---	---	---	---	---	---	---	---	---	---	---		
CD OPP	---	---	---	---	---	---	---	---	---	---	---		
CD 1	---	---	2.0 4	---	---	---	---	2.9 5	---	3.4 7	---		
R DMD	---	---	---	---	---	---	---	2.2 8	---	4.9 10	---		
ALT 1	---	---	2.5 4	---	---	---	---	1.5 3	---	1.8 4	---		
LLT 2	---	---	.0 0	---	---	---	---	---	---	---	---		
RLT 3	---	---	.0 0	---	---	---	---	---	---	---	---		
ALT 4	---	---	---	---	---	---	---	---	---	---	---		
RLT 5	---	---	---	---	---	---	---	---	---	---	---		
LLT 6	---	---	.0 0	---	---	---	---	---	---	---	---		

Figure A.1 Sample Computer Output from MODCOMP

The data in Figure A.1 (along with data on the other 167 pages from Thursday May 27) were entered as a series of numbers in two flat files (called *slouis4o.raw* and *slouis4f.raw* for the occupancy and flow data respectively). Figure A.2 is a partial listing of the contents of *slouis4o.raw*. The data from the spreadsheet are entered in order in the file, reading from top to bottom and right to left. Note that the occupancy data were entered **as** integers to save data entry time; they were converted to real values later in the process. The *slouis4f.raw* file looks similar.



Next, a custom program was used to convert the raw data input files (e.g., *slouis4o.raw*) to a tabular format that could be used in a spreadsheet. The program in Figure A.3 (*rawdata.pas*) was developed using the Pascal computer language to accomplish this task. The program takes the a raw data input file like *slouis4o.raw* and converts it into a series of detector tables (one for each zone in the file). In this case, the program was run eight times and eight output files were created: *slouis4f.dat*, *state_4f.dat*, *bustat4f.dat*, *eofmac4f.dat*, *vermon4f.dat*, *budlon4f.dat*, *norman4f.dat*, and *westrn4f.dat*.

```

program RawDataProcessor (input,output,infile,outfile);

(This program converts the raw data input files keyed in from the
MODCOMP computer output. It creates output files in tabular form
that can be easily imported into a spreadsheet. For occupancy data,
the program converts integer data entries into real percentages.

                Developed by: Loren Bloomberg
                                Institute for Transportation Studies
                                University of California, Berkeley
                                June, 1993                                )

type
  dataArray = array[1..20,1..168] of integer;

var
  infile, outfile: text;
  i, j, start, finish, length: integer;
  stuff: dataArray;

begin
  assign(infile, 'slouis4o.raw');      (raw data in flat file format)
  reset(infile);
  assign(outfile, 'westrn4f.dat');     (output in tabular format)
  start:=36;                          {range of input for this zone}
  finish:=39;
  length:=39;                          (total number of detectors)

  for i:=1 to 168 do begin (for each five minute interval)
    [ignore other detectors before and after key detectors]
    for j:=0 to start - 1 do readln(infile);
    for j:=start to finish do readln(infile,stuff[j+1-start,i]);
    if finish < length then
      for j:=finish+1 to length do readln(infile);
    end;
  close(infile);

  {write output file in tabular form}
  rewrite(outfile);
  for i:=1 to 168 do begin
    for j:=start to finish do
      write(outfile, (stuff[j+1-start,i]/10):6:1);
    writeln(outfile);
  end;
  close(outfile);
end. (program)

```

Figure A.3 *rawdata.pas* Computer Program

Figure A.4 is a sample output file from *rawdata.pas*. In this example, the data for the Western 2 detector are converted into a table, with each five minute interval listed on a line. The four values on each line correspond to the four mainline detectors that are functioning in that zone.

10.9	12.0	13.5	10.5
11.9	14.2	14.3	13.6
15.0	15.1	15.6	13.8
16.0	15.7	16.4	15.0
15.4	16.2	16.8	15.1
17.4	17.7	19.6	16.8
15.9	15.6	17.6	16.0
18.0	17.8	20.9	20.8
20.6	20.3	19.7	21.8
15.3	15.5	16.3	14.9
13.7	15.3	17.9	18.0
20.7	20.0	20.8	22.3
28.8	26.6	25.5	29.0
20.2	22.3	24.7	24.9
(etc.)			

Figure A.4 Sample Output File

Once these tabular output files were prepared, the **final** step was to import the data into spreadsheets. Figure A.5 shows multiple pages of a detector spreadsheet (in this case Western 2). The spreadsheet contains the raw occupancy and volume data for five minute intervals from 6 A.M. to 8 P.M. (pages 1 and 2), 15 minute aggregate volume counts (page 3), and 30 minute aggregate flow and volume counts (page 4). Not shown are the graphs that are automatically generated from these data; examples are provided in Appendix 2.

Zone: Western 2		Direction: WB												
Occupancy Data														
Tuesday														
Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04	
Main1	11.1	11.4	14.4	14.4	17.5	15.8	16.6	16.2	19.7	22.1	15.6	14.7	18.3	
Main2	12.8	13.1	15.4	14.2	17.4	17.8	17.0	16.1	20.5	20.7	16.6	15.7	19.4	
Main3	11.0	14.1	15.2	15.3	17.8	17.2	19.8	17.3	19.4	21.6	19.3	17.8	21.4	
Main4	10.6	12.8	14.7	12.9	16.4	15.3	18.8	18.8	20.4	21.5	18.8	18.3	20.9	
Wednesday														
Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04	
Main1	12.0	13.0	13.5	14.4	14.3	18.4	17.4	25.1	22.9	27.6	19.9	18.1	29.4	
Main2	13.4	14.7	14.6	15.3	16.9	18.5	16.4	22.6	23.3	26.4	19.4	18.5	31.1	
Main3	13.8	15.3	14.8	14.0	15.9	19.8	18.5	21.7	25.0	25.0	23.5	22.8	29.1	
Main4	11.9	14.8	12.9	13.3	15.9	17.3	17.4	23.7	26.2	27.6	23.6	21.2	29.6	
Thursday														
Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04	
Main1	10.9	11.9	15.0	16.0	15.4	17.4	15.9	18.0	20.6	15.3	13.7	20.7	28.8	
Main2	12.0	14.2	15.1	15.7	16.2	17.7	15.6	17.8	20.3	15.5	15.3	20.0	26.6	
Main3	13.5	14.3	15.6	16.4	16.8	19.6	17.6	20.9	19.7	16.3	17.9	20.8	25.5	
Main4	10.5	13.6	13.8	15.0	15.1	16.8	16.0	20.8	21.8	14.9	18.0	22.3	29.0	

Figure A.5 Sample Spreadsheet (page 1)

Volume Data

Tuesday

Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04
Main1	33	31	39	39	44	40	43	41	43	43	39	38	43
Main2	34	34	38	37	41	42	40	38	41	39	38	39	45
Main3	27	31	33	34	37	36	39	38	37	37	37	36	41
Main4	20	26	30	25	32	29	34	33	34	33	32	33	39

Wednesday

Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04
Main1	33	36	36	39	37	45	39	35	39	33	34	37	33
Main2	35	38	38	38	40	42	34	37	37	35	33	36	32
Main3	32	33	32	30	33	41	37	32	36	30	34	36	34
Main4	24	28	25	26	30	32	30	31	33	29	31	34	31

Thursday

Detector	06:04	06:09	06:14	06:19	06:24	06:29	06:34	06:39	06:44	06:49	06:54	06:59	07:04
Main1	31	33	40	44	42	45	41	42	41	37	34	38	37
Main2	32	36	40	40	40	42	38	38	39	35	35	36	39
Main3	31	32	33	36	36	40	37	38	36	34	35	35	36
Main4	21	26	28	29	28	32	31	32	34	29	32	32	34

Figure A.5 Sample Spreadsheet (page 2)

15 minute Average Flows:

Tuesday

Detector	06:15	06:30	06:45	07:00	07:15	07:30	07:45	08:00	08:15	08:30	08:45	09:00	09:15
Main1	2060	2460	2540	2400	2320	1900	1600	1620	1600	1780	1800	1880	1680
Main2	2120	2400	2380	2320	2360	1900	1680	1640	1640	1820	1820	1880	1960
Main3	1820	2140	2280	2200	2220	1840	1660	1640	1620	1700	1860	1800	1920
Main4	1520	1720	2020	1960	2100	1820	1560	1680	1520	1660	1660	1780	1660

Wednesday

Detector	06:15	06:30	06:45	07:00	07:15	07:30	07:45	08:00	08:15	08:30	08:45	09:00	09:15
Main1	2100	2420	2260	2080	1920	1980	1440	1460	1540	1240	1920	1860	1940
Main2	2220	2400	2160	2080	1960	2020	1440	1460	1600	1460	1840	1820	1980
Main3	1940	2080	2100	2000	1920	1900	1460	1480	1600	1480	1840	1660	2020
Main4	1540	1760	1880	1880	1820	1760	1460	1480	1540	1320	1520	1680	1680

Thursday

Detector	06:15	06:30	06:45	07:00	07:15	07:30	07:45	08:00	08:15	08:30	08:45	09:00	09:15
Main1	2080	2620	2480	2180	2160	1980	1420	1440	1360	1560	1340	1680	1880
Main2	2160	2440	2300	2120	2240	2020	1380	1420	1440	1580	1400	1660	1840
Main3	1920	2240	2220	2080	2140	1920	1340	1320	1380	1480	1360	1580	1780
Main4	1500	1780	1940	1860	1980	1840	1420	1440	1480	1460	1460	1660	1740

Figure A.5 Sample Spreadsheet (page 3)

30 minute Average Occupancies:

Tuesday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	14.1	17.5	24.8	29.9	20.0	14.7	14.2	13.4	13.1	15.0	13.6	13.4	11.0
Main2	15.1	17.8	26.0	31.4	21.1	16.2	15.9	15.3	14.3	16.0	15.3	14.9	12.4
Main3	15.1	19.2	25.6	30.7	20.7	18.9	17.8	16.3	15.6	18.2	17.6	16.5	14.1
Main4	13.8	19.4	25.8	32.1	22.5	19.4	17.0	16.2	15.8	18.0	16.1	16.0	13.8

Wednesday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	14.3	21.8	26.8	38.3	14.0	14.3	13.8	16.1	16.5	17.0	15.4	14.5	12.7
Main2	15.6	21.1	27.7	37.5	15.7	15.2	15.0	16.5	16.8	17.7	16.9	15.8	14.6
Main3	15.6	22.8	29.4	36.5	16.3	17.0	16.6	18.4	18.3	18.7	18.5	17.0	16.0
Main4	14.4	23.3	28.9	36.9	17.4	17.2	15.7	17.6	18.6	18.4	17.6	16.5	15.7

Thursday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	14.4	17.4	23.9	38.3	36.1	35.1	21.9	16.2	16.1	18.1	16.4	15.0	13.5
Main2	15.2	17.4	25.7	41.0	36.4	34.3	21.4	17.4	16.2	18.4	17.6	16.1	15.2
Main3	16.0	18.9	26.4	37.8	35.8	35.0	21.9	17.7	17.8	19.7	19.0	18.0	16.9
Main4	14.1	19.0	26.7	34.9	34.4	31.0	22.4	17.2	17.0	19.3	19.4	17.0	16.4

30 minute Average Flows:

Tuesday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	2260	2470	2110	1610	1690	1840	1910	2080	1940	2130	2110	2110	1630
Main2	2260	2350	2130	1660	1730	1850	2110	2180	2010	2140	2240	2170	1750
Main3	1980	2240	2030	1650	1660	1830	2000	1990	1920	2060	2150	2060	1760
Main4	1620	1990	1960	1620	1590	1720	1690	1850	1760	1860	1880	1850	1630

Wednesday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	2260	2170	1950	1450	1390	1890	1980	2200	2210	2320	2200	2230	2030
Main2	2310	2120	1990	1450	1530	1830	2070	2160	2100	2220	2270	2250	2150
Main3	2010	2050	1910	1470	1540	1750	2020	2030	2000	2030	2120	2160	2040
Main4	1650	1880	1790	1470	1430	1600	1700	1780	1860	1820	1890	1900	1850

Thursday													
Detector	06:30	07:00	07:30	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30
Main1	2350	2330	2070	1430	1460	1510	1880	2200	2200	2300	2250	2250	2110
Main2	2300	2210	2130	1400	1510	1530	1860	2200	2140	2200	2310	2320	2240
Main3	2080	2150	2030	1330	1430	1470	1770	1950	2060	2120	2140	2210	2120
Main4	1640	1900	1910	1430	1470	1560	1700	1730	1780	1850	2000	1920	1890

Figure A.5 Sample Spreadsheet (page 4)